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MANUAL OF BAROMETRY

(WBAN)

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FOREWORD

The ideas which led to the development of the mercury barometer began historically with the curiosity of Galileo regarding the causes for the failure of a suction pump to raise water in a tube higher than about 27–33 feet with the best vacuum obtainable during his time (1564–1642). Although he reasoned that the tensile strength of the water determined the limiting height to which the column of liquid of given density could be sustained under a vacuum, he was not completely satisfied with the sufficiency of this explanation of the phenomenon; he was disinclined, also, to accept the speculation common to many philosophers of that era that nature's abhorrence of a vacuum supported the column. The speculatons of Galileo on this subject, published in 1638, gave impetus to the performance of a crucial experiment about 1640–41 in Rome. Here, G. Berti and his collaborators constructed an ingenious design of what amounted to a water barometer. Shortly after Galileo's death, the quest was taken up by his pupil, Torricelli. The latter reasoned that we live submerged at the bottom of an ocean of air and that the known weight of the air causes the atmosphere to press down upon the free surface of the liquid, therefore impelling it up into the tube at the top of which there is a vacuum. He pointed out that since the vacuum at the top of the tube had no weight it could not press down on the surface of the liquid within the tube, and hence it could not resist the force due to the weight of the atmosphere, acting to raise the fluid. Torricelli came to the logical conclusion that the liquid must rise in the tube until its weight comes to equalize the weight of the air pressing down on the same area of the free surface of the liquid exposed to the atmosphere. A beautiful test of the deduction was obtained by Torricelli's famous experiment of 1643 in which he immersed the open end of a full tube of mercury into a dish of this metallic liquid and observed that it was supported to a height of about 30 inches, which is approximately 1/14th the height of a column of water raised under a vacuum pump at the same time. Since the density of mercury is about 13.595 times as great as that of water, the experiment proved that the weights of the columns of the two dissimilar liquids were the same, suggesting that they were sustained by a common pressure (namely, atmospheric). The Torricellian tube thus became the first barometer, creating a landmark in the history of science. See fig. 12.2.1.3.

Since 1643 there have been many developments in the field of barometry, covering such matters as the determination of heights in the atmosphere by means of barometric observations; the measurement of pressure changes associated with various systems such as HIGHS, LOWS, tornadoes, etc.; and the representation of the pressure field over extensive areas of the globe for purposes of synoptic weather analysis. Thus, barometry may be categorized under several headings, such as those listed above, and is concerned not only with the subject of the barometer as an instrument used for the measurement of atmospheric pressure but also with these other important aspects. Unfortunately, the broad scope of the field together with certain inherent complexities have led to the employment of diverse practices in regard to the various phases over a period of years, with a resultant lack of consistency.

On these grounds an imperative need has arisen for the establishment of standardized procedures to be used in connection with pressure observations, reduction of pressure, altimetry, and other aspects of the subject. In the light of that requirement, the preparation of this manual was undertaken. We are happy to express appreciation for the work of Louis P. Harrison, U.S. Weather Bureau, whose deep interest in the subject has led to significant advances, and who is the one primarily responsible for completion of the task of writing the Manual of Barometry.

August 1, 1963

Chief, U.S. Weather Bureau

PREFACE

It is the purpose of this manual to provide instructions to those concerned with various operational practices relating to *barometry,* and to present scientific and technical information pertinent to the subject regarded in a rather broad sense. As a matter of choice it is considered that *altimetry* may be properly regarded as falling within the province of this work. On these grounds the manual serves not only the meteorologist and the laboratory technician, but also those persons concerned with the various aviation and scientific aspects of the subject, together with the interested citizen.

Chapter 1, section 1.1, explains the scope of "barometry" as considered for the purposes of this publication. Briefly, the subject may be subdivided into parts for individual treatment as indicated by the following list:

(a) Measurement of atmospheric pressure by means of a barometric instrument, which involves the proper calibration, standardization, correction, reading, and maintenance of the device.

(b) Reduction of pressure from one level to another by means of the hypsometric equation (see Appendix 7.1) in order to obtain data of such comparable character as to permit their being studied on a synoptic basis. Note: The reduction of pressure to sea level with reference to stations on land is a case in point, involving suitable assumptions regarding the non-existent vertical distributions of temperature and humidity in the fictitious "air column" which hypothetically extends downward from the station to sea level.

(c) Hypsometry; that is, the computation of the difference in height between two levels pertaining to neighboring points of given atmospheric pressure, under the assumption that the height difference is related to the logarithm of the pressure ratio by virtue of the hypsometric equation, subject to the proviso that the vertical distributions of temperature and humidity are either observed or assumed.

(d) Altimetry; that is, the determination of altitudes or heights, usually with respect to sea level, by means of an altimeter, particularly of the type employed in aviation; and the investigation of the accuracy of the altimetry system in its various aspects, together with a consideration of the problems that stem from uses of the system in air navigation for purposes of landing, vertical separation of aircraft, and terrain clearance.

(e) Representation and analysis of the pressure field over the earth's surface by means of special parameters involving systems based on functions, potential or otherwise, designed to enable one to ascertain the distribution of pressure and its horizontal gradient, or more precisely the horizontal gradient of the local isobaric surface nearest the ground, depending upon the topography and the pertinent observed meteorological quantities. (It may be noted that the latter gradient is related to the geostrophic wind in a mathematical sense.)

(f) Investigation of the effects of irregular terrain and nonstatic atmospheric conditions on the distribution of pressure and its variations with time over the surface; for example, the effects on the pressure of such phenomena as air drainage, wind, and accelerated atmospheric motions in mountainous regions.

Owing to the need for this manual it was decided to publish it in two volumes at different times. Volume I consists of Chapters 1–8, inclusive, together with Chapters 12, 13 and 14. Volume II which is to be issued later will consist of Chapters 9, 10 and 11, plus certain additions to the appendices which comprise Chapter 12; also the complete index for both volumes.

In order to facilitate the finding of material the work is organized in chapters and sections, numbered according to a decimal system of classification. The pagination of each chapter is separate; such that a bold face number is used to indicate the chapter, while the page number within the chapter is given by the number which comes immediately after the dash that follows the bold face number. This system has the great added advantage that it permits adding new material to future editions without the need for disturbing the numbering in earlier pages or in other chapters which do not require revision or addition.

As a rule the introductory paragraphs of sections (usually numbered to end with .0) outline the scope of the succeeding related sections, and therefore they serve the useful purpose of providing a sort of directory to help the reader find the material in those sections relevant to the subject under consideration.

From a scrutiny of the table of contents, it may be seen that the manual is organized on the following basis:

(A) *Chapter 1* is introductory, and is concerned mostly with matters of definition, the running of levels to determine the elevation (height above sea level) of barometric instruments, and the computation of the geopotential of the station. A detailed explanation of geopotential is presented in Appendix 1.3.1 (see Chapter 12).

(B) *Chapter 2* is concerned with various kinds of barometers and related equipment, considered mostly from an instrumental point of view. It presents general discussions relating to the various errors to which these instruments are subject, and tells how to read and install a barometer. The Annex of Chapter 2 contains a good deal of information of a special technical nature, such as cleaning of barometers, maintenance, packing and shipping of the instruments, etc.

(C) *Chapters 3, 4 and 5* deal with corrections of certain definite categories. Thus, one has *Chapter 3* on the gravity correction for mercury barometers; *Chapter 4* on the so-called "removal correction" for difference in height between instrument and station elevations, also on the so-called "residual correction" for any residual instrument error which is determined after a barometer is in use at a station; and *Chapter 5* on the temperature correction for mercury barometers.

(D) *Chapter 6* gives instructions relating to the calibration and standardization of barometric instruments, usually on the basis of comparative readings between the given instrument and a standard barometer or other device that serves as an intermediate standard.

(E) *Chapter 7* presents information mainly in regard to the special techniques of reduction of pressure to sea level as used in the United States, and provides instructions to permit one to compute pertinent reduction factors for field stations.

(F) *Chapter 8* deals with various problems relating to altimetry.

(G) *Chapters 9, 10, and 11* which are to appear in Volume II, will be categorized as follows: *Chapter 9* on "Reduction to Constant Pressure Surfaces, and Hypsometry"; *Chapter 10* on "Special Potential or Other Functions Representing the Earth's Pressure Field"; and *Chapter 11* on "Atmospheric Pressure as Affected by Accelerations, Nonstatic Conditions, and Terrain."

(H) *Chapter 12* is composed of a series of appendices which provide scientific and technical information relevant to the matters dealt with in the main body of the manual. By separating these items from the main body, interruption of the principal trend of thought in the text is obviated; however, in many cases, one may find it useful or necessary to refer to the special material contained in the appendices.

(I) *Chapter 13* consists of nothing but a collection of samples of all forms referred to in the text in connection with data entries pertinent to the various aspects of the subject.

(J) *Chapter 14* is a compilation of tables specifically useful for the purpose of obtaining certain corrections which must be applied to some barometric instruments, and other tables giving data specifically necessary for the objective of permitting one to compute different factors which may be involved in one or more phases of the subject, such as the reduction of pressure to sea level.

While all tables involving computational data are assembled in Chapter 14, the numbering of tables is designed to show the chapter and section numbers in which first use of the tables is made. For example, Tables 5.2.1 and 5.2.2 are two tables used in connection with instructions in section 5.2 (that is, the second full section of Chapter 5).

Similar systems of numbering of figures and appendices are employed. However, since all of the appendices are collected in Chapter 12, the numbering in the latter shows both the chapter and the appendix.

In some instances it has been found desirable to supplement the information embodied in a particular chapter with an annex. When these are given, they will always be found at the end of the chapter to which they relate.

The present manual supersedes the pamphlet, now out of print, by C. F. Marvin, entitled "Barometers and the Measurement of Atmospheric Pressure" (Weather Bureau Circular F), which went through seven editions, from its inception until its last printing in 1941. An inestimable debt is owed to that publication.

With reference to the technique of reduction of pressure to sea level used in the United States, it is worthy of special mention that the method of reduction developed by F. H. Bigelow about the year 1900 forms the underlying basis of the reduction procedure covered by the instructions in Chapter 7, although some of the precise details of the technique have been modified since that time for the sake of simplicity or gain in efficiency of operations. A monument to Bigelow's work in the field of reduction technique still remains in the form of his book, long out of print and now virtually a rarity, entitled "Report on the Barometry of the United States, Canada, and the West Indies," Volume II—Report of the Chief of the Weather Bureau, 1900–1901, Washington, D. C.

An effort has been made to embody in this manual the most recent decisions and recommendations of the World Meteorological Organization (WMO) pertaining to various matters relevant to barometry. In this connection, the following items may be mentioned: (a) Appendix 1.4.1 which cites the complete text of the "International Barometer Conventions" as adopted by the WMO in 1953; (b) information in Chapter 3 relating to procedures recommended by the WMO for the calculation and determination of local gravity under various conditions; and (c) the Annex to Chapter 6 on "International Comparison of Barometers" adopted by the WMO in 1953.

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By Chapters

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[1] Each chapter or annex has a separate system of page numbers. In Chapters 1 through 8 and associated annexes the boldface number denotes the chapter or annex number while the number following the dash indicates the page within the chapter or annex. The letter A associated with a chapter number signifies the annex of that chapter.

CHAPTER 2 INSTRUMENTS FOR DETERMINING ATMOSPHERIC PRESSURE; THEIR INSTALLATION AND CHARACTERISTICS (Cont'd.)

CHAPTER 2 INSTRUMENTS FOR DETERMINING ATMOSPHERIC PRESSURE; THEIR INSTALLATION AND CHARACTERISTICS (Cont'd.)

CHAPTER 2 INSTRUMENTS FOR DETERMINING ATMOSPHERIC PRESSURE; THEIR INSTALLATION AND CHARACTERISTICS (Cont'd.)

CHAPTER 2 INSTRUMENTS FOR DETERMINING ATMOSPHERIC PRESSURE; THEIR INSTALLATION AND CHARACTERISTICS (Cont'd.)

CHAPTER 3 GRAVITY CORRECTION FOR MERCURY BAROMETERS

ANNEX TO CHAPTER 3: AUXILIARY GRAVITY INFORMATION

CHAPTER 4 "REMOVAL CORRECTION" AND "RESIDUAL CORRECTION"

CHAPTER 5 TEMPERATURE CORRECTION OF MERCURY BAROMETERS

CHAPTER 6 STANDARDIZATION AND COMPARISON OF BAROMETERS

CHAPTER 6 STANDARDIZATION AND COMPARISON OF BAROMETERS (Cont'd.)

CHAPTER 6 STANDARDIZATION AND COMPARISON OF BAROMETERS (Cont'd.)

ANNEX TO CHAPTER 6: SPECIAL PROCEDURE FOR BAROMETER COMPARISONS

CHAPTER 7. REDUCTION OF PRESSURE TO SEA LEVEL, AND OTHER LEVELS

CHAPTER 7 REDUCTION OF PRESSURE TO SEA LEVEL, AND OTHER LEVELS (Cont'd.)

CHAPTER 7 REDUCTION OF PRESSURE TO SEA LEVEL, AND OTHER LEVELS (Cont'd.)

CHAPTER 8 ALTIMETRY

CHAPTER 8 ALTIMETRY (Cont'd.)

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[2] Each appendix of Chapter 12 has a separate system of page numbers. Each page in Chapter 12 is identified by **12. App.** followed by the appendix number, all in boldface type, after which there is a dash and the number of the page within the given appendix.

CHAPTER 12 APPENDIXES (THEORY AND TECHNICAL INFORMATION) (Cont'd.)

CHAPTER 13 FORMS [3]

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[3] Each form in Chapter 13 appears on a separate page. Each page in the Chapter is identified by **13. F.** followed by the part of the form number that comes after the prefix WBAN 54—, all in boldface type. Page numbers for Chapter 13 are omitted from the Table of Contents since all the forms are arranged in consecutive order. See also under List of Figures those forms which pertain to Chapter 13.

[4] The prefix WBAN 54— used in form numbers indicates that the forms relate to barometry within the scope of this manual.

CHAPTER 13 FORMS[3] (Cont'd.)

CHAPTER 14 TABLES[5]

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[5] Each table in Chapter 14 has a separate system of page numbers. Each page in Chapter 14 is identified by **14. Tab.** followed by the table number, all in boldface type, after which there is a dash and the number of the page within the given table.

CHAPTER 14 TABLES[5] (Cont'd.)

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LIST OF FIGURES

Each form in Chapter 13 appears on a separate page. Each page in the Chapter is identified by **13. F.** followed by the part of the form number that comes after the prefix WBAN 54—, all in boldface type. The page number of the form comes after the dash. Page numbers for Chapter 13 are omitted from the Table of Contents since all the forms are arranged in consecutive order.

CHAPTER I. INTRODUCTION—DEFINITIONS—ELEVATIONS—GEOPOTENTIAL

1.0 INTRODUCTION

This chapter presents essentially the following material: (1) an outline of the scope of the subject of barometry as understood for purposes of writing this manual; (2) a compilation of definitions and explanations of various terms and symbols used in regard to "elevations," "heights," and "altitudes," followed by instructions pertaining to the determination of elevations of barometers by precise leveling; (3) formulas and instructions for the calculation of the geopotential of a station; and (4) the statement of standard conditions relative to units of pressure, which are defined. Appendix 1.3.1 presents the theory of geopotential, and the derivation of the formulas on the basis of which geopotential is calculated. Appendix 1.4.1 deals with the "International Barometer Conventions" pertinent to item (4) above; and Appendix 1.4.2 concerns the basic relationships involved in the correction of Fortin-type barometer readings for instrumental error, gravity, and temperature. Some of the results in Appendix 1.4.2 are given in a general form valid for all types of mercurial barometers.

1.1 SCOPE OF SUBJECT

For the purposes of this manual the subject of "barometry" will be understood to include the topics covered under the following descriptions:[1]

(a) Measurement

Primarily, barometry is the study of the measurement of atmospheric pressure, taking account of the various sources of error in the data obtained by means of the barometer, and of the appropriate methods to correct for these errors, so as to secure relative or absolute atmospheric pressure data compatible with accepted international standards. The foregoing represents the conventional meaning of the term *barometry.*

(b) Reduction

By certain usages, the subject has been broadened to embrace the study of the extrapolation of atmospheric pressure from station level, either downward or upward. The basis for such extrapolation is generally the hypsometric equation, under suitable assumptions. Results obtained by this means are intended to refer to some definite level, such as, for example, mean sea level or the level of a surface in the atmosphere at an altitude of say 5,000 feet, 10,000 feet or 1 kilometer. Pressures found in this way by calculations, without actual barometric observations at the level referred to, are termed in general "reduced pressures." In particular, those relating to mean sea level are termed "pressures reduced to sea level" or "sea-level reduced pressures." Pressures reduced downward below ground level entail the assumption of a fictitious atmosphere or air column, whose properties in regard to pressure, temperature and humidity must be tied in with observed conditions at the station. Atmospheric pressures at different stations are rendered comparable by their referral to a constant level surface, for which isobars may be constructed to represent the horizontal pressure field. Pressures reduced upward above a station are generally based on information relating to the meteorological conditions in the air column extending from the station elevation to the level at which the pressures are desired. When an actual sounding in the free air is unavailable as a basis for such information, assumptions are usually made regarding the vertical variations of temperature and humidity in the air column. It is conventional to tie in these variations with temperature observed at the surface. See Chapters 7 and 9.

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[1] For definitions of special technical terms the reader is referred to sec. 1.2.

(c) Hypsometry

The subject here refers to the study of the measurement of heights with reference to mean sea level, in particular by application of the hypsometric equation to calculate the vertical thickness of a layer of atmosphere, or a succession of such layers. For this purpose the barometric pressures at the base and top of each layer and the vertical distributions of temperature and water vapor within the layer must be known. In meteorology, the most common use of hypsometry is for the determination of the altitudes of points lying within a surface characterized by constant barometric pressure. Such altitudes, measured with reference to sea level, are rendered comparable by referring them to a particular surface of constant pressure (that is, an isobaric surface). Contour lines may be constructed to represent the field of altitude within such a surface. A series of charts pertaining to a succession of constant pressure surfaces distributed through the atmosphere and depicting the relevant contour lines may be regarded as providing a method of representing the pressure field in the atmosphere which is alternative to that based on a series of charts pertaining to a succession of constant levels depicting the appropriate isobars. See Chapter 9.

(d) Potential Functions Relating to Pressure

One of the most difficult problems involved in the subject is that of representing the pressure field over irregular terrain, or over land and water surfaces of different elevation. A solution to this problem is afforded by the use of special potential functions which are designed to have certain properties considered desirable and necessary. In general these functions do not involve the explicit use of the hypsometric equation for reduction purposes. The subject is dealt with in Chapter 10.

Experience has shown that pressures reduced to sea level, described in paragraph (b) above (see also Chapter 7), have certain shortcomings, especially in the case of elevated, irregular terrain, or in the case where steep, horizontal temperature gradients exist. By use of the special potential functions a different line of attack is made, without the assumption of a fictitious air column whose conditions in regard to temperature and humidity are considered to vary with the related, observed conditions at the station.

(e) Altimetry

Altimetry specifically relates to the determination of height using that type of altimeter which is actuated by changes in barometric pressure. Properly falling within the scope of the subject are questions connected with the setting of the altimeter at various places and times to secure appropriate readings from the instrument. See Chapter 8.

1.2 ELEVATIONS, HEIGHTS, AND ALTITUDES

1.2.0 General

The user of this Manual of Barometry should be familiar with the definitions, terminology and symbols set forth herein, since they are used repeatedly. In many places the symbol is employed to represent the concept, in order to save words. Fig. 1.2.0 illustrates various reference marks and positions relating to barometry at a typical station where considerations pertaining to elevation are involved.

Basic terms in the sense of "vertical distance" are given restricted technical meanings in accordance with the recommendation of the World Meteorological Organization,[2] as follows:

Height: When the term *"height"* is used in this sense, it signifies "the vertical distance of a level, point, or an object considered as a point, measured from a specified datum." The datum must always be stated.

Altitude: When the term *"altitude"* is used in this sense, it signifies "the vertical distance of a level, point, or an object considered as a point, measured from mean sea level."

Elevation: When the English term *"elevation"* is used in this sense, it signifies "the vertical distance of a point or level on or affixed to the surface of the earth, measured from mean sea level."

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[2] W.M.O., Commission for Instruments and Methods of Observation, Toronto Meeting, 1953, Recommendation No. 8 "Definition of Various Altitudes and Heights at a Meteorological Station." (W.M.O.—No. 19, RP. 9)

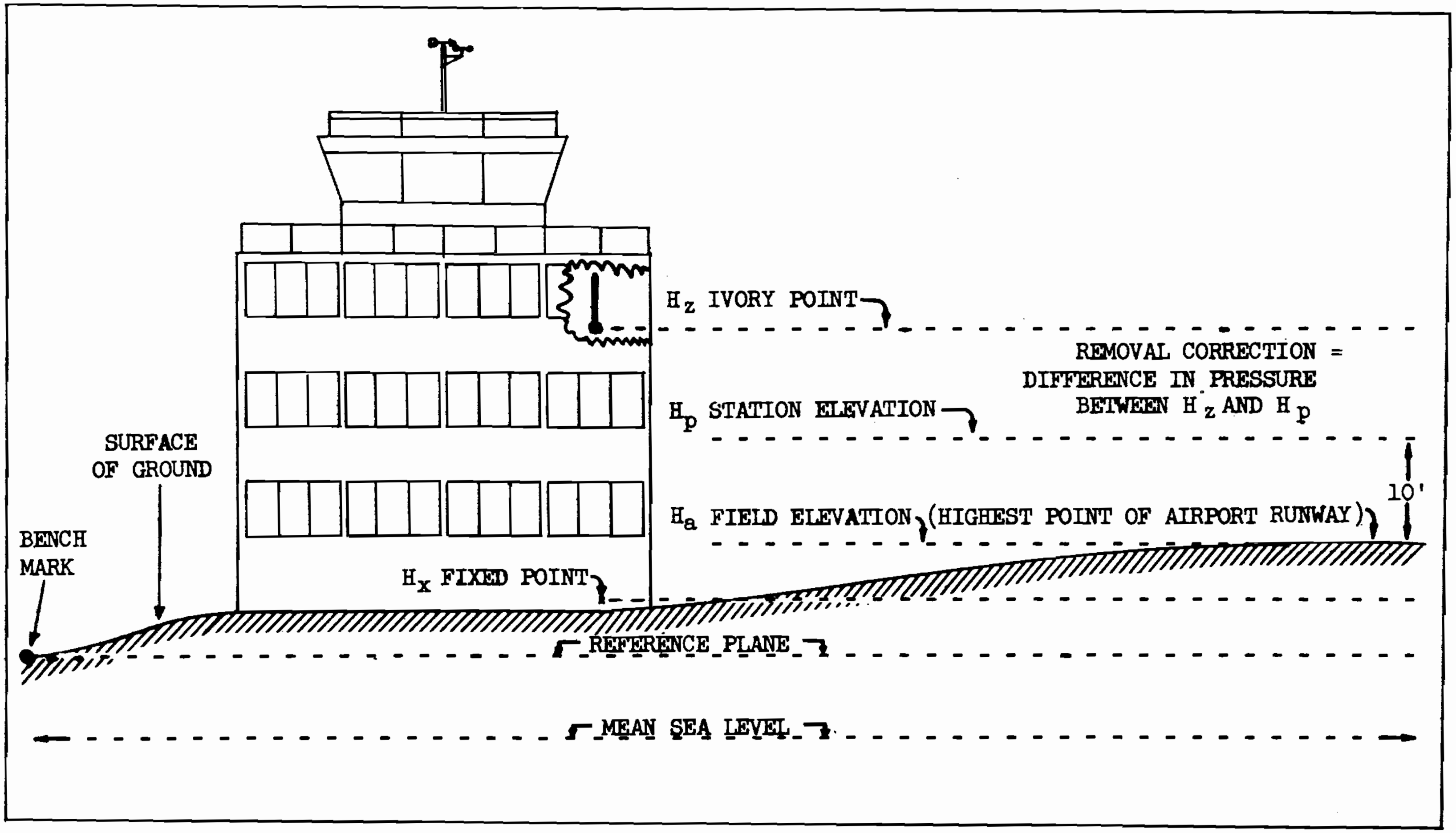

Figure 1.2.0. Elevations in association with reference marks and planes pertaining to barometry.

Certain symbols are employed to denote the concepts defined above; namely, h for "height"; Z for "altitude," particularly when reference is made to the geometric distance above mean sea level of an object or point in the free air, *not* affixed to the ground; and H for "elevation." When it is intended to have the symbol refer to a particular point or instrument, an appropriate subscript is attached to the symbol, except that "H" without a subscript represents "elevation of ground at the meteorological station" (see further details in sec. 1.2.1). The list of subscripts adopted by the World Meteorological Organization follows:

Subscript	**Meteorological parameter or entity**
d	direction of wind (for wind vane)
a	aerodrome (official datum level at aerodrome)
i	instrument shelter (floor)
p	pressure (indicative of adopted datum level for current reports)
pc	pressure for climatological datum in locality
r	rain (precipitation—rim of rain or snow gauge)
R	ground directly beneath rain gauge, or in its immediate vicinity
t	temperature (thermometer)
s	wind speed (for anemometer)
z	zero point of scale of barometer

A brief list of elevation terms and symbols most often used in this manual is now given for convenience in reference, although detailed definitions will be found in sec. 1.2.1:

H_x	"elevation at fixed point";
H_z	"elevation of zero point of barometer," or "actual elevation of barometer";
H_p	"station elevation (in geometric units)";
H_{pc}	"climatological station elevation";
H_{pg}	"station elevation (in geopotential meters)."

1.2.1 Definitions, Symbols, and Terminology

Datum

This term represents any position in relation to which other positions or points are determined. It may be used in the context of *"datum point," "datum line," "datum plane,"* or *"datum surface,"* meaning respectively point, horizontal line, horizontal plane, or specified surface with reference to which measurements are made in determining the position of other points, usually in a vertical sense.

Reference Plane

This term is used in referring to a *"datum point"* used as the basis for determining elevations of other points in leveling (see below). Usually, the *"reference plane"* is a permanent bench mark (see below) whose elevation above mean sea level has been determined accurately. The phrase *"plane of reference"* is equivalent to *"reference plane."*

Bench Mark

This term refers to a permanent marker (generally bronze tablet) used for reference purposes in surveying. The bench mark is fixed rigidly in the ground or on massive objects such as on concrete foundations resting on ground not likely to be moved or disturbed. Usually, surveyors establish the height of bench marks above (or below) mean sea level with great care by means of leveling. In the United States, the U.S. Coast and Geodetic Survey has established extensive networks of bench marks whose elevations have been accurately determined with reference to a common datum point at mean sea level, by means of a general adjustment of precise leveling data.

Fixed Point

This term is generally applied to a fixed mark (such as an X cut) made in the outer surface of a concrete or stone structure, or other feature not likely to be disturbed. Usually, the *"fixed point"* is at the foot of the station building. The height of the fixed point is determined accurately with reference to an established bench mark whose elevation above mean sea level is known or can be ascertained. Heights of all instruments at the station are measured with reference to the fixed point. The vertical distance of the fixed point above mean sea level is represented by the symbol H_x.

Level

The term *"level"* is often used in referring to a device for establishing a horizontal line. The essential part of the level is a glass tube the inside of which is ground to the arc of a circle. A non-freezing liquid such as alcohol or ether is made to nearly fill the tube, leaving a bubble. When the bubble is centered, the tangent to the tube at that point is truly horizontal. A *"surveyor's level"* is an instrument consisting of a telescope to which is attached a sensitive level tube. The assembly is mounted on a spindle and held in position by a casting called the *"leveling head,"* which is usually supported on a tripod. By means of leveling screws, the bubble is accurately centered. In this position the line of sight is truly horizontal. A *"level line"* or a *"level surface"* is one that cuts perpendicularly all plumb lines that it meets; therefore, such a line or surface would everywhere coincide with a surface of still water. The term *"level"* when used to modify another word, signifies "coinciding or parallel with the horizon; horizontal." In regions where there are no irregularities (anomalies) of the earth's gravity field, which is usually well away from mountains or hills, a suspended, undisturbed plumb line hangs vertically; and the line is then perpendicular to a level (horizontal) surface at the point of suspension. In surveying terminology, *"to level"* means "to find the heights of different points in a piece of land, as with the surveyor's level and rod" and *"to run a line of levels"* means "to find the heights of a sequence of points along a line, as with the surveyor's level and rod."

Leveling

Surveyors do leveling by means of rods and surveyor's levels, whereby the levels are used to establish horizontal lines of sight, and measurements are made on the rod to determine the vertical difference in height between two points separated in space. A line of levels is run from one bench mark (A) to another bench mark or a fixed point (B). When a return line of levels is run (B to A), a closed circuit is made, and it is possible to check the accuracy of the leveling by noting the difference between the final measured elevation of the first bench mark (A) at the time of closing the circuit and the assigned elevation of that bench mark as initially assumed. This difference is termed the *"closure error,"* evaluated as: (final measured value *minus* initial assumed value). After the *"closure error"* has been determined, one-half of it should always be *subtracted algebraically* from the measured elevation at point B, as a correction to allow for probable error in the leveling at that point (see examples below). Insofar as practicable, closed circuits of leveling lines should be run to permit determination of the closure error, so that the correction can be applied. Under normal conditions, accuracy to the nearest hundredth of a foot (0.01 foot) is desirable in leveling operations, although under emergency conditions, accuracy to the nearest foot will be considered tolerable. Results of leveling operations should be submitted in the form of "Leveling Notes," usually prepared by surveyors. These notes must be carefully checked before being rendered. See sec. 1.2.3.7.

Two examples of closure errors and of the method of applying the correction for closure error follow:

		Example 1	**Example 2**
		feet	feet
(I)	Initial assumed value of elevation taken for point A	100.00	100.00
(II)	Final value of measurement obtained at point A upon closing circuit	99.96	100.04
(III)	Closure error = (final − initial) = (II − I)	= −0.04	+0.04
(IV)	One-half of closure error	= −0.02	+0.02
(V)	Correction for closure error = algebraic negative of Item (IV)	= +0.02	−0.02
(VI)	Value found for elevation of point B on first run of level (A to B)	= 156.85	156.85
(VII)	Corrected elevation for point B (algebraic sum of items V and VI)	= 156.87	156.83

Elevation of bench mark

This expression refers to the most accurate, precise obtainable value of the height above mean sea level of the bench mark. In the United States, the U.S. Coast and Geodetic Survey, Department of Commerce, Washington 25, D.C., is the best source of data regarding elevations of networks of bench marks based on first-order and second-order leveling. Reliable sets of bench marks have also been established by the U.S. Geological Survey, Department of Interior, Washington 25, D.C.; the U.S. Army Engineers; and some other agencies. City engineers generally have established some bench marks for local use, and can advise in regard to the locations of such marks. When writing to an agency such as the U.S. Coast and Geodetic Survey to request data regarding the elevation of some given bench mark, the description and location of the mark should be carefully stated. Accurate information with respect to descriptions, elevations, and locations of bench marks should be presented in the "Leveling Notes," and in other forms relating to the elevations of barometers.

H, termed *"elevation of the ground"*

This refers to the vertical distance above mean sea level of the ground at the meteorological station. It is given in feet or meters, m.s.l. (The abbreviation m.s.l. represents "mean sea level" to indicate that the vertical distance is measured with reference to that level.) The average height, m.s.l., of the terrain contained within a circle having a radius of 20 meters (65.6 feet) centered on the instrument shelter (thermometer screen) is generally considered to represent an appropriate value for H. When a hygrothermometer is ordinarily used, this will serve to pinpoint the center of the circle.

H_a, termed *"official altitude of the aerodrome,"* or *"official elevation of the aerodrome"*

This represents the vertical distance above mean sea level of the official datum level of the aerodrome (airport or airfield). It is general practice to pick that datum level at a mark on the highest point of the runways. At sea-plane bases the mean high-tide mark may be taken as the appropriate level.

H_z, termed *"elevation of the zero point of the barometer"*

Another term used for H_z is "actual elevation of the barometer." This represents the vertical distance above mean sea level of the zero point of the barometer. The "zero point of the barometer" is the point corresponding to the zero of the scale of the instrument. In the case of the Fortin-type barometer, this is the level of the ivory point in the cistern at which the mercury surface must rest when making readings.

H_p, termed *"station elevation"*

This represents the vertical distance above sea level adopted as the datum level to which barometric pressure reports at the station refer, such current barometric values being termed "station pressures," and understood to refer to the given level for the purpose of maintaining continuity in the pressure records. H_p is given in feet or meters, m.s.l. At old, established meteorological stations in the United States, the elevation adopted for H_p was the elevation of the zero point of the barometer (H_z) in effect on January 1, 1900. At stations established since that date the practice has varied; however, as a general policy the two rules here listed are to be followed:

(a) At stations located in cities or at points some distance removed from airports and sea-plane bases, H_p is taken as the value of H_z which obtained when the station was first established;

(b) At stations located at airport or sea-plane bases, the station elevation, H_p, is taken at a height ten (10) feet above the field elevation. (See definition of H_a, termed "official altitude of the aerodrome," or "field elevation.")

If it is necessary to adopt a new value of H_p for any reason, rules (a) and (b) should be used as a guide in choosing the appropriate value for the new station elevation, considering the new H_z or field elevation as the case may be, in lieu of the original one.

Exceptions to the foregoing rules have already been made in the case of certain stations which are in existence. For example, when a station is moved from a city to an airport, the latter is generally considered as a different location from the former, and hence a change in station elevation is appropriate. Under the following conditions, additional exceptions to the general policy are made when a station is moved: (1) when the new value of H_z differs from the previously adopted value of H_p by over 50 feet; and (2) when the annual variation of temperature at the station is such that the difference in pressure between the levels of the new value of H_z and the previous value of H_p will vary by more than 0.2 millibar. (See Chapter 4 regarding the calculation of "Removal Correction." The coldest days of winter under high pressure conditions yield a maximum difference in pressure between the levels; and the warmest days of summer, possibly under low pressure conditions, yield a minimum difference in pressure between the levels. Under these circumstances, a variable "removal correction" would be necessary if the deviation between these extreme differences of pressure exceeded 0.2 mb. In order to obviate variable *"removal corrections,"* the new value of H_z at city offices or the ten-foot-plane at airports is generally adopted as H_p in cases where the deviations are large as outlined above.)

H_{pc}, termed *"climatological station elevation"*

This represents the vertical distance above mean sea level chosen as the datum level to which climatological records of barometric pressure at stations in the locality refer. The quantity H_{pc} will generally differ from H_p for a given station if earlier stations have had extensive tabulations of barometric pressure referring to another level. Central Headquarters makes the choice of H_{pc} in each case.

H_{pg}, termed *"geopotential of the station"*

This represents the geopotential corresponding to the "station elevation," H_p. In this manual, H_{pg} will always be expressed in terms of the unit "geopotential meter" (abbreviated gpm.). For explanation of the meanings of "geopotential" and of "geopotential meter," the reader is referred to the next paragraph entitled "geopotential," and to the references given therein.

Geopotential

The geopotential of a point in space is the potential energy, due to gravity, of a unit mass situated at the point, relative to mean sea level. For simplicity in routine observational work, geopotential may be thought of as a kind of measure of height above mean sea level, since the magnitude of the practical unit of geopotential has been so chosen that the number of geopotential meters corresponding to a given point in space is *approximately* equal to the number of geometric meters measured vertically to the point from mean sea level. The concept of geopotential may be applied equally well to a point on the surface of the earth or in a mine, as to a point in the free air. A recapitulation and further details concerning the subject are given in Appendix 1.3.1 and in sec. 1.3.

1.2.2 Units of Height Employed in This Manual

By means of leveling, the U.S. Coast and Geodetic Survey measures elevations in meters above mean sea level. Afterward, when the leveling data have been computed and adjusted, the metric elevations are converted to feet for general use. Private surveyors in the United States usually perform leveling in terms of feet. In many foreign countries elevations are given in terms of meters.

For the calculation of geopotential, elevations in feet will first be converted to meters; and the geopotential of the station in terms of geopotential meters (gpm.) will be computed on the basis of the station elevation expressed in meters. It should be noted that in the preparation of tables for reduction of pressure either downward or upward, the geopotential of the station (in gpm.) is used as the elevation argument.

The following conversion factors are used in this manual:

1 foot = 0.3048 meter
1 geopotential foot = 0.3048 geopotential meter
3.28084 feet = 1 meter
3.28084 geopotential feet = 1 geopotential meter.

The basic factors underlying the foregoing conversions are as follows:

2.54 centimeters = 1 inch
100 centimeters = 1 meter
12 inches = 1 foot
30.48 centimeters = 1 foot.

1.2.3 Determination of Elevations for Barometry

1.2.3.0 General Instructions.—Whenever a station is established or the elevation of the barometer is changed, the appropriate elevations must be determined by precise measurements. If leveling is necessary, the work must be carried out by a surveyor, city engineer, or other person competent in running levels. Often the survey of elevations will be made gratuitously by U.S. Government or city engineers. Whenever circumstances permit, the levels will be run over a closed circuit, and the correction for the "closure error" should be made as explained under "Leveling" in sec. 1.2.1. In the simplest case, levels will be run from the bench mark (reference plane) to the fixed point, then to the zero point of the scale of the barometer and return through the fixed point to the reference plane. Measurements of barometer heights relative to a fixed point marked within or on the exterior of a structure may be made by means of a steel tape, a surveyor's rod, a yardstick, or a footrule. Under emergency conditions, hypsometry as described in Chapter 9 can be employed to ascertain the height of a fixed point with respect to a reference plane, pending the availability of suitable conditions and equipment to permit leveling of the required accuracy to be made for the same purpose.

1.2.3.1 Accuracy and Precision of Measurements.—Careful surveying will usually permit determination of H_x (elevation of fixed point) and of H_z (elevation of zero point of barometer) relative to the elevation of the reference plane, within the desired accuracy of about 0.01 foot. Under emergency field conditions on land, accuracy to the nearest whole foot will be considered acceptable, although a more precise resurvey of levels should be undertaken when occasion permits.

1.2.3.2 Heights on Vessels.—On vessels, the height of the "fixed point" and the "zero point of the barometer" above mean water level should be determined by measurement with respect to the load line of the ship. On the high seas, the mean water level may be considered as practically coincident with mean sea level. In the case of vessels on inland bodies of water, the normal mean elevation of the water surface above mean sea level may be considered as the reference plane for purposes of computing the elevation of the barometer (H_z).

1.2.3.3 Leveling Required When a Station is Moved.—When a station other than a mobile or other temporary station is moved from one location to another, the line of levels should be run, if practicable, as follows: Begin at the reference plane for the original location; proceed to the fixed point for the original location; then to the zero point of the barometer at the same location; back through the same fixed point to the new bench mark or reference plane (if any) for the new location; thence to the fixed point at the new location; next to the zero point of the barometer at the new location; return through the new fixed point and reference plane; and finally closing the circuit by running levels back to the original reference plane. If the elevations of both reference planes are based on first-order leveling, it will not be necessary to run levels from the original fixed point to the new reference plane and from the new to the original reference plane.

1.2.3.4 Choice of Reference Plane.—If the original reference plane is about equidistant to the original and new locations, a new reference plane may not be required, except for later convenience. In the case of moves through relatively short distances, the original bench mark for the old location should be retained as the reference plane for the new location. Other conditions being equal, the bench mark which is closest to the station and is of greatest reliability should be given preference in choosing the reference plane.

1.2.3.5 Relocation of Barometer Through Short Distances.—When the barometer is moved from one floor to another in a given building, it is necessary to determine the heights of the barometers in both locations relative to the fixed point. Running of new levels from the reference plane is then not essential. When the barometer is moved from one building to an adjacent building, a new fixed point should be established in connection with the building in the new location. In this case, a closed circuit should be run beginning at the zero point of the barometer in the old location, proceeding through the old and new fixed points to the zero point of the barometer in the new location, and return through the same points to the original barometer location, thus closing the circuit.

1.2.3.6 Comparative Barometer Readings Incident to Moving Barometers.—Assuming that two or more pressure measuring instruments are available, it is a good rule to move only one at a time. All of the barometers should not be moved at one time except in an emergency or when necessary in mobile operations. Comparative barometer readings should be made at the old location immediately prior to moving each instrument, so long as one remains. Several sets of simultaneous comparative barometer readings should be made at the *two locations* when practicable, before all the instruments have been transferred. The outdoor temperatures at the time of the simultaneous readings should be noted. Difference in the pressures at the two locations will often permit checking the difference of the values of H_z at the two points determined by leveling. Comparative barometer readings should be made at the new location after two instruments are installed. This should also be done for each additional pressure measuring instrument which is transferred. Time should be allowed for the mercurial barometers to come to temperature equilibrium at the new location following a move, before placing reliance on the readings. For this reason two or three hours time should elapse, as a rule, before comparative readings are taken. (See Chapter 4 for additional details.)

1.2.3.7 Rendition of Data.—The surveyor's leveling notes (Form WBAN 54–1.2.2) should be certified by the person running the survey. The figures on the notes should be verified in regard to arithmetic operations; and if practicable, the value of elevation ascribed to the bench mark and its description should be checked with the information furnished by the original authority for the data. It is important to check whether the correction for the closure error has been properly applied.

Form WBAN 54–1.2.1 should be prepared giving the following data:

(1) Description and location of reference plane; and authority for the information, including agency which established the bench mark.
(2) Elevation of the reference plane above mean sea level.
(3) Description and location of the fixed point.
(4) Height of the fixed point above or below the reference plane.
(5) Height of the zero point of the barometer above or below the fixed point.
(6) Height of barometer, H_z, above or below the reference plane.
(7) Elevation of the zero point of the barometer above mean sea level (H_z).
(8) Station elevation (H_p).
(9) Name or agency of the surveyor; date on which the survey was made.
(10) Any additional data regarding the station history, as may be called for on the reverse side of the form.

Samples of completed forms WBAN 54–1.2.1 and 1.2.2 are shown in fig. 1.2.1, 1.2.2, and 1.2.3.*

The figures on both sides of Form WBAN 54–1.2.1 should be carefully checked for accuracy and for agreement with the results given on the surveyor's leveling notes. The reverse side of the form should be completed and compared with previous records for consistency. In all cases, one carbon copy of Form WBAN 54–1.2.1 should be retained in the permanent station files.

Disposition of Additional Copies of Forms

U.S. Air Force: Three copies of Form WBAN 54–1.2.1 and the leveling notes consisting of the original for permanent retention in the station, the first carbon for forwarding to and retention by the next higher headquarters and the second carbon for forwarding to and retention by the Data Control Division, Air Weather Service.

U.S. Navy Land Stations: Two copies consisting of the original and first carbon of Form WBAN 54–1.2.1 and the leveling notes

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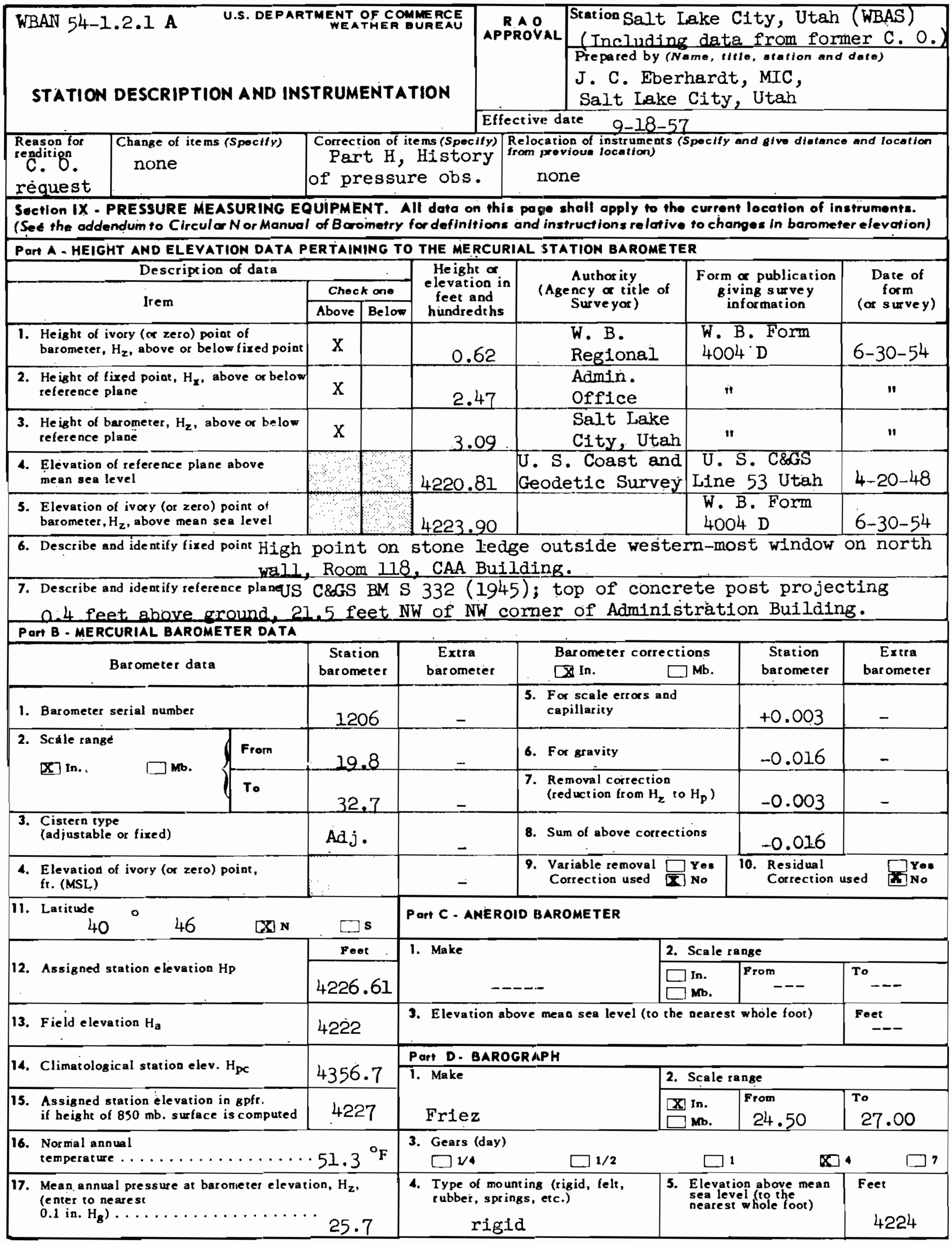
*Forms WBAN 54–1.2.1A and 54–1.2.1B (printed back to back) have been issued by the Weather Bureau under the designation WB Form 500–10, pages 6 and 6a, respectively. The latter are merely two of the pages in the set of 11 pages that constitute Form 500–10, which consists of a series of 13 sections dealing with various matters, mostly not related to barometry.



WBAN 54-1.2.1 A

U.S. DEPARTMENT OF COMMERCE
WEATHER BUREAU

STATION DESCRIPTION AND INSTRUMENTATION

RAO APPROVAL

Station Salt Lake City, Utah (WBAS) (Including data from former C. O.)

Prepared by *(Name, title, station and date)* J. C. Eberhardt, MIC, Salt Lake City, Utah

Effective date 9-18-57

Reason for rendition	Change of items *(Specify)*	Correction of items *(Specify)*	Relocation of instruments *(Specify and give distance and location from previous location)*
C. O. request	none	Part H, History of pressure obs.	none

Section IX - PRESSURE MEASURING EQUIPMENT. All data on this page shall apply to the current location of instruments. *(See the addendum to Circular N or Manual of Barometry for definitions and instructions relative to changes in barometer elevation)*

Part A - HEIGHT AND ELEVATION DATA PERTAINING TO THE MERCURIAL STATION BAROMETER

Description of data			Height or elevation in feet and hundredths	Authority (Agency or title of Surveyor)	Form or publication giving survey information	Date of form (or survey)
Item	Check one					
	Above	Below				
1. Height of ivory (or zero) point of barometer, H_z, above or below fixed point	X		0.62	W. B. Regional	W. B. Form 4004 D	6-30-54
2. Height of fixed point, H_x, above or below reference plane	X		2.47	Admin. Office	"	"
3. Height of barometer, H_z, above or below reference plane	X		3.09	Salt Lake City, Utah	"	"
4. Elevation of reference plane above mean sea level			4220.81	U. S. Coast and Geodetic Survey	U. S. C&GS Line 53 Utah	4-20-48
5. Elevation of ivory (or zero) point of barometer, H_z, above mean sea level			4223.90		W. B. Form 4004 D	6-30-54

6. Describe and identify fixed point High point on stone ledge outside western-most window on north wall, Room 118, CAA Building.

7. Describe and identify reference plane US C&GS BM S 332 (1945); top of concrete post projecting 0.4 feet above ground, 21.5 feet NW of NW corner of Administration Building.

Part B - MERCURIAL BAROMETER DATA

Barometer data		Station barometer	Extra barometer	Barometer corrections ☒ In. ☐ Mb.	Station barometer	Extra barometer
1. Barometer serial number		1206	–	5. For scale errors and capillarity	+0.003	–
2. Scale range ☒ In. ☐ Mb.	From	19.8	–	6. For gravity	-0.016	–
	To	32.7	–	7. Removal correction (reduction from H_z to H_p)	-0.003	–
3. Cistern type (adjustable or fixed)		Adj.	–	8. Sum of above corrections	-0.016	
4. Elevation of ivory (or zero) point, ft. (MSL)			–	9. Variable removal Correction used ☐ Yes ☒ No	10. Residual Correction used	☐ Yes ☒ No

11. Latitude 40 ° 46 ☒ N ☐ S

	Feet
12. Assigned station elevation Hp	4226.61
13. Field elevation H_a	4222
14. Climatological station elev. H_{pc}	4356.7
15. Assigned station elevation in gpfr. if height of 850 mb. surface is computed	4227
16. Normal annual temperature	51.3 °F
17. Mean annual pressure at barometer elevation, H_z, (enter to nearest 0.1 in. H_g)	25.7

Part C - ANEROID BAROMETER

1. Make -----

2. Scale range ☐ In. ☐ Mb. From --- To ---

3. Elevation above mean sea level (to the nearest whole foot) Feet ---

Part D - BAROGRAPH

1. Make Friez

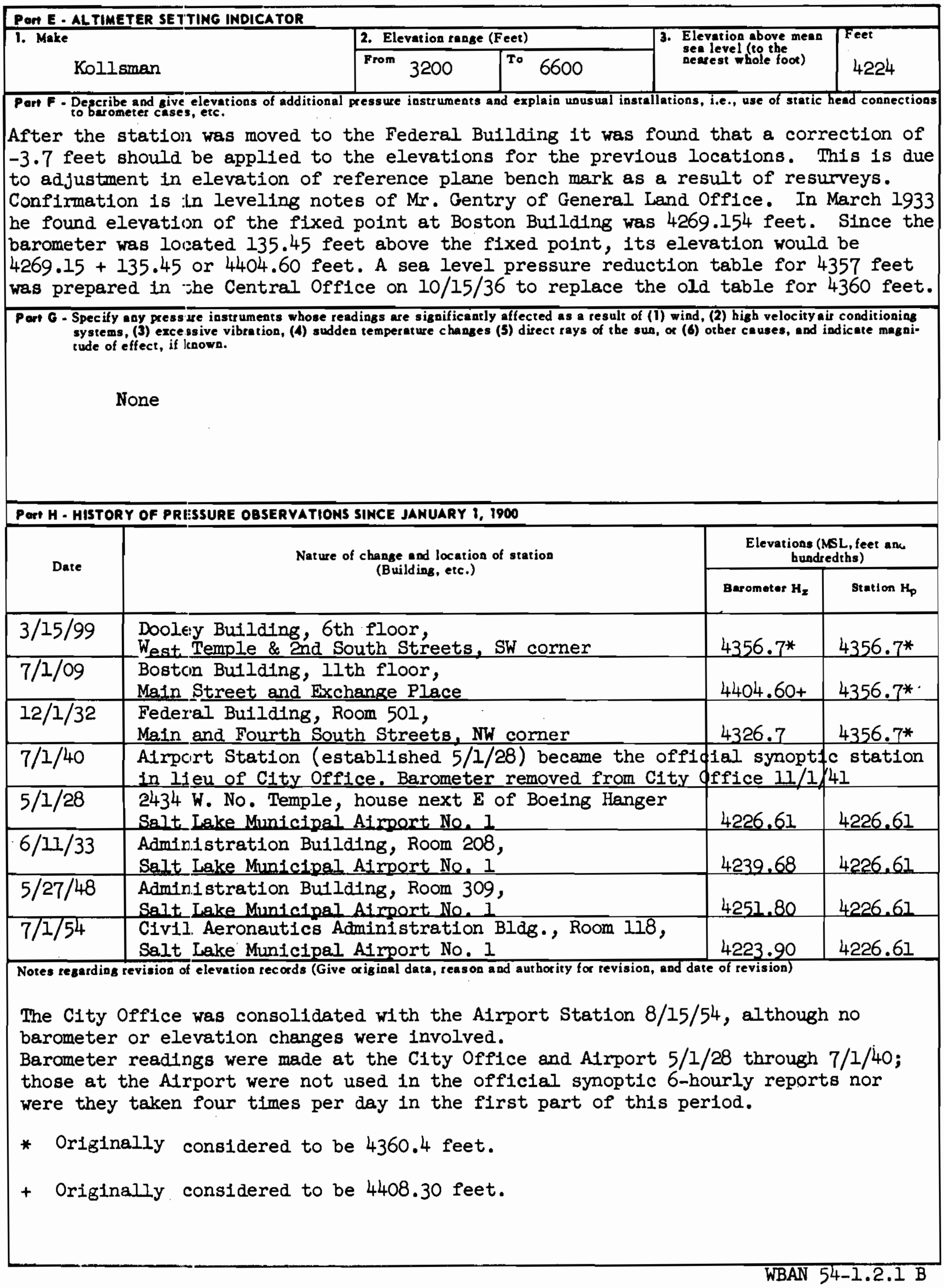
2. Scale range ☒ In. ☐ Mb. From 24.50 To 27.00

3. Gears (day) ☐ 1/4 ☐ 1/2 ☐ 1 ☒ 4 ☐ 7

4. Type of mounting (rigid, felt, rubber, springs, etc.) rigid

5. Elevation above mean sea level (to the nearest whole foot) Feet 4224

FIGURE 1.2.1. Example of completed copy of Form WBAN 54-1.2.1 A, used for recording all of the summary data in connection with the determination of the elevation above sea level of the ivory point of a mercury barometer. Other pertinent information relating to elevations and heights of barometric equipment are also indicated.



Part E - ALTIMETER SETTING INDICATOR

1. Make	2. Elevation range (Feet) From	To	3. Elevation above mean sea level (to the nearest whole foot)	Feet
Kollsman	3200	6600		4224

Part F - Describe and give elevations of additional pressure instruments and explain unusual installations, i.e., use of static head connections to barometer cases, etc.

After the station was moved to the Federal Building it was found that a correction of -3.7 feet should be applied to the elevations for the previous locations. This is due to adjustment in elevation of reference plane bench mark as a result of resurveys. Confirmation is in leveling notes of Mr. Gentry of General Land Office. In March 1933 he found elevation of the fixed point at Boston Building was 4269.154 feet. Since the barometer was located 135.45 feet above the fixed point, its elevation would be 4269.15 + 135.45 or 4404.60 feet. A sea level pressure reduction table for 4357 feet was prepared in the Central Office on 10/15/36 to replace the old table for 4360 feet.

Part G - Specify any pressure instruments whose readings are significantly affected as a result of (1) wind, (2) high velocity air conditioning systems, (3) excessive vibration, (4) sudden temperature changes (5) direct rays of the sun, or (6) other causes, and indicate magnitude of effect, if known.

None

Part H - HISTORY OF PRESSURE OBSERVATIONS SINCE JANUARY 1, 1900

Date	Nature of change and location of station (Building, etc.)	Elevations (MSL, feet and hundredths) Barometer H_z	Station H_p
3/15/99	Dooley Building, 6th floor, West Temple & 2nd South Streets, SW corner	4356.7*	4356.7*
7/1/09	Boston Building, 11th floor, Main Street and Exchange Place	4404.60+	4356.7*
12/1/32	Federal Building, Room 501, Main and Fourth South Streets, NW corner	4326.7	4356.7*
7/1/40	Airport Station (established 5/1/28) became the official synoptic station in lieu of City Office. Barometer removed from City Office 11/1/41		
5/1/28	2434 W. No. Temple, house next E of Boeing Hanger Salt Lake Municipal Airport No. 1	4226.61	4226.61
6/11/33	Administration Building, Room 208, Salt Lake Municipal Airport No. 1	4239.68	4226.61
5/27/48	Administration Building, Room 309, Salt Lake Municipal Airport No. 1	4251.80	4226.61
7/1/54	Civil Aeronautics Administration Bldg., Room 118, Salt Lake Municipal Airport No. 1	4223.90	4226.61

Notes regarding revision of elevation records (Give original data, reason and authority for revision, and date of revision)

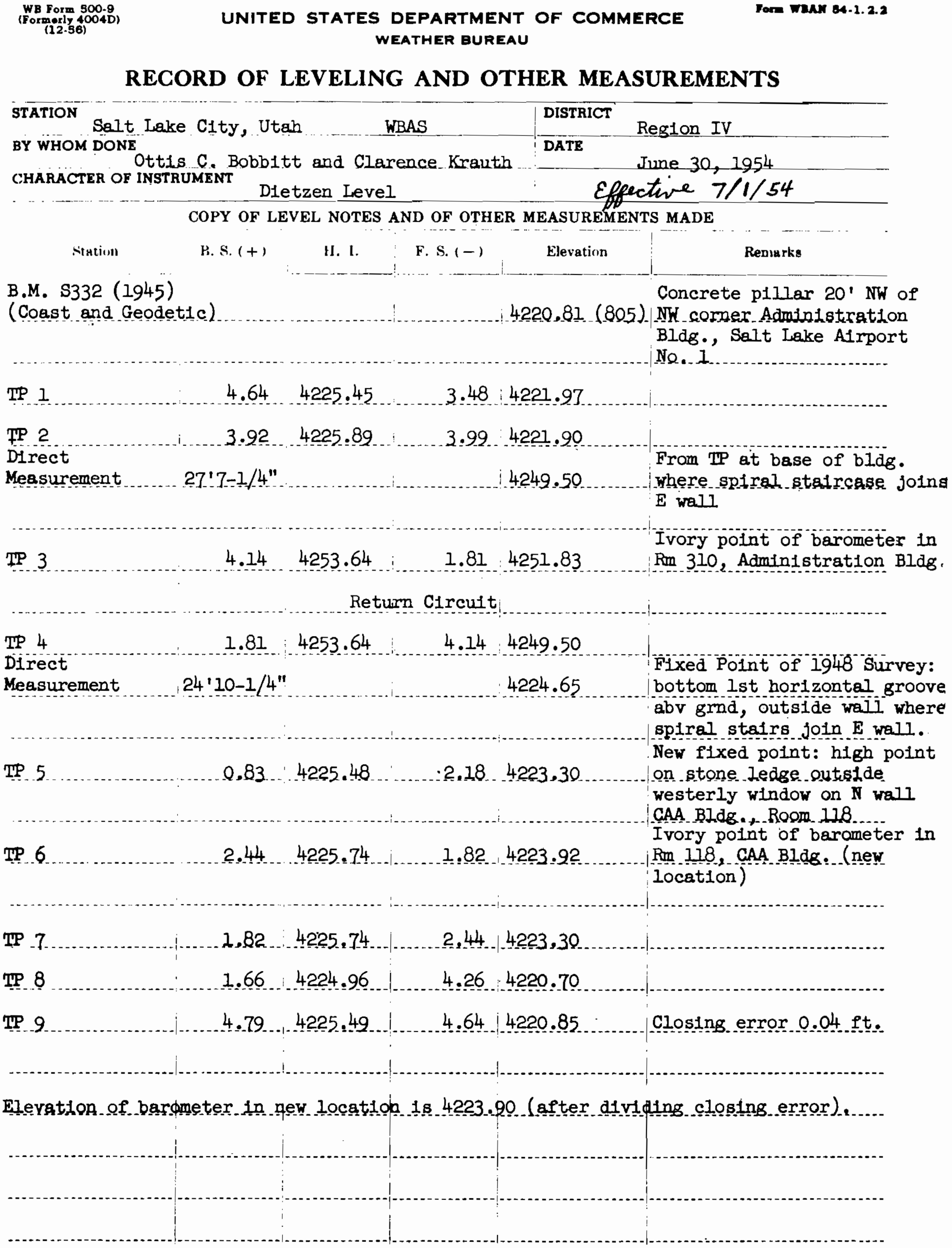
The City Office was consolidated with the Airport Station 8/15/54, although no barometer or elevation changes were involved.
Barometer readings were made at the City Office and Airport 5/1/28 through 7/1/40; those at the Airport were not used in the official synoptic 6-hourly reports nor were they taken four times per day in the first part of this period.

* Originally considered to be 4360.4 feet.

\+ Originally considered to be 4408.30 feet.

WBAN 54-1.2.1 B

FIGURE 1.2.2. Example of completed copy of Form WBAN 54–1.2.1 B, used for maintaining a record of the history of pressure observations at a station, including dates, location, actual barometer elevation, and station elevation above sea level (see Part H). In Part F additional pertinent information is recorded.



WB Form 500-9
(Formerly 4004D)
(12-56)

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

Form WBAN 54-1.2.2

RECORD OF LEVELING AND OTHER MEASUREMENTS

STATION Salt Lake City, Utah WBAS
DISTRICT Region IV
BY WHOM DONE Ottis C. Bobbitt and Clarence Krauth
DATE June 30, 1954
CHARACTER OF INSTRUMENT Dietzen Level
Effective 7/1/54

COPY OF LEVEL NOTES AND OF OTHER MEASUREMENTS MADE

Station	B. S. (+)	H. I.	F. S. (−)	Elevation	Remarks
B.M. S332 (1945) (Coast and Geodetic)				4220.81 (805)	Concrete pillar 20' NW of NW corner Administration Bldg., Salt Lake Airport No. 1
TP 1	4.64	4225.45	3.48	4221.97	
TP 2	3.92	4225.89	3.99	4221.90	
Direct Measurement	27'7-1/4"			4249.50	From TP at base of bldg. where spiral staircase joins E wall
TP 3	4.14	4253.64	1.81	4251.83	Ivory point of barometer in Rm 310, Administration Bldg.
		Return Circuit			
TP 4	1.81	4253.64	4.14	4249.50	
Direct Measurement	24'10-1/4"			4224.65	Fixed Point of 1948 Survey: bottom 1st horizontal groove abv grnd, outside wall where spiral stairs join E wall.
TP 5	0.83	4225.48	2.18	4223.30	New fixed point: high point on stone ledge outside westerly window on N wall CAA Bldg., Room 118
TP 6	2.44	4225.74	1.82	4223.92	Ivory point of barometer in Rm 118, CAA Bldg. (new location)
TP 7	1.82	4225.74	2.44	4223.30	
TP 8	1.66	4224.96	4.26	4220.70	
TP 9	4.79	4225.49	4.64	4220.85	Closing error 0.04 ft.

Elevation of barometer in new location is 4223.90 (after dividing closing error).

FIGURE 1.2.3. Example of "Record of Leveling and Other Measurements" used for keeping a record of surveying data pertinent to the determination of the elevations above sea level of the "fixed point" at a station and of the ivory point of the mercury barometer. (Form WBAN 54–1.2.2.)

should be forwarded to the Navy Representative, National Weather Records Center, Asheville, North Carolina.

U.S. Weather Bureau: The original and the first carbon copies of Form WBAN 54–1.2.1 together with the leveling notes, should be forwarded to the Regional Administrative Office for review and appropriate disposition.

1.3 GEOPOTENTIAL

1.3.1 Introduction

Restricting our attention to a single fixed point located either on the surface of the earth or in the atmosphere, it is possible to consider that the point in question has a definite altitude. The altitude is technically called "*geometric altitude*" if it corresponds with the vertical distance above mean sea level that would be measured with a calibrated tape measure. Here, the vertical represents the upward direction along a plumb line in equilibrium position.

An alternative representation of height above mean sea level is *geopotential* which is related to geometric altitude in a manner depending principally upon the latitude of the point. In making this statement we disregard the small effect which gravity anomalies may have upon the actual relationship between geopotential and geometric altitude at any given point (see Chapter 3). On this basis one may consider that for all points *at a fixed latitude* the geopotential is a function of geometric altitude, and vice versa (see Smithsonian Meteorological Tables, Sixth Revised Edition, 1951, especially Tables 49–51; and Appendix 1.3.1 of this manual). Geopotential has certain distinct advantages over geometric altitude, especially when used in the hypsometric equation as the height argument and when employed in specifying heights above sea level of contour lines in constant pressure surfaces.

While this subject is dealt with at greater length in Appendix 1.3.1, a digression long enough to present two of the important reasons that justify the use of geopotential is not out of place here:

(a) The hypsometric equation given in terms of this variable may be expressed in a form independent of latitude, which makes its application simpler.

(b) The geostrophic wind velocity (V_g) is directly proportional to the horizontal gradient of geopotential in a constant pressure surface, and inversely proportional to the sine of the latitude ($\sin \phi$). However, V_g is directly proportional to the horizontal gradient of pressure in a level surface and inversely proportional to the product of $\sin \phi$ and the air density. It is evident from the comparison between these two relationships, that the first one is simpler and is independent of air density, hence independent of altitude. This permits the use of a single geostrophic wind scale for all constant pressure surfaces whose topography is described by contours in terms of geopotential.

1.3.2 Some Characteristics of Geopotential

The geopotential of a point fixed with respect to the earth is a measure of the gravitational potential energy relative to mean sea level possessed by a unit mass located at the point. That is, geopotential is a quantity representing the work that would have to be done against gravity in lifting a unit mass from mean sea level to the point. Accordingly, the geopotential at mean sea level is always zero (0). Geopotential is assumed to be measured in the absence of nongravitational forces acting on the mass such as those of electrical nature, or those which stem from friction and buoyancy produced by the atmosphere. In all cases the *local* rate of increase of geopotential with increase of geometric altitude at a point is proportional to the *local* acceleration of gravity. The "acceleration of gravity" represents the acceleration which a freely-falling body will undergo in a vacuum, owing to the action of gravity. Acceleration is expressed in meters/second squared (m./sec.^{2}), or in feet/second squared (ft./sec.^{2}), since it represents rate of change of velocity with time. A continuous surface which has a constant geopotential is everywhere a level surface, and conversely, a continuous level surface is characterized by a constant geopotential. This means that in the free air a spirit level whose bubble is accurately centered will lie tangent to the local surface of constant geopotential provided the level is motionless, and that a quiescent plumb line will always be perpendicular to that surface.

1.3.3 International Units of Geopotential

The World Meteorological Organization in 1947 adopted two units of geopotential for international use. These are: (a) the geopotential meter (abbreviated gpm.) and (b) the geopotential foot (abbreviated gpft.).

By agreement between the Members employing the English system of units, the following relationship between the units was adopted:

$$1 \text{ gpft.} = 0.3048 \text{ gpm.}$$

1.3.4 Formulas Expressing Geopotential

Let

Z = geometric altitude above mean sea level of a point;

H_g = geopotential of the point;

$g_{\phi,o}$ = acceleration of gravity at mean sea level at the latitude (ϕ) of the point;

$g_{45,o}$ = acceleration of gravity at mean sea level at latitude 45°;

ϕ = latitude;

$\cos 2\phi$ = cosine of twice the latitude.

$$H_g = \left(\frac{g_{\phi,o}}{a}\right) Z - bZ^2 \qquad (1)$$

where

$$g_{\phi,o} = g_{45,o}(1 - 0.0026373 \cos 2\phi + 0.0000059 \cos^2 2\phi), \qquad (2)$$

and a, b and $g_{45,o}$ are constants depending on the units. When Z is in meters and H_g is to be in geopotential meters (gpm.), $a = 9.8$ m.^{2} sec.$^{-2}$ gpm.$^{-1}$, $b = 0.0000001574$ m.$^{-2}$ gpm., and $g_{45,o} = 9.80616$ m./sec.^{2}. When Z is in feet and H_g is to be in geopotential feet (gpft.), $a = 32.15223$ ft.^{2} sec.$^{-2}$ gpft.$^{-1}$, $b = 0.00000004798$ ft.$^{-2}$ gpft., and $g_{45,o} = 32.17244$ ft./sec.^{2}

Equation (1) is valid for altitudes below 10,000 meters, and thus it is sufficiently good when used in pressure reductions.[3]

1.3.5 Formula for Geopotential of Station

In particular, let

H_p = station elevation, expressed in *meters* above mean sea level (that is, the datum level to which barometric pressure reports at the station refer, in metric units) ; and

H_{pg} = geopotential of the station; expressed in *geopotential meters* (that is, the geopotential corresponding to the level of the station elevation, H_p, as defined above), then the formula giving the geopotential of the station is

$$H_{pg} = \left(\frac{g_{\phi,o}}{9.8}\right) H_p - 0.0000001574\, H_p^2 \text{ in gpm.} \qquad (3)$$

where

$$g_{\phi,o} = 9.80616\ (1 - 0.0026373 \cos 2\phi + 0.0000059 \cos^2 2\phi),\ \text{m./sec.}^2 \qquad (4)$$

The expression *"geopotential of the station"* (symbol H_{pg}) as used in this manual shall always be understood to denote the geopotential representing the "station elevation," given in *terms of the geopotential meter as the unit.*

1.3.6 Instructions for Calculating Geopotential of Station

The following four items are used in making the calculations:

Form WBAN 54–1.3.1	"Calculation of Geopotential of Station (H_{pg}, in gpm.)"
Table 1.3.1	"Feet Converted to Meters"
Table 1.3.2	"Gravity Factor, $\left(\frac{g_{\phi,o}}{9.8}\right)$"
Table 1.3.3	"Altitude Correction Applicable to First Term of Geopotential Formula, $0.0000001574\, H_p^2$ as a function of H_p."

Samples of forms are presented in Chapter 13 and the tables are contained in Chapter 14.

All of the calculations to determine H_{pg} in geopotential meters should be carried out on Form WBAN 54–1.3.1. Instructions regarding the steps to be carried out are listed below in connection with the numbered lines on the form. Two worked-out

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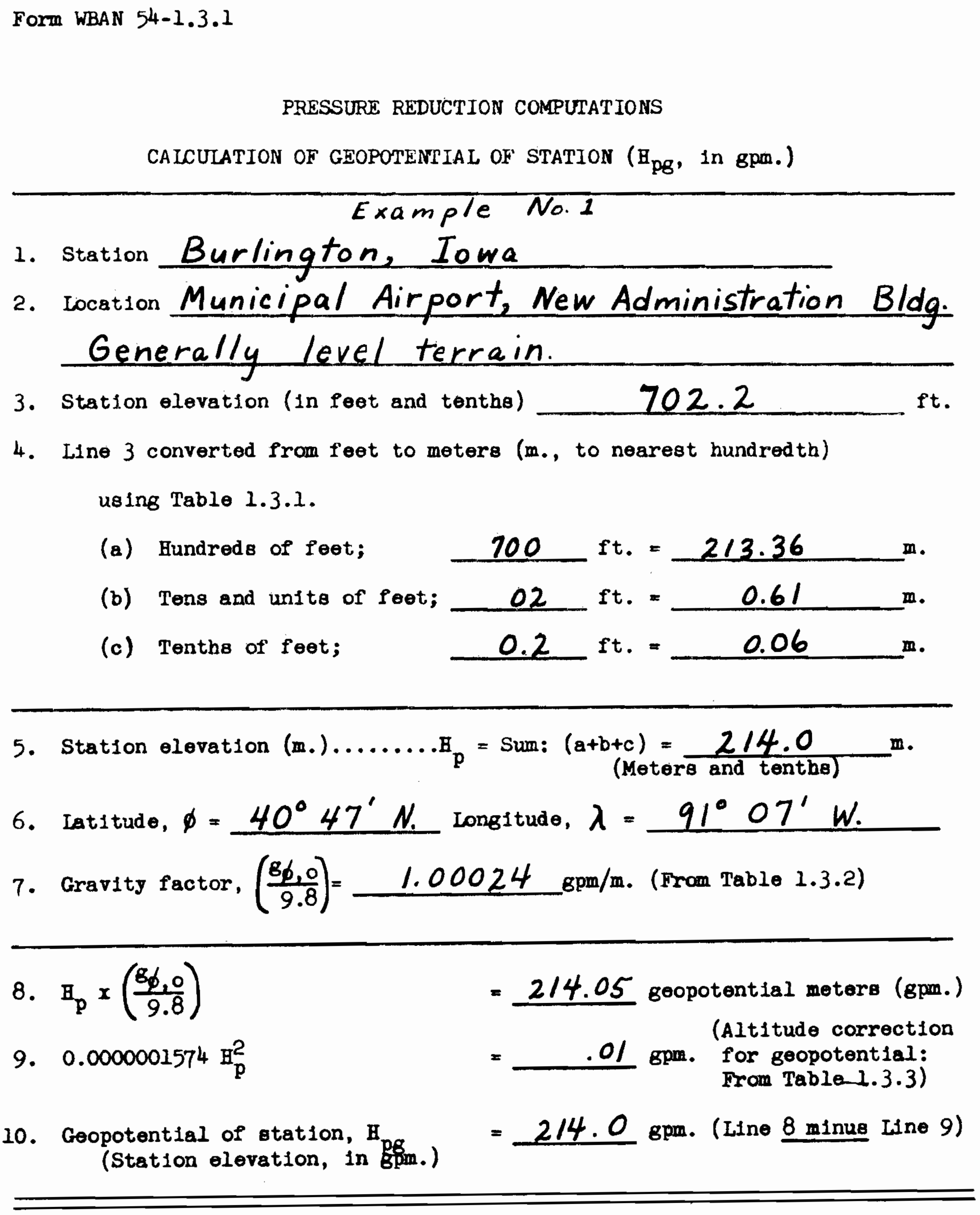
[3] For higher levels some correction terms should be applied to equation (1), depending on the accuracy desired, and the altitude and latitude of the point whose geopotential is required (see Appendix 1.3.1). Reference may also be made to the Smithsonian Meteorological Tables, 6th Edition (1951), pages 217–223.



Form WBAN 54-1.3.1

PRESSURE REDUCTION COMPUTATIONS

CALCULATION OF GEOPOTENTIAL OF STATION (H_{pg}, in gpm.)

Example No. 1

1. Station Burlington, Iowa

2. Location Municipal Airport, New Administration Bldg.
Generally level terrain.

3. Station elevation (in feet and tenths) 702.2 ft.

4. Line 3 converted from feet to meters (m., to nearest hundredth) using Table 1.3.1.

(a) Hundreds of feet; 700 ft. = 213.36 m.
(b) Tens and units of feet; 02 ft. = 0.61 m.
(c) Tenths of feet; 0.2 ft. = 0.06 m.

5. Station elevation (m.).........H_p = Sum: (a+b+c) = 214.0 m. (Meters and tenths)

6. Latitude, ϕ = 40° 47′ N. Longitude, λ = 91° 07′ W.

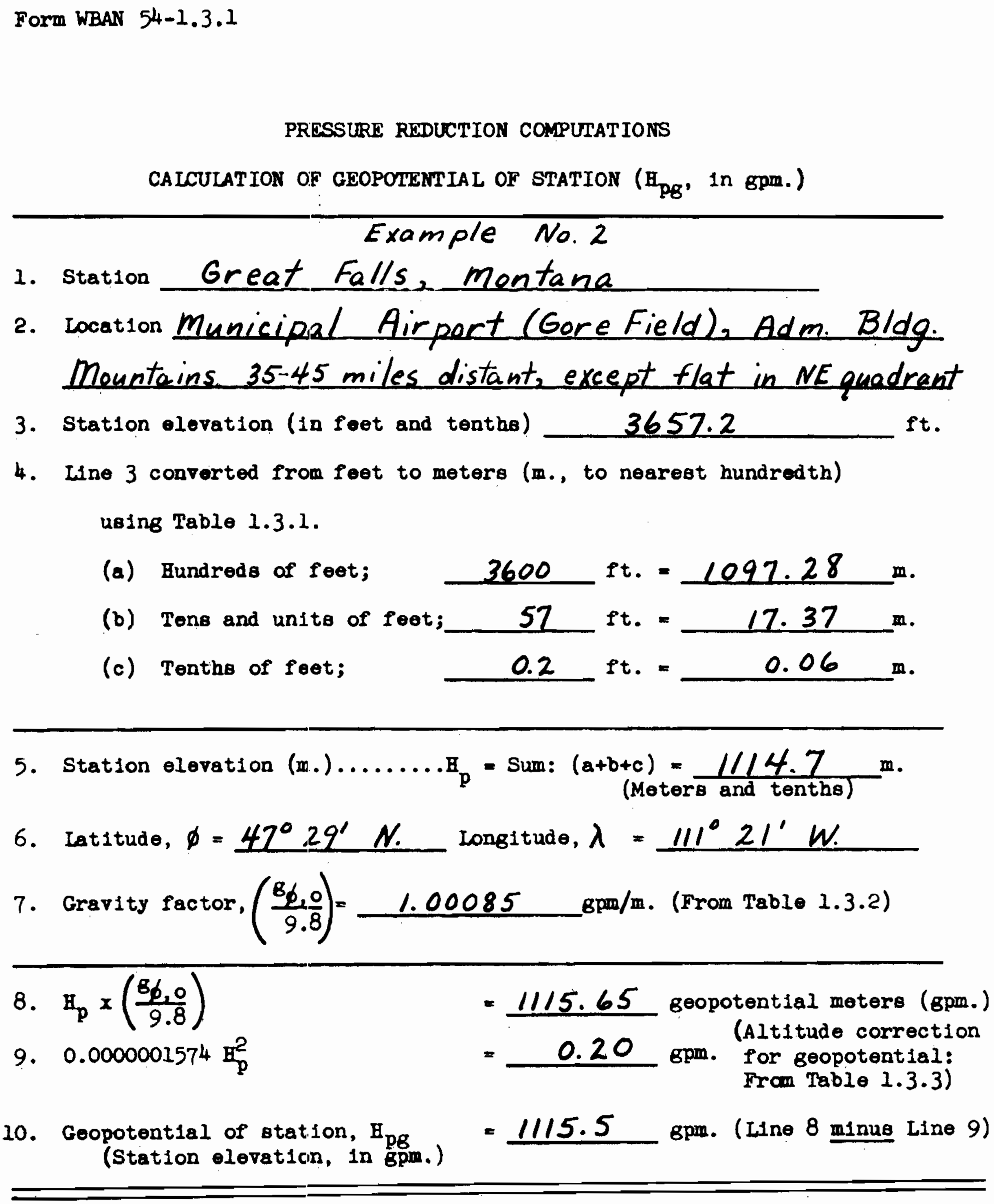
7. Gravity factor, $\left(\frac{g_{\phi,0}}{9.8}\right)$ = 1.00024 gpm/m. (From Table 1.3.2)

8. $H_p \times \left(\frac{g_{\phi,0}}{9.8}\right)$ = 214.05 geopotential meters (gpm.)

9. $0.0000001574\ H_p^2$ = .01 gpm. (Altitude correction for geopotential: From Table 1.3.3)

10. Geopotential of station, H_{pg} (Station elevation, in gpm.) = 214.0 gpm. (Line 8 minus Line 9)

FIGURE 1.3.0. Sample of Form WBAN 54–1.3.1 showing calculation of geopotential of station at Burlington, Iowa.



Form WBAN 54-1.3.1

PRESSURE REDUCTION COMPUTATIONS

CALCULATION OF GEOPOTENTIAL OF STATION (H_{pg}, in gpm.)

Example No. 2

1. Station Great Falls, Montana

2. Location Municipal Airport (Gore Field), Adm. Bldg.
Mountains 35-45 miles distant, except flat in NE quadrant

3. Station elevation (in feet and tenths) 3657.2 ft.

4. Line 3 converted from feet to meters (m., to nearest hundredth)
using Table 1.3.1.

(a) Hundreds of feet; 3600 ft. = 1097.28 m.

(b) Tens and units of feet; 57 ft. = 17.37 m.

(c) Tenths of feet; 0.2 ft. = 0.06 m.

5. Station elevation (m.).........H_p = Sum: (a+b+c) = 1114.7 m.
(Meters and tenths)

6. Latitude, ϕ = 47° 29′ N. Longitude, λ = 111° 21′ W.

7. Gravity factor, $\left(\frac{g_{\phi,0}}{9.8}\right)$ = 1.00085 gpm/m. (From Table 1.3.2)

8. $H_p \times \left(\frac{g_{\phi,0}}{9.8}\right)$ = 1115.65 geopotential meters (gpm.)

9. $0.0000001574\ H_p^2$ = 0.20 gpm. (Altitude correction for geopotential: From Table 1.3.3)

10. Geopotential of station, H_{pg} (Station elevation, in gpm.) = 1115.5 gpm. (Line 8 minus Line 9)

FIGURE 1.3.1. Sample of Form WBAN 54-1.3.1 showing calculation of geopotential of station at Great Falls, Montana.

examples of the form are presented in figs. 1.3.0 and 1.3.1.

Line 1. Write the name of the station.

Line 2. Describe the location of the station, airport, city office or other, street address, type of building, and surrounding terrain.

Line 3. Write the *station elevation*; expressed in feet, to the nearest tenth of a foot. (Note definition of term in section 1.2.)

Line 4. Refer to Table 1.3.1 and use the data given therein to convert the station elevation from feet to meters. The conversion is performed stepwise as shown on lines 4(a), 4(b), and 4(c), by use of the information contained in Tables 1.3.1(a), 1.3.1(b) and 1.3.1(c), respectively. Enter the converted values to *meters and hundreths* in the extreme right-hand column. Details are as follows: For the purpose of making the conversions, split the station elevation, in feet, into three parts as shown on the line under 4; thus, on line 4(a) enter the hundreds of feet, on line 4(b) enter the tens and units of feet, and on line 4(c) enter the tenths of feet. By means of Table 1.3.1(a) convert to meters the whole hundreds of feet as given on line 4(a); by means of Table 1.3.1(b) convert to meters the tens and units of feet as given on line 4(b); and by means of Table 1.3.1(c) convert to meters the tenths of feet as given on line 4(c).

Line 5. Take the sum of the values shown in the right-hand column of line 4 and write the result rounded to meters and tenths. The sum represents the station elevation (H_p) in metric units.

Line 6. Enter the latitude (ϕ) and the longitude (λ) of the station in degrees and minutes.

Line 7. Refer to Table 1.3.2. Find the gravity factor ($g_{\phi,o}/9.8$) in gpm./m. corresponding to the latitude (ϕ) of the station, interpolating for the minutes if necessary. (60 minutes = 1 degree). Enter the result expressed to the fifth decimal place on line 7.

Line 8. Muliply H_p by the gravity factor ($g_{\phi,o}/9.8$), and enter the result in gpm. to the nearest hundredth of a unit. For this purpose, H_p, in meters and tenths, is obtained from line 5, and the gravity factor ($g_{\phi,o}/9.8$), is secured from line 7.

Line 9. Refer to Table 1.3.3. Find the altitude correction $0.0000001574\ H_p^2$ corresponding to the station elevation H_p in meters as given on line 5, interpolating if necessary in Table 1.3.3 for values of the argument H_p intermediate between the tabulated arguments. Enter the result in gpm. to the nearest hundredth of a unit on line 9.

Line 10. *Subtract* the value given on line 9 from the value given on line 8, and enter the result on line 10, in geopotential meters, *rounded to the nearest tenth of a unit.* The datum thus determined is called the "*geopotential of the station*" and is represented by the symbol H_{pg} in the hypsometric equation used for calculating reductions to sea level in this manual.

1.4 INTERNATIONAL BAROMETER CONVENTIONS AND UNITS OF PRESSURE

In 1953, the World Meteorological Organization adopted certain agreements concerning standard units of pressure and related matters pertaining to mercurial barometers. These agreements are embodied in the "International Barometer Conventions,"[4] which are presented in Appendix 1.4.1. Other publications of the material contained in the Conventions are also in existence.[5] [6] The conversion factors and information given below are consistent with the provisions of the "International Barometer Conventions."

The fundamental physical concept of "pressure" may be grasped from an experimental situation like the following, which involves a fluid such as the atmosphere of the earth or the water of the oceans: Consider an infinitesimal area dA surrounding a point on a plane surface immersed in a fluid, and let dF denote the force exerted by the fluid upon the area; then, the pressure at the point is the ratio dF/dA; that is, force

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[4] World Meteorological Organization, Commission for Instruments and Methods of Observation, "Abridged Final Report of the First Session," Toronto, 10th August—4th September, 1953, WMO—No. 19. RP. 9, Secretariat of the World Meteorological Organization—Geneva, Switzerland. (See Recommendation No. 9, (CIMO-I), pp. 73–78.)

[5] World Meteorological Organization, "Guide to International Meteorological Instrument and Observing Practice" WMO—No. 8. TP. 3, Secretariat of the World Meteorological Organization—Geneva, Switzerland, 1954. (See Chapter 3—"Measurement of Pressure.")

[6] British Standards Institution, "Barometer Conventions and Tables," B.S. 2520, London (1954).

acting per unit area. In Appendix 1.4.2 further details will be found regarding the fundamental considerations pertaining to the measurement of atmospheric pressure by means of fluid columns which are supported by it, as in the case of mercury barometers.

The following conversion factors are useful in relating various units of pressure, under the assumption that 1 inch = 2.54 centimeters:

1 millibar = 1,000 dynes per square centimeter

1 millibar = 0.0295300 inch of mercury (standard)

1 millibar = 0.750062 millimeter of mercury (standard)

1 inch of mercury (standard) = 33.8639 millibars

1 inch of mercury (standard) = 25.4 millimeters of mercury (standard)

1 millimeter of mercury (standard) = 1.333224 millibar

1 millimeter of mercury (standard) = 0.03937008 inch of mercury (standard)

1 Torr = 1/760 of one standard atmosphere pressure = 1,013.250/760 millibar. The result of this division carried to seven significant figures is 1.333224 millibar. On the basis of the definition of "one millimeter of mercury (standard)" given below we find for this unit the same numerical value in millibars expressed to seven significant figures.

The basic definitions are as follows:

(*a*) *"One standard atmosphere pressure"* is defined as a pressure of 1013.250 millibars (by action of the International Committee on Weights and Measures, Paris, 1954).

(*b*) *"One inch of mercury (standard)"* represents the difference between the pressures at base and top of a layer of mercury which occupies the space between two horizontal planes one inch apart crossing a vertical column of mercury of unit cross-section area which has a temperature of 0° C. and is subjected to a gravitational acceleration of 980.665 cm./sec.^{2} (standard gravity), where the density of the mercury under these standard conditions shall be considered to be 13.5951 grams per cubic centimeter.

(*c*) The definition of *"one millimeter of mercury (standard)"* is similar to that of "one inch of mercury (standard)" except that the phrase "one inch apart" is replaced by "one millimeter apart."

(*d*) *"One millibar"* is equal to 1,000 dynes per square centimeter, where one dyne is the force which when exerted continuously upon a one gram mass gives it an acceleration of one centimeter per second per second.

Table 1.4.1 provides data for converting standard inches of mercury, $(\text{in. Hg})_n$, to millibars, and Table 1.4.2 provides data for converting millibars to standard inches of mercury, $(\text{in. Hg})_n$.

Note Regarding Linear Conversion Factor

It will be observed that the conversion factor 1 inch = 2.54 centimeters, used here, is taken to be consistent with the value for converting meters to feet (0.3048 meter = 1 foot) adopted for aerological observations by the World Meteorological Organization (see Publication No. 79).

The relationship between the English and metric units specified above for conversion purposes is given sanction under the terms of an agreement announced on January 1, 1959, as follows:[7]

> "The Directors of the following standards laboratories:
>
> Applied Physics Division, National Research Council, Ottawa (Canada)
> Dominion Physical Laboratory, Lower Hutt (New Zealand)
> National Bureau of Standards, Washington (United States of America)
> National Physical Laboratory, Teddington (United Kingdom)
> National Physical Research Laboratory, Pretoria (South Africa)
> National Standards Laboratory, Sydney (Australia)

have discussed the existing differences between the values assigned to the yard and to the pound in different countries. To secure identical values for each of these units in precise measurements for science and

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[7] U.S. Department of Commerce, National Bureau of Standards, TRG–6234, January 1, 1959, "Announcement on the International Yard and Pound."

technology, it has been agreed to adopt an international yard and an international pound having the following definition:

the international yard equals
0.9144 metre;
the international pound equals
0.453 592 37 kilogramme.

"It has also been agreed that, unless otherwise required, all non-metric calibrations carried out by the above laboratories for science and technology on and after July 1, 1959, will be made in terms of the international units as defined above or their multiples or submultiples.

* * *

"The international inch, derived from the international yard, is exactly equal to 25.4 millimeters. This value for the inch has been legally adopted by Canada. Also this value was approved by the American Standards Association for 'Inch-millimeter conversion for industrial use' in 1933 (ASA Standard B48.1–1933), was adopted by the National Advisory Committee for Aeronautics in 1952, and has been adopted by many standardizing organizations in other countries."

For historical reasons it is necessary to point out that prior to the date of the foregoing announcement of January 1, 1959, the National Bureau of Standards employed a different definition of the inch for the calibration of line standards and end gages. The basis for this was the act of the U.S. Congress of July 28, 1866,[8] which sanctioned and legalized the use of the metric system in the United States; and at the same time set forth an adopted relationship between the yard and the meter in the form of a ratio as follows:

$$\frac{1 \text{ U.S. yard}}{1 \text{ meter}} = \frac{3600}{3937}$$

Late in 1889 duplicates of the international prototype meter and the international prototype kilogram were brought to the United States from the International Bureau of Weights and Measures; and these were opened by the President of the United States on January 2, 1890. By virtue of the adoption of the above ratio and the receipt of the international meter standard bar, a legal basis was established for the definitions of the U.S. yard and inch. In order to implement the law of 1866, the Office of Weights and Measures of the Treasury Department issued an Executive Order on April 5, 1893,[9] which interpreted the act of Congress of 1866 as equivalent to the specification of the U.S. yard in terms of the international meter according to the given ratio. Since there are 36 inches to the yard, the specified ratio yields an assumed relationship between the original legal U.S. inch and the meter as follows:

$$1\text{–}1866 \text{ legal U.S. inch} = 2.54000508 \text{ centimeters.}$$

In Great Britain a physical line standard of the *"Imperial Yard"* made about 1845 has been compared with the international meter, yielding the result that

$$\frac{1 \text{ British Imperial Yard}}{1 \text{ meter}} = \frac{3600}{3937.0147},$$

which is equivalent to the relationship

$$1 \text{ British Imperial Inch} = 2.5399956 \text{ centimeter.}$$

Thus, it is evident that the legal inch as used by various English speaking countries differed slightly prior to the date of effectiveness of the agreement.

By virtue of the announcement of January 1, 1959, quoted above, it will be possible for all countries to employ the international inch, international yard, and international pound with common meanings to be attributed to these units, regardless of nationality, after July 1, 1959.

It should be noted that the conversion factors used in this manual are in accord with provisions of the announcement quoted above, specifically

$$1 \text{ inch} = 2.54 \text{ centimeters.}$$

The International Prototype Meter is a graduated line standard made of platinum-iridium; and the International Prototype Kilogram is a definite mass of the same material. In carefully conditioned archives the

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[8] United States Code, title 15, ch. 6, sec. 205 (Revised Statutes, sec. 3570)

[9] U.S. Coast and Geodetic Survey Bulletin 26, April 5, 1893, "Fundamental Standards of Length and Mass," by T. C. Mendenhall. This order stated that the Office of Weights and Measures, with the approval of the Secretary of the Treasury, would in the future regard the International Prototype Meter and Kilogram as fundamental standards, and that the customary units would be derived therefrom in accordance with the Act of July 28, 1866.

International Bureau of Weights and Measures, at Sevres, France, maintains the International Prototype Meter and the International Prototype Kilogram. Copies are in the possession of the National Bureau of Standards (United States Prototype Meter No. 27 and United States Prototype Kilogram No. 20). The latter prototypes are recognized as effectively the primary standards of length and mass of both the metric and the customary systems of measurements in this country.

Standards employed by the British have been discussed elsewhere.[10]

The 11th General Conference of Weights and Measures on October 14, 1960, adopted a light wave standard in place of the international prototype meter. Under plans envisaged, the wave length of a monochromatic ray of light secured as a sharp line in the spectrum of an isotopically pure chemical substance will be employed as the universal standard of length, and all meter bars will thereafter be defined in relation to the wave-length standard. Krypton–86 has been designated for the substance.[11] In effect the meter was defined as equal to 1,650,763.73 wavelengths in a vacuum of the radiation corresponding to the transition between the levels $2p_{10}$–$5d_5$ of the atom of krypton–86. The above-mentioned sharp line in the case of krypton–86 is colored orange-red. By virtue of the foregoing definition, one inch will be equal to 41,929.399 wavelengths of the krypton light as specified above.

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[10] Sir Charles Darwin and others, "A Discussion on Units and Standards" Proc. Roy. Soc. (London) Ser. A, *186*, pp. 149–217 (9 July 1946)

[11] Jour. Opt. Soc. Amer., vol. 48, May, 1958, p. 361.

CHAPTER 2. INSTRUMENTS FOR DETERMINING ATMOSPHERIC PRESSURE—THEIR INSTALLATION AND CHARACTERISTICS

2.0 SCOPE OF THIS CHAPTER

The purpose of this chapter is, first of all, to present instructions regarding the installation, unpacking, and moving of barometers. Secondly, the purpose is to describe the various types of instruments used for determining atmospheric pressure, to give an account of the especially significant characteristics of some of the more important types of barometers (particularly aneroid, Fortin, and fixed-cistern), and to consider in fairly general terms a number of factors which affect the measurement of atmospheric pressure. It is necessary to take these factors into account either by means of appropriate corrections or by taking suitable precautions.

In addition to the main body of Chapter 2, there is the Annex, appended, which contains brief descriptions of various atmospheric-pressure measuring instruments, arranged according to categories, in more or less systematic order. The information in the Annex pertaining to this matter is intended for those who are interested in gaining some perspective regarding almost the entire field of such measuring equipment, without undue detail. In the Annex one will also find additional information relating to the packing, care, and shipping of barometers, where so many details are involved that it was deemed inadvisable to include that material in the main body of Chapter 2. Furthermore, the Annex gives some information on the subjects of cleaning of mercury, and the cleaning and filling of mercury barometers.

The plan of Chapter 2 is to present first in sec. 2.2 the operational instructions which an observer is likely to need in setting up a station, particularly in regard to picking a suitable site for the barometer, determining the height at which it should be mounted above the floor, unpacking the barometer, checking it for possible damage it might have sustained during transit, etc., installing the barometer, and rendering it vertical (in the case of mercury or other liquid types of barometers), and moving the barometer. When it is necessary to ship a barometer, the instrument is generally placed in a packing box and suitably packed. All of these matters require many precautions, involving details with which the person handling the barometer must become familiar. The observer who will be confronted with the duty of performing these tasks should take the time to study the instructions in sec. 2.2 and other information pertinent to the matter given in the Annex.

The material is organized so as to introduce the more important types of barometers in the early sections of the chapter following sec. 2.2, and to provide more information of a detailed nature concerning the operation and characteristics of these important types in later sections. Thus, sec. 2.3 introduces the aneroid barometer, while secs. 2.8, 2.9, and 2.10 give additional details. Mercurial barometers are introduced in sec. 2.4, while the Fortin and fixed-cistern types are discussed in secs. 2.5 and 2.6, respectively.

In sec. 2.7, there are presented general discussions of factors governing the absolute accuracy of mercurial or other liquid barometers; and finally in sec. 2.11 some additional information is given, particularly with regard to factors such as wind which have an influence upon all determinations of atmospheric pressure, regardless of type of instrument.

It is intended that the information contained in this chapter serve as a guide to users of barometers, concerning such matters as the best choice of site and precautions to be taken for installation of barometers; the selection of pressure measuring instruments most suitable for specific purposes; the underlying reasons for application of various corrections; the basis for good operational practices pertaining to barometers; and the characteristics of the various instruments which impose limitations on their accuracy and precision.

For readers interested in the origin of the mercury barometer, in the related experiments which scientists performed during the seventeenth century to understand the phenomenon of atmospheric pressure and of vacuum, and in the various designs which pressure measuring instruments assumed during the relatively early years of their development, additional material is presented in Appendix 2.1, "Background History Relating to the Invention of the Barometer and Some of Its Miscellaneous Types."

2.1 GENERAL INFORMATION REGARDING PRESSURE MEASUREMENTS

Pressure such as that exerted by a gas like the atmosphere is caused by the random bombardment of the molecules of the fluid against the surface at which the pressure is manifested. Thus, in order to measure pressure it is necessary to balance the force which it exerts upon any given surface area, and to determine the magnitude of that force per unit area (see sec. 2.4).

Barometric instruments are mostly used to ascertain the pressure exerted by the atmosphere, which depends upon the weight of the vertical column of air extending above the instrument to the top of the atmosphere. No barometric instrument yields an accurate absolute pressure measurement directly without either the application of suitable corrections or the calibration of the instrument against a standard barometer. Therefore, a number of factors are involved, both with regard to the determination of the necessary corrections and the precautions which must be taken in order to obtain reliable measurements. Certain physical considerations govern the functioning of the various kinds of barometers in existence and these should be understood by any scientist interested in the problem of securing reliable pressure measurements. For this reason, much of the material in this chapter following sec. 2.2 on installation of barometers, etc., deals with the basic characteristics of the more important types of barometers. These include the aneroid barometer, and the two principal types of mercury barometer used in the United States, namely the Fortin-type and the fixed-cistern type. Some other types of instruments for determining atmospheric pressure are described in the Annex.

The most fundamental type, generally used in the construction of standard barometers, is the U-shaped tube, siphon design, which is discussed to some extent in Appendix 1.4.2 (see Chapter 12). By means of an instrument of such a basic character, which permits the determination of pressure from first principles, one may measure pressure in an absolute sense. Owing to this fact, the instrument presented diagrammatically in Appendix 1.4.2 may be called a primary barometer, which serves as a standard (see also Annex, secs. A–2.5 and A–2.6). The calibration of all other types of barometers ultimately depends upon the comparison of the readings of these types with the readings of the primary, standard barometer (see Chapter 6 and its Annex).

Accordingly, the precision aneroid barometer which is extensively used owing to its portability and ease of reading, must be calibrated carefully against a mercury barometer in accordance with a procedure designed to take account of its inherent, mechanical characteristics, described in secs. 2.3, 2.8, 2.9, and 2.10. The method of calibration is presented in detail in Chapter 6.

The Fortin-type is the design of the mercury barometer most widely used for synoptic observations of atmospheric pressure at U.S. land stations. This type therefore serves as the local standard for aneroid barometers, but since it is not a primary instrument it must be compared at intervals with a primary barometer, or in lieu of this with a sub-standard barometer which has itself been calibrated against a primary, standard barometer. In sec. 2.5 the reader will find a description of the Fortin-type barometer, whose design is such that it must be regarded as more fundamental in character than the fixed-cistern barometer depicted in sec. 2.6.

Many factors have a significant influence upon the measurement of absolute atmospheric pressure, such as gravity, temperature of the instrument, etc., while there are some conditions which affect the ambient pressure at the site of the instrument, such as the influence of the wind on the pressure within the building. A discussion is presented in regard to these matters so that the user of the barometric instruments may be enabled to understand the reasons for the corrections which must be applied and to have a grasp of causes, so as to be better able to overcome the more significant effects.

2.2 INSTRUCTIONS FOR INSTALLATION, UNPACKING, AND MOVING OF BAROMETERS

2.2.0 Introduction

Before a barometer can be installed, it is necessary to select the site where the instrument is to be located by following carefully certain principles laid down in sec. 2.2.1. Selection of the site and preparation of the wall or bulkhead for mounting of the instrument must be completed before the barometer is unpacked; and the unpacking must be done in the immediate vicinity of the final site. Instructions for the unpacking of barometers are given in sec. 2.2.3. It is very important that these instructions be carefully observed, since a misstep in the operations may result in damage to the instrument.

Certain precautions are necessary in the handling and moving of barometers. Persons installing or otherwise dealing with these delicate instruments must observe the precautions as described in sec. 2.2.7 and A–2.16.

Anyone who is called upon to pack barometers for shipment or to transport them from one place to another should carefully read the information given regarding this subject in the pertinent sections of the Annex of this chapter, especially secs. A–2.16, A–2.20 and A–2.21.

Two main points are to be emphasized: (A) barometers should be safeguarded against shocks; and (B) when barometers are to be transported any great distance or away from a given floor or deck, there is a definite, preferred position in which they should be carried. Instructions regarding the preferred position will be given for each type of barometer. For example, it may be pointed out here that Fortin-type barometers must always be in an inverted position when transported over such distances, that is, with the cistern uppermost, or in an inclined position with the cistern at a slightly higher level than the top of the barometer tube.

The scientific reasons underlying the principles which govern the selection of sites for barometers and the installation of these instruments are described at some length in secs. 2.7 and 2.11, and the person who is interested in understanding the bases on which the instructions rest would do well to read those sections.

Instructions given hereunder with regard to the selection of the site for the barometer are intended for guidance. Exceptions to the general instructions will be permitted during emergencies or in circumstances where closest possible adherence to those instructions would lead to an impracticable situation. For these reasons, the instructions must be followed with discretion and good judgment.

2.2.1 Instructions for Picking a Barometer Site

(1) Determine the most suitable location for the barometer based on the conditions that the instrument must be readily accessible to the observer; must be safe from tampering; must be free from rough treatment or jolts; must be in a location with minimum possible vibration and least mechanical jar; must be in a place which is clean, relatively dry, and maintained at as nearly steady temperature as practicable, without direct sunshine on the instrument, and free from drafts, hot air currents, or other sources of heat or cold capable of producing rapid temperature fluctuations. The mercurial barometer is preferably installed in a case which is mounted vertically on the wall and which is provided with a door or hinged cover. Purpose of the case is to keep away dust and moisture from the instrument, to help maintain its temperature at a

uniform level, and to provide protection against physical damage. For reasons of economy, the barometer is installed on a specially constructed board at some stations, provided it is never exposed to the direct sun. As a rule the best location for the barometer is on an inside wall which no direct rays from the sun can reach. The site should be away from doors, windows, radiators, chimney openings, or ventilators, since these can yield undesirable currents of cold or warm air. It is necessary to avoid sites on an outside wall because they vary more in temperature through the day; and it is important not to install the barometer at a place where steep horizontal or vertical gradients of temperature exist. If practicable, locations should be avoided where there are chimneys, ventilators, or arrangements producing either natural or artificial pressure differences of significant amount with respect to the outside, undisturbed atmosphere, giving consideration to the fact that strong winds and high velocity ventilation systems may give rise to such differences, and excessive pumping of the barometer. Proper lighting facilities must be provided as explained below.

In the case of a mercury barometer on shipboard, the location of the instrument must be in a place where the barometer may be swung out on the gimbal arm in position for reading, bringing the top of the mercury column to the normal eye height above the deck. When observing the barometer in the selected location, the observer must be in a position where he will not be brushed by passers-by. Thus, the barometer must be in a spot readily accessible to the observer, but never in a passageway or other space where the barometer will be subject to injury by careless personnel. When the barometer is to be mounted with gimbal arm swung down at all times, a semi-circular metal guard, projecting at least four inches past the barometer cistern should be installed to protect the instrument from accidental injury. Provision should be made, if practicable, for a convenient source of power supply for the electric light, either an electrical outlet or an extension cord connected to an outlet, for connecting to the plug and cord of the barometer case.

2.2.2 Instructions for Establishing Height of Barometer Above Floor

The height of the aneroid barometer should be at convenient eye level for all observers, in such a position that errors due to parallax may be avoided (see sec. 2.10.9). Once the location of the aneroid barometer has been decided upon and calibrations made to determine the correction for the instrument on the basis of comparative readings against a mercury barometer (see Chapter 6), the location and position of the aneroid barometer should not be changed without careful consideration and sufficient cause. The aneroid may be mounted on a bench with face horizontal, or on a wall with face vertical. It is important that the height of the instrument be such that readings may be taken when the observers stand in a normal relaxed position.

Every mercury barometer has a zero point pertaining to its scale. In the case of Fortin-type barometers, the tip of the ivory point serves as the zero point, whereas in the case of fixed-cistern barometers the zero point is not generally indicated specifically. The proper height of the mercury barometer above the floor is determined by the condition that the height of the meniscus in the barometer tube when maximum pressure occurs at the station should be situated at or slightly below eye level of each observer when standing in a normal, relaxed position. An important criterion is that no observer must be forced to stand on tiptoe to make an observation of the meniscus in the tube when maximum pressure exists. If necessary, a stable platform should be provided to enable short persons to make such observations while standing in a normal, relaxed position. Tall persons may stoop to make the observations. As a rule, maximum pressure is about 1.20 inches of mercury higher than mean station pressure. By referring to Table 8.1, it is possible to obtain some idea of the approximate value of mean station pressure at various elevations.

Once the eye level of observers standing in a normal, relaxed position is determined, a mark is made on the wall at this level.

After the approximate maximum station barometer reading has been estimated, measure down from this mark a distance in inches equal to this maximum reading, and make a second mark to indicate the level at which the zero point of the mercury barometer is to be located. Thus the scale graduation labelled 30 inches on the barometer scale is to be 30 inches above the second mark which indicates the proper height of the zero point above the floor; and similarly the 1000 mb. scale graduation will be 29.53 inches above the second mark. A convenient rule of thumb, now outlined, may be used to check the height of the second mark, thus: the approximate height of the zero point of the barometer above the floor should be calculated as 33 inches *plus* one inch for every thousand feet of elevation of the barometer. For example, a barometer at an elevation of 5,000 feet should have its zero point approximately (33″ + 5″) or 38 inches above the floor. This rule of thumb is based on the assumption that the eyes of the observers are at an average height of about 63 inches above the floor. In cases where this is not representative of the average height the rule may be modified to fit the requirements which exist.

2.2.3 Unpacking and Checking Barometers

2.2.3.0 Introduction.—*Caution:* Do not unpack the barometer until provision has been made for mounting it. Handle the packing box with care, and never jolt or tilt it suddenly. The use of a crowbar or other implement to force open the packing box is not permitted, and hammering on the box should be strictly avoided. See instructions for installation of barometer in sec. 2.2.4.

Mercury barometers are shipped in specially built packing boxes. Fortin barometers are tilted at an angle so that the cistern of the barometer is slightly elevated. Fixed-cistern barometers are usually shipped in a vertical position.[1] The unpacking of the mercury barometer should be done in the immediate vicinity of the site selected for mounting the instrument.

2.2.3.1 Unpacking.—(1) Remove the screws that hold the lid and remove the lid without jarring the packing box. This should be done while the box is still at the proper angle for shipment as explained.

(2) Remove the excelsior or other loose packing material which is on top of the barometer. (Some special boxes have packing material cemented inside. In such cases do not attempt to remove this material.)

(3) Remove the barometer in its wrappings from the packing box. If the barometer is of the Fortin type it may be gently laid on a horizontal surface and carefully unwrapped. Carefully read the instructions in sec. 2.2.7.1–2.2.7.5. While the Fortin-type barometer is horizontal, it is important that the instructions given in sec. 2.2.7.3 with respect to the size of the air bubble should be observed.

(4) If the barometer has been received in an inverted position (that is, with the cistern up), follow the instructions in sec. 2.2.7.1–2.2.7.5 and turn the barometer upright very carefully until it is in a vertical position with the cistern down. Hang the barometer in place at the installation point previously prepared for it.

(5) Replace the wrappings and packing material carefully in the empty packing box; then screw the lid on and put the packing box away for future use.

2.2.3.2 Checking.—Check the barometer to see that it is intact and that no breakage has occurred during shipment. Report any damage or breakage on the appropriate forms available for this purpose, depending on the service, means of transportation, etc. involved.

2.2.4 Instructions for Installation of Barometers

2.2.4.0 Introduction.—The choice of site for the barometer should be governed by the principles already stated in sec. 2.2.1. If it is necessary, owing to unusual circumstances, to set up any type of barometer out of doors, do not place it where it will be exposed to direct rays of the sun: and shielding from variable sources of heat is desirable, if practicable.

With regard to the position of aneroid barometers, it should be noted that some

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[1] If the barometer is a fixed-cistern type see the special instructions furnished by the Service for the particular type of instrument.

models are calibrated for vertical mounting and some for horizontal mounting. In either case, the proper position of mounting should be employed, in conformity with the existing, pertinent instructions for the given model.

Mercury barometers as used at land stations should be installed in a barometer box or mounting case securely fastened to a suitable wall, column, or other rigid support. The purpose of the case already has been explained in sec. 2.2.1. In some circumstances, the walls of buildings are frequently subject to vibration, possibly owing to movement of people, vehicles, wind or other causes. Such vibration tends to hamper accurate reading of the barometer. If the walls of the room at the chosen site vibrate excessively, or if they are constructed of some material that makes it impracticable to mount the case securely, consideration should be given to building a vertical rack from the floor on which to mount the barometer case. This can yield a satisfactory solution to the problem if the floor provides a firm foundation, as when made of concrete. In cases where both the wall and the floor are subject to excessive vibration, the best solution to the problem is usually afforded by constructing a concrete pier. To make it relatively free from vibration, the pier should extend through the floor at least 30 inches into the ground beneath, and the pier should not be in contact with any part of the building. When this is completed, a rack for mounting the barometer case should be fastened to the pier.

CAUTION

It is important that the barometer cases be supported by screws which are firmly imbedded in studding or other solid material in walls or bulkheads. Barometers have fallen and broken as a result of having been fastened insecurely to wall board or lath and plaster walls.

Sometimes it will be necessary to fasten to the wall hardwood strips or other suitable material, to provide support for the barometer case or board. The strips are arranged horizontally, and they are so spaced that the top and bottom of the case (or board) can be secured to them by means of screws. In the more elaborate type of barometer case the screws pass through metal plates which give strength to the support. With the smaller types of barometer case (or barometer board), it is often desirable to fasten vertically to the wall a stout board of suitable length to run the full height of the case, in order to provide a strong base for it which can be supported by the studs or columns in the wall. In such situations where iron brackets are supplied for the purpose of mounting the barometer case to a suitable vertical surface, the brackets can be screwed into the board or wall at the correct height.

2.2.4.1 Mounting the Barometer Case and Hanging the Barometer.—Designs of barometer cases differ somewhat among the various Services. (See figs. 2.2.0–2.2.5 and 2.6.1 for examples of these respective cases.) Accordingly, the procedures for securing the case to the wall and hanging the barometer vary in certain details, depending on the type of case. However, the basic principles are the same in all instances: (1) The case is put into position on the wall and the center screw for supporting the case near the top is screwed into the wall or the board attached to the wall. (2) The case is aligned so that it is vertical, as judged by means of a plumb bob or a small heavy weight suspended on a cord. (3) The center screw for supporting the barometer case near the bottom is inserted, and the verticality of the case is checked. (4) The screws thus far inserted are tightened up and if there is provision for additional screws they should be screwed into the supporting surface. (5) To hang the barometer, pass the cistern end of the barometer down through the centering ring near the bottom of the case or board, and put the swivel ring at the top of the barometer over the hanger near the top of the case. (6) If there is a screw provided in the swivel hanger be careful that the point of the screw fits into the depression on the support. (7) If there is a vertical screw or knurled nut provided for the front of the support to prevent the barometer from sliding off, replace the vertical screw or the knurled nut and tighten it adequately. (8) If the barometer is of the Fortin type,

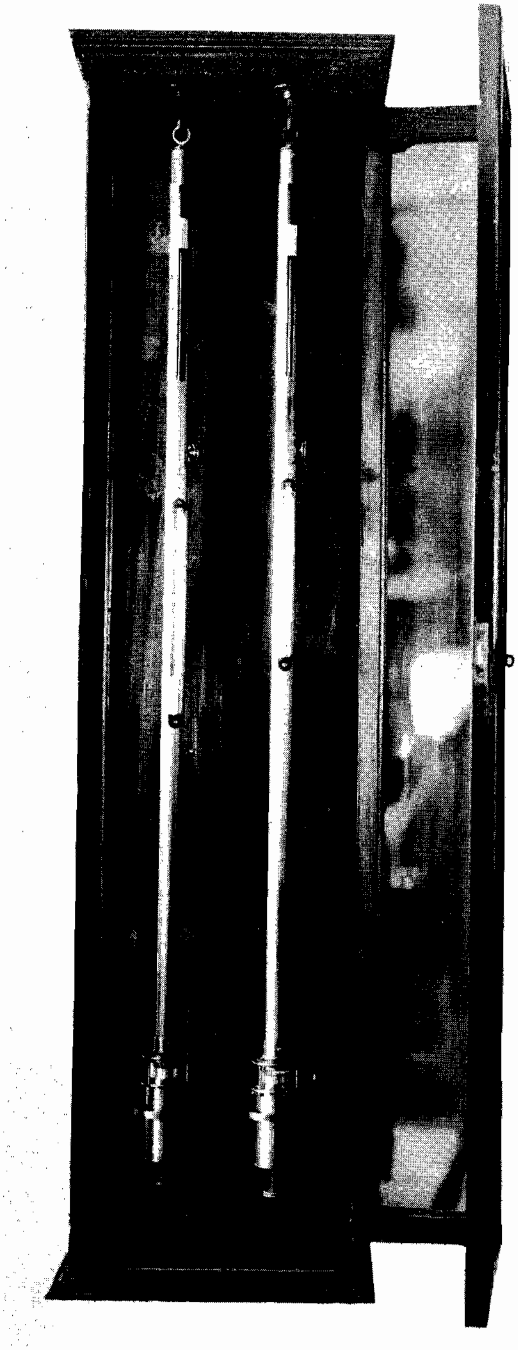

FIGURE 2.2.0. Fortin-type barometers in double barometer case (Weather Bureau type).

the ivory point should be oriented so that it is clearly viewed against a suitable white background (such as white, opal glass) fastened to the case back of the cistern. (9) If the barometer is of the large type (usually of 0.6 inch internal bore) designed to be used as a substandard instrument and comes equipped with an air-vent screw at the top of the cistern, the adjusting screw beneath the cistern should be turned counterclockwise a little until the surface of the mercury just perceptibly separates from the roof of

FIGURE 2.2.1. Fortin-type barometer in single barometer case (Weather Bureau type).

the cistern. At this stage the air-vent screw which is at the top of the cistern should be opened five (5) full turns in order to admit air to the cistern. *The air-vent screw should not, however, be removed.* Next, the adjusting screw beneath the cistern should be turned an additional amount in order to lower the mercury further until the surface of the mercury in the cistern is a little below the ivory point, but not exceeding 1/4 inch. (10) Finally, the verticality of the barometer should be established and fixed in the manner described below in sec. 2.2.4.2.

Marine barometers of the Navy type generally come already attached in their glass barometer case. In such instances the case together with its instrument should be mounted on the bulkhead or wall in accordance with the foregoing instructions. Before the marine barometer of the Navy type is ready for operation the removable dust cap must be unscrewed and the cistern adjustment knob must be rotated as far as it will go counterclockwise until the lower cistern section rests on the lower cistern casing as shown in fig. 2.6.2. It will be noted that the latter operation will be attended by a fall of mercury in the tube. When the cistern has been lowered to the operating position, allow three or four hours for the mercury column to come to a correct reading before observing. This time is necessary because the constricted tube slows down the fall of mercury in the tube (see fig. 2.6.0, and sec. 2.7.6 and 2.11.1).

Immediately prior to making a mercury barometer observation on board ship, the barometer should be left free in the gimbal, with the gimbal arm out in operating position, for not less than fifteen minutes before the observation is to commence.

2.2.4.2 Procedure Used so Barometer Will Hang Vertically.—The centering ring (shown in fig. 2.5.0) is a ring-shaped guide designed to confine the barometer, by means of three centering screws. When the ring is to be placed at the cylindrical, metal part of the cistern, it should be positioned at a convenient height where it will not bear against the nomenclature plate, as in the case of the 1/4-inch bore Fortin barometer illustrated in fig. 2.5.0. However, in the special case of

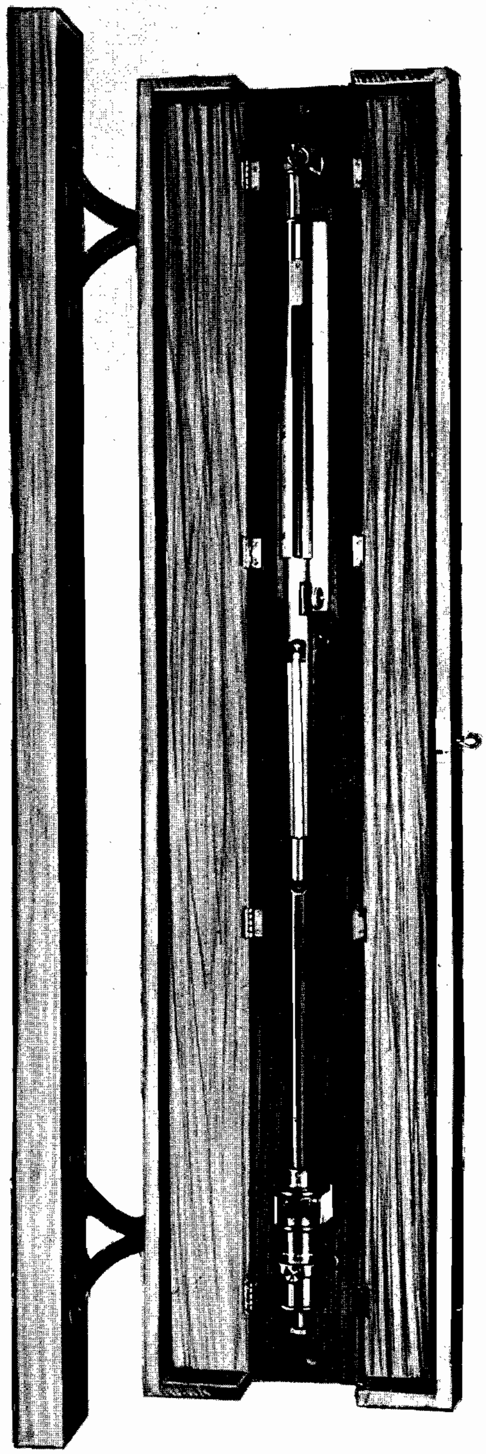

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FIGURE 2.2.2. Fortin-type barometer (ML–2) in barometer case (ML–48); U.S. Army Signal Corps type used by the U.S. Army and the U.S. Air Force (U.S. Army photograph).

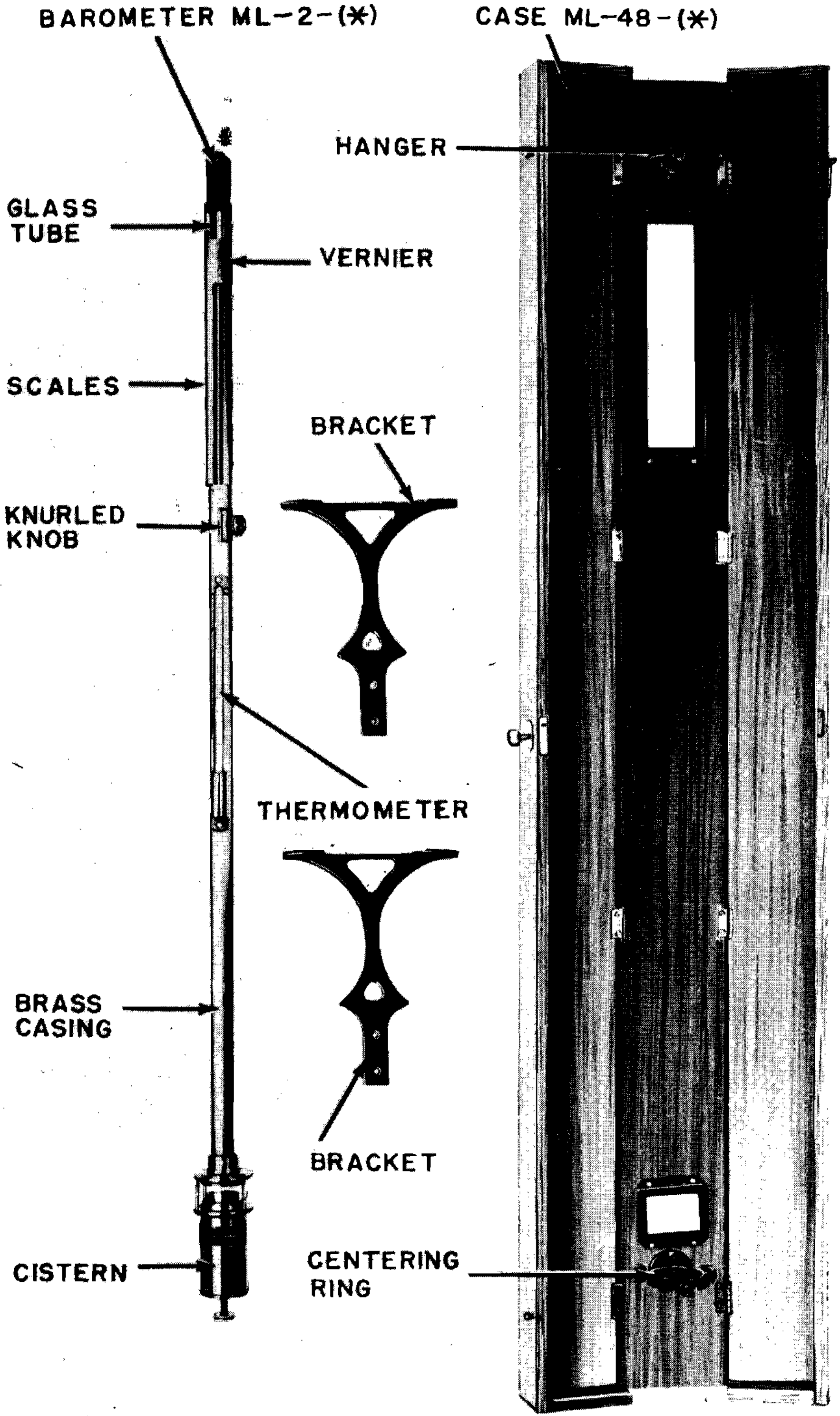

FIGURE 2.2.3. Fortin-type barometer (ML–2), and barometer case (ML–48), with various parts identified; U.S. Army Signal Corps type used by the U.S. Army and the U.S. Air Force (U.S. Army photograph).

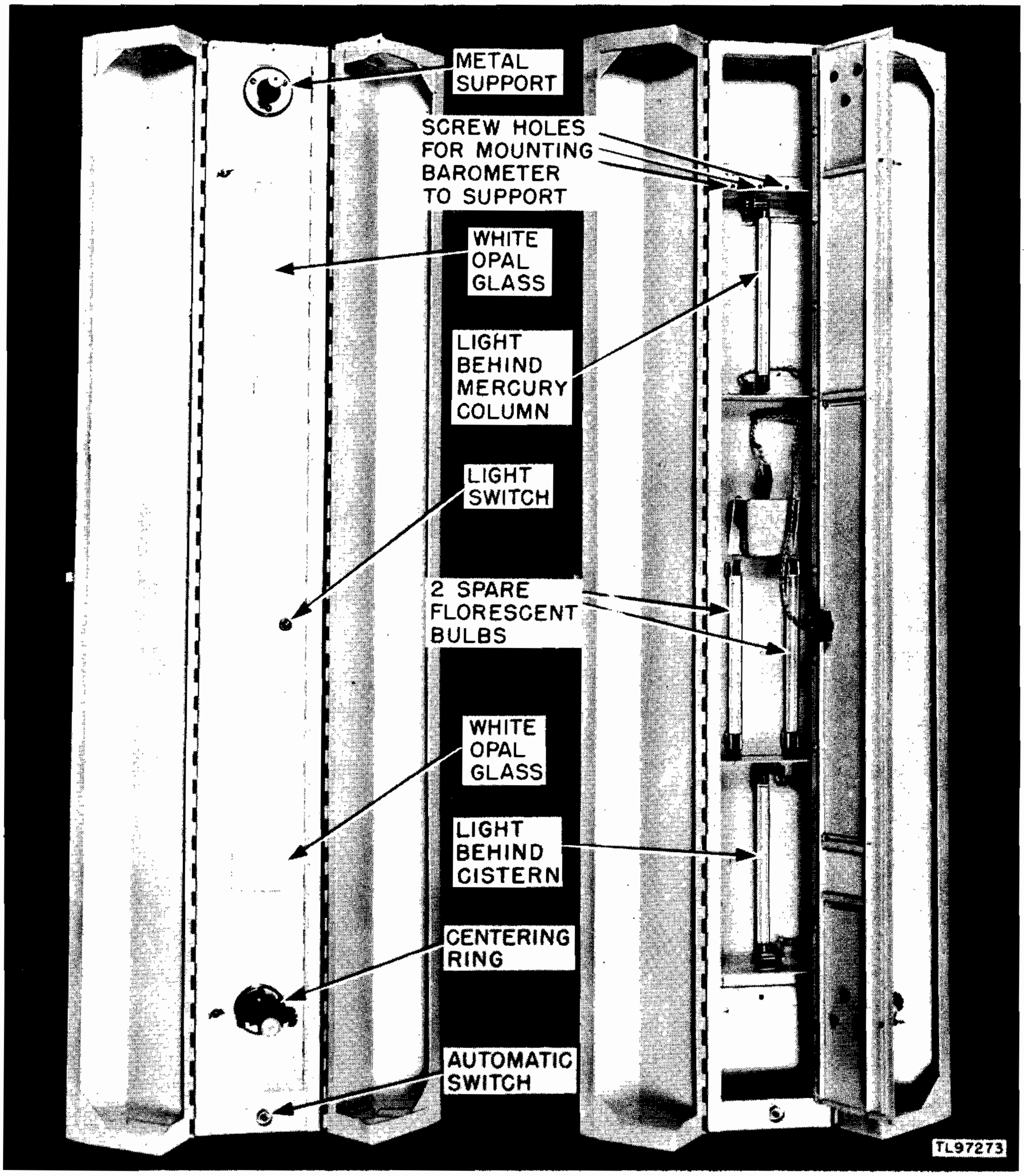

FIGURE 2.2.4. Mounting case for barometer ML–330/FM, showing mounting panel and wiring behind mounting panel, U.S. Army Signal Corps type used by the U.S. Army and the U.S. Air Force (U.S. Army photograph).

the large bore Fortin barometer, type ML–330/FM, the ring bears against the bushing immediately above the adjusting screw at the bottom of the cistern, as illustrated in fig. 2.2.5. When the mercury barometer hangs free at complete rest, it assumes a vertical position like a plumb bob. While the barometer is in this state, the centering screws should be carefully screwed up until the barometer cistern is very *gently*

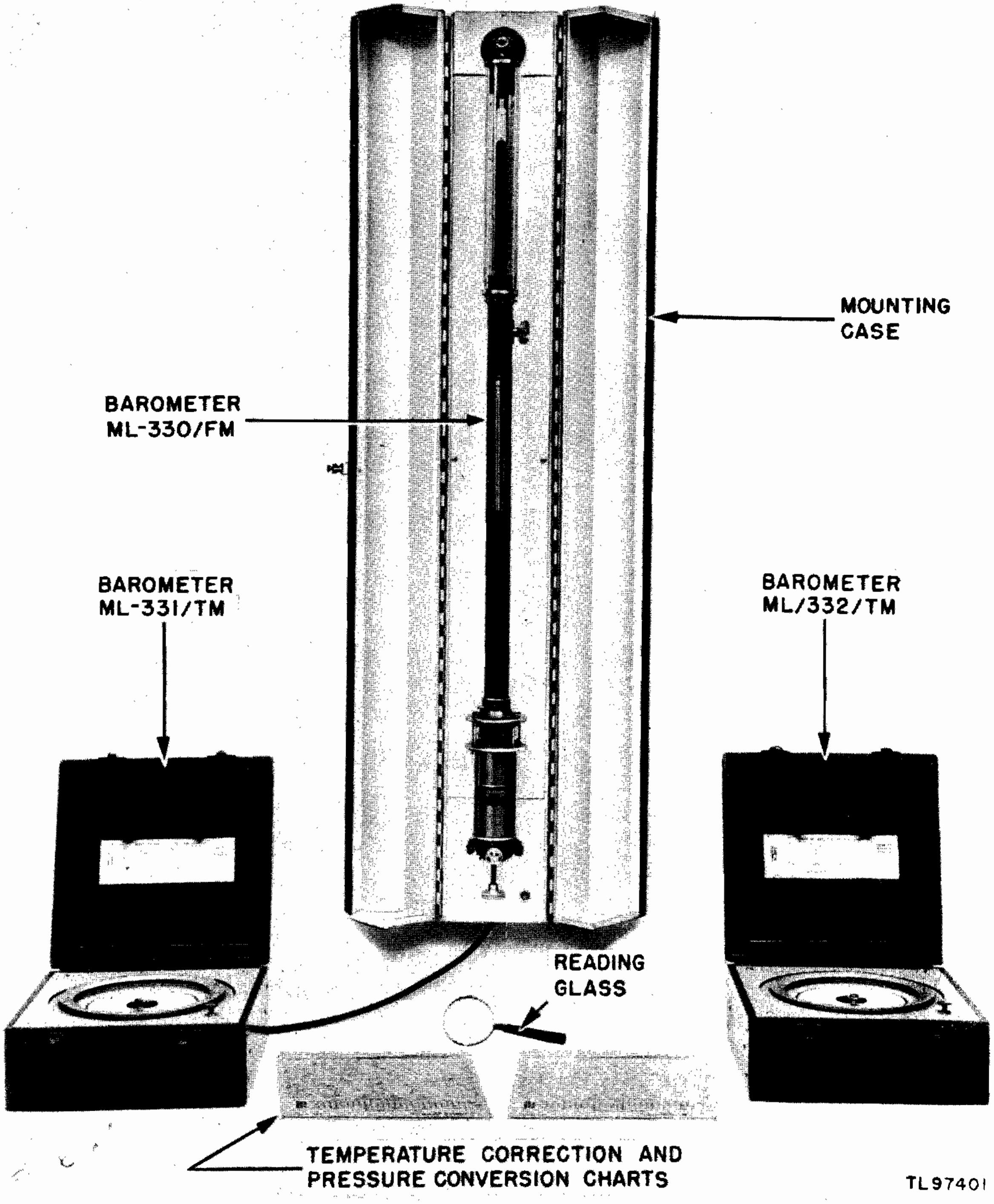

FIGURE 2.2.5. Fortin-type barometer (ML–330/FM) in barometer case together with portable precision aneroid barometers, of U.S. Army Signal Corps type used as secondary standard and inspection barometers, respectively, by the U.S. Army and the U.S. Air Force (U.S. Army photograph).

clamped and held steadily. If the barometer is not truly vertical at the instant it is read, an error will result as explained in sec. 2.7.2; hence it is essential to check the verticality of the instrument by use of a plumb bob, weight on a cord, or some other means. When the barometer is of the Fortin type, its verticality should also be checked in the following manner: adjust the centering screws of the ring-shaped guide until they just barely clamp the barometer in the vertical position; during a period when the pressure is fairly steady, adjust the level of the mercury in the cistern until the surface of the mercury just makes contact with the ivory point; rotate the barometer slowly about its axis and observe whether the contact of the ivory point with the mercury surface is uniform at all orientations of the barometer. In case the tip of the ivory point dips into the mercury surface at some orientations and clears it at others, the barometer is not truly vertical, and further leveling by the above procedure is required until verticality is achieved.

2.2.4.3 White Surfaces Back of Barometer Tube and Cistern.—The barometer case or barometer board should be provided with white surfaces to serve as backgrounds to reflect light for the meniscus in the barometer tube and for the mercury surface in the cistern where the ivory point makes contact. About the best type of reflecting surface for this purpose is provided by so-called "milk or opal glass." However, if this is unavailable, any convenient white surface may be employed as a reflecting background, preferably one which diffuses the reflected light and is fire-proof.

2.2.4.4 Light Sources to Permit Reading of Barometer.—For a permanent installation, it is desirable to have artificial lights mounted on either side of the barometer case to provide illumination for viewing the mercury column and the ivory point in the cistern. The lights should be properly shaded to prevent glare in the observer's eyes or reflections which produce such glare. By employing shaded fluorescent lights or frosted bulb lights an even, diffused illumination may be obtained, as is desirable. Glaring lights near the barometer should be avoided. In the elaborate barometer cases furnished for sub-standard barometers, provision is made for fluorescent lights installed behind the opal glass back of the mounting panel on which the barometer is supported. For the more simple type of barometer case (or board such as is in use at some stations), it is sufficient to provide a low- or medium-wattage light connected with the power outlet to furnish satisfactory illumination when adjusting and reading the barometer. A flashlight may be used instead of the lamp. Avoid the prolonged use of light sources at distances that allow the heat flowing from them to significantly affect the temperature of the barometer. Incandescent lights used near the instrument should not be left on after a reading is completed.

2.2.5 Installation of Static-Pressure Head for Fixed-Cistern Barometers

Where the mercurial barometer is of the fixed-cistern type, it is desirable to install a static-pressure head in a free exposure out-of-doors, and to connect it by means of a tube of adequate diameter to the cistern of the barometer. The static-pressure head should be located well away from the roof and walls of the building. The inside diameter of the tube should not be too small, in order to reduce lag effects. See sec. 2.11.1 and Appendix 2.11.1 regarding choice of inside diameter of tubing. Since liquid water may collect in the tube owing to precipitation and condensation, some means for detecting the presence of the liquid and for draining it off should be provided. In regions where ice or frost may collect on the static head, it is considered advisable to equip the head with a suitable anti-icing electrically-heated element.

2.2.6 Obtainment of Elevation Data and Running of Levels

In accordance with the information given in Chapter 1, sec. 1.2.3, on elevation data, arrange for the establishment of a "fixed point" on or near the station building; and secure the services of a competent surveyor to run levels for the purpose of determining the elevations of the fixed point and of the zero points of the barometers. Data regarding location, description and elevation of bench marks may usually be obtained from local city engineers, and from the U.S. Coast and Geodetic Survey, Department of Commerce, Washington 25, D.C. So far as practicable, verify independently the arithmetical computations of the survey, including the closure error data, and the bench mark value, as furnished by the surveyor in his notes (see "Leveling" under sec. 1.2.1). Prepare the "Report on Elevation of the Barometer and Other Instruments," Form WBAN 54–1.2.1. Double check all entries and computations. Data should be rendered in accordance with instructions given in sec. 1.2.3.7, pertaining to Forms WBAN 54–1.2.1 and 1.2.2.

When a barometer is moved from one location to another on the same level within a structure and the elevation of the instrument at the original location has been previously determined accurately, running of levels to the new location will not be necessary. Thus, in order that there be no change in elevation of the barometer, the instrument should be re-mounted at the same height above the flooring, provided the latter is level.

2.2.7 Moving a Barometer

2.2.7.0 Introduction.—The moving of a mercury barometer is a delicate operation, requiring great care to avoid damage to the instrument. In general, three different situations must be envisaged: *Situation* (A) when the barometer is to be carried by hand a very short distance on one level, as from one room to another on the same floor of a building; *Situation* (B) when the barometer is to be moved a somewhat greater distance or from one level to another, provided conditions are such that the barometer can be safely carried entirely by hand without special packing or in a carrying case; and *Situation* (C) when the barometer is to be shipped a considerable distance and will not be carried by hand, hence where it must be shipped in a special packing box. See Annex sec. A–2.20 with regard to packing and shipping of barometers. The best method of moving the barometer, in order to provide maximum safeguard of the instrument, depends upon its type. In general, observance of the following rules will give satisfactory results, provided that the pertinent instructions given below in secs. 2.2.7.1–2.2.7.5 are carefully executed:

(1) *Fortin-type barometer.*—In situation (A), the instrument may be carried in an upright position; and in situations (B) and (C) the instrument should be moved in an inclined or inverted position, with the cistern at a higher level than the top of the barometer. Pertinent instructions are contained in secs. 2.2.7.1, 2.2.7.2, and 2.2.7.3.

(2) *Fixed-cistern barometer of the Kew Pattern.*—This is the type of fixed-cistern barometer commonly used in Great Britain and on some ships (in the marine version). It has no provisions for changing the level of the mercury in the cistern. In all situations it should be transported in an inclined or inverted position, with the cistern at a higher level than the top of the glass tube. See instructions in sec. 2.2.7.4.

(3) *Fixed-cistern barometer of the design with a nipple on the cistern and no provisions for changing the level of the mercury.*—This is exemplified by the instrument shown in fig. 2.4.0. A rubber tube may be attached to the vent in the cistern. Experience has indicated that the best method of preparing this instrument for transportation is to evacuate the air from the cistern and to seal it off by means of a suitable clamp on the rubber tube. This process keeps the cistern full of mercury during the move and assures that the open end of the tube remains covered with mercury. In such circumstances, the barometer is carried upright, by hand if possible. See instructions in sec. 2.2.7.2.

(4) *Fixed-cistern barometer of the (Navy) type where provisions exist for controlling the level of the mercury.*—This instrument is illustrated in fig. 2.6.2. In situation (A) the level of the mercury is raised by means of the jackscrew so that the cistern just becomes filled with the liquid; and then the barometer may be carefully carried upright by hand. In situations (B) and (C), the mercury is first raised to the top of the glass tube by means of the jackscrew, and the barometer is carefully inverted; the instrument is then packed and shipped in an

inclined or inverted position, with the cistern at a higher level than the top of the tube. The pertinent instructions given in secs. 2.2.7.1, 2.2.7.2, and 2.2.7.5 should be followed.

Whenever conditions permit, the new site of the barometer at the destination to which the instrument is to be moved should be selected and prepared in advance of the move, if practicable. This will help to safeguard the barometer, and facilitate and expedite the installation of the instrument at the new location, thus enabling the observers to begin using it promptly.

Comparative barometer readings at the old location before the move and at the new location after the move are necessary, in order to determine whether there is any change in its instrumental correction, attendant upon its transport. Instructions regarding such comparative barometer readings are given in sec. 6.6.

2.2.7.1 Method of Carrying a Barometer by Hand; Precautions Necessary.—A very important precaution which must be observed when carrying a barometer upright is to avoid violent splashing or oscillation of the mercury. This is true for at least two reasons: (1) the glass barometer tube may be broken if the mercury strikes the top of the tube with a hard, sudden blow; and (2) the oscillation may expose the open, lower end of the tube in the cistern to the air, which would permit an air bubble to rise into the tube, thus impairing the vacuum. As a further essential precaution, when carrying a Fortin-type barometer upright, it is necessary to have the cistern filled with mercury to the roof of the cistern by means of the adjusting screw. This practice tends to hamper splashing of the mercury, and reduces somewhat the horizontal oscillations and a portion of the rending forces that act upon the leather bag in the cistern. It should be noted that if this precaution is not taken, the shifting, heavy weight of the mercury which the leather bag must support as the instrument is carried, could possibly cause the bag to spring a leak and lose some mercury, or suffer other damage. To safeguard the barometer while it is being carried upright, it is necessary to avoid sudden starts and stops, and to avoid pronounced up-and-down motions, or other marked accelerations and decelerations. When carrying the barometer upright it is essential to walk slowly and steadily, proceeding in a shuffling manner, i.e., not raising the feet very much. The person carrying the barometer must be careful to see that the instrument does not strike any solid objects or suffer jolts. Such a precaution should be observed even in the case of a barometer being carried in an inclined or inverted position, since the sudden concussion may cause breakage of the glass tube or permit air to enter its open end. Other safeguards which must be taken are described in the following sections.

2.2.7.2 Moving Mercury Barometers in an Upright Position.—The reader should review the information given in sec. 2.2.7.0 regarding the situations in which it is permissible to carry a barometer in an erect position. This information may be summarized thus: Fortin-type and fixed-cistern barometers of the Navy type can be carried erect in situation (A), that is, over a short distance on one level; Kew-pattern, fixed-cistern barometers are *never* carried erect; and fixed-cistern barometers of the type shown in fig. 2.4.0 having no means for controlling the level of the mercury are carried upright, provided that the air is evacuated from the cistern. Procedures to be followed in connection with the transport of a barometer in the upright position depend upon the type or design of the instrument, as specified below:

(1) *Fortin-type barometer*

(a) Before moving the barometer and while it is still hanging, the adjusting screw beneath the cistern should be turned up until the mercury nearly reaches the roof of the cistern, then stop. If the cistern has an air vent, it must then be tightly closed at this stage. (By this procedure there is always a vacuum space left above the meniscus in the barometer tube.)

(b) Carry the barometer very carefully in an upright position from the original site to the new site where the instrument is to be hung up again, following the instructions given in sec. 2.2.7.1 relative to carrying the barometer by hand and precautions necessary.

(c) After the barometer is suspended securely in the new location, the instructions contained in sec. 2.2.4.1 and 2.2.4.2 should be followed in regard to hanging the instrument and rendering it vertical.

(2) *Fixed-cistern barometer of the Kew pattern*

Barometers of this type are *not* moved in an upright position. (See secs. 2.2.7.0, and 2.2.7.4.)

(3) *Fixed-cistern barometer of the design with a nipple on the cistern and no provisions for changing the level of the mercury*

In order to prepare the type of barometer shown in fig. 2.4.0 for a move, it is desirable to employ a vacuum pump to evacuate the air from the cistern. The cistern is then sealed off by use of a heavy clamp of a suitable character on the rubber tube. Finally, the barometer can be carried upright, preferably in a carrying case, taking the sort of precautions described in sec. 2.2.7.1 so far as practicable.

(4) *Fixed-cistern barometer of the Navy type*

The type of barometer depicted in fig. 2.6.1 is made ready for a move in an upright position (see sec. 2.2.7.0), by screwing up the jackscrew at the bottom of the cistern until the mercury completely fills the cistern. The point at which this condition is reached may possibly be detected visually by removing the air vent and observing the level of the mercury in the cistern with the aid of a flashlight. It is then necessary to replace the air vent screw and to tighten it. Another method of determining at what point the cistern becomes filled is to note the height of the jackscrew with respect to the thread when the rate of rise of the mercury in the tube per degree of turn of the jackscrew undergoes a sudden increase. After the cistern is just filled with mercury and the air vent screw tightened in place, the barometer may be carried in an upright position, provided the precautions described in sec. 2.2.7.1 are carefully followed. Instructions given in secs. 2.2.4.1 and 2.2.4.2 apply after the barometer has been moved and is ready for installation.

2.2.7.3 Procedures for Inverting a Fortin-type Barometer and Bringing it Upright.— When a Fortin barometer is to be moved from one level to another or over a considerable distance, it is necessary to transport the instrument in an inclined or inverted position cistern uppermost. The following procedure is recommended for inverting this type:

(I) Prior to moving the barometer and while it is still hanging, the adjusting screw beneath the cistern should be turned up until the mercury nearly reaches the roof of the cistern, and at this point the turning should be stopped. If the cistern has an air vent, it must be closed tightly at this stage.

(II) Now the barometer is removed from its hanger, and a gradual process of tilting it is carried out, all the while the adjusting screw is turned so as to keep the cistern very nearly filled with mercury as the tilting progresses, and the cistern is kept under almost continuous watch to be sure that there is always a small bubble of air present in the uppermost part of the cistern. (*Note:* This procedure is designed to prevent exposure of the open, bottom end of the glass barometer tube to the air bubble, and to avoid overloading the leather bag in the cistern. If a bubble of air were to get into the tube, it might impair the vacuum at the top of the tube, and subject the instrument to a serious error. In addition, it is considered a bad practice to raise the mercury to the very top of the barometer tube while the instrument is in an upright position, since this will impose a severe extra load on the leather bag in the cistern which may cause loss of mercury through the pores or even cause the bag to suffer a tear. Under such a condition, the extra load arises owing to the fact that the pressure yielded by the unusually high column of mercury reaching to the top of the tube exceeds the ambient atmospheric pressure by several inches of mercury, which is a considerable amount, especially large at elevated stations, 3,000 feet or more above sea level.) The process of tilting the barometer is continued as described in the first sentence of this paragraph until the mercury reaches the top of the glass tube, care being necessary to maintain a slow rate of tilting as the head of the mercury column approaches the top of the tube so that the mercury flows gently to the top making a slight click as it reaches the top (see Annex A–2.17.3 on the subject of the "metallic click.") By this procedure, it is possible to avoid letting the mercury come to the closed end of the tube with a sharp impact which could cause breakage of the glass. After the mercury reaches the top of the tube, the tilting is continued until the barometer is horizontal. At this stage the adjusting screw should be turned until the air bubble visible through the glass portion of the cistern is about the size of a dime, but no larger. From the horizontal position with the air bubble of this size the barometer may be inverted, cistern uppermost. Finally, the cistern screw should be loosened about one or one and one-half turns in order that there may be sufficient free space for expansion of the mercury in the event of an increase of temperature. When the barometer is in this condition it may be safely transported or carried by hand in an inverted or inclined position, cistern up, as long as care is used to avoid subjecting it to concussion or rough handling. When it is necessary to carry the instrument very far by hand, it is advisable to use a carrying case for the purpose, transporting it in the inverted or inclined position described above. When shipping the instrument, careful packing in a stout packing box is required so that it may travel without damage if the necessary precautions for careful handling are observed.

(III) After the barometer has been brought to its destination, prior to hanging it at the new site, the process outlined in paragraph (II) should be executed in reverse in order to turn the barometer right-side up. This means that the barometer must be first brought gradually to a horizontal position, taking care to see that a small bubble appears in the cistern. The bubble must always be present as the barometer approaches the horizontal position, since if it were absent an excessive pressure within would tend to force mercury out through the joints of the cistern, and possibly cause serious damage. When the barometer is horizontal, the adjusting screw should be turned so that the air bubble in the cistern is about the size of a dime, but not larger. Then a process of tilting the barometer to bring the tube end up is gradually carried out, all the while turning the adjusting screw so as to keep the cistern very nearly filled with mercury as the tilting progresses, and observing the cistern to be sure that there is always a small bubble present in the uppermost part of the cistern. By this procedure the barometer is brought to an upright position, cistern down.

(IV) After the barometer is right-side up, the instructions given in secs. 2.2.4.1 and 2.2.4.2 with regard to installation of the barometer and establishment of its verticality should be observed.

2.2.7.4 Procedure for Inverting a Fixed-cistern Barometer of Kew Pattern.—Fixed-cistern barometers of the Kew pattern should always be transported in an inclined or inverted position, cistern uppermost. When inverting this type of barometer, it should at first be inclined slowly in order to permit the mercury to flow gently to the top of the tube. Then, the barometer should be placed horizontal or inverted, depending upon the needs or purposes. As a general rule, Kew-pattern barometers should be carried by hand in an inverted position, cistern uppermost, preferably in a suitable carrying case. When shipped over long distances, a special packing crate should be employed to permit transport of the instrument while held securely in an inclined position, with the cistern at a higher level than the top of the tube. After re-erecting a Kew-pattern barometer, it is important to inspect the instrument carefully to determine whether there has been any loss of mercury, which would impair it seriously. For instructions regarding installation of the barometer, the reader is referred to secs. 2.2.4.1 and 2.2.4.2.

2.2.7.5 Procedure for Inverting a Fixed-cistern Barometer of Navy Type.—Barometers of this type are to be transported in an inverted position when carried from one level to another or when shipped a considerable distance. As shown in fig. 2.6.2 this design of barometer has a jackscrew cover beneath the bottom of the cistern. The *first step in* the procedure is to unscrew the cover at the lower end of the instrument, revealing the jackscrew at the bottom of the cistern. Then the jackscrew must be turned up slowly in order to raise the mercury to the top of the glass tube. As the head of the mercury column just reaches the top of the tube, there is generally produced the sound of a slight "metallic click," which the observer should listen for. At this stage the observer will notice that the turning of the jackscrew has become harder, hence he should immediately slow down on the turning process, and stop as soon as it is clear that the mercury fills the tube. (Caution: It is important not to continue the turning of the jackscrew after it becomes hard, as this may force mercury out through the doeskin cistern seal, or cause other damage such as breakage of the glass tube.) Next the barometer should be secured in the clamps within the instrument case. Now the case with its barometer should be removed from the bulkhead, and the assembly should be carefully and slowly inverted so that the cistern end is finally uppermost. While the instrument is in this position, it is important immediately to slack off about one full turn of the jackscrew in order to allow room for expansion of the mercury if the temperature should increase.

When it is desired to re-erect the barometer, the foregoing procedure should be carried out in reverse; and the instructions in secs. 2.2.4.1 and 2.2.4.2 are to be observed in connection with suspension of the barometer and establishment of its verticality.

If the barometer is to be shipped to another place, the instructions in Annex sec. A–2.20 are to be followed.

2.3 INTRODUCTION TO ANEROID BAROMETERS

The aneroid barometers (see figs. 2.3.0 to 2.3.4) consist essentially of a metallic box or capsule which is sealed after any gases or vapors it may originally contain are exhausted by means of a vacuum pump and replaced with a small amount of dry, inert gas at low pressure. Increase of atmospheric pressure compresses the opposing faces of the capsule, and decrease of pressure permits a relaxation. The motion thus produced is transmitted to a delicate linkage mechanism which includes a needle that moves over a dial. To obtain increased sensitivity two or more capsules are often mounted in a series, as in a stack. When the evacuated capsules are composed of certain strong elastic metals (e.g. beryllium copper or phosphor bronze) with corrugated faces to give added strength and flexibility, they are capable of withstanding the external pressure without collapsing. However, in some aneroid barometers, especially those of older design, involving brass or German silver for the capsule, use is made of strong springs, either internal or external, attached in such a manner as to prevent the capsules from collapsing.

At points where the springs can move with respect to their bearing surfaces, there will be developed a certain amount of friction which may be variable. This sometimes gives rise to sticking and errors of inconstant character. Even when a helical spring is used, its free contact point rotates with respect to the fixed one as the spring expands or contracts in harmony with changes in pressure on the diaphragm, thus causing some friction. This can be kept at a low value by employing ball bearings, but is still not negligible. For these reasons supporting springs are omitted in the high precision aneroid barometers and altimeters through the expedient of employing the special metals referred to above. The complex mechanical properties of the metals and the physical construction of the instrument do not lend themselves to direct interpretation of aneroid readings in terms of ambient pressure, without some independent means of establishing a correlation. It may be readily seen from the foregoing that the aneroid barometer cannot be graduated from fundamental considerations in the way a U-tube or siphon mercury barometer can be, but rather it is necessary to interpret the aneroid readings on the basis of a calibration. Some means of compensating for the effects of temperature must also be employed, to avoid the need to apply corrections for such effects. Thus by comparison of the positions of the needle on the dial with the readings

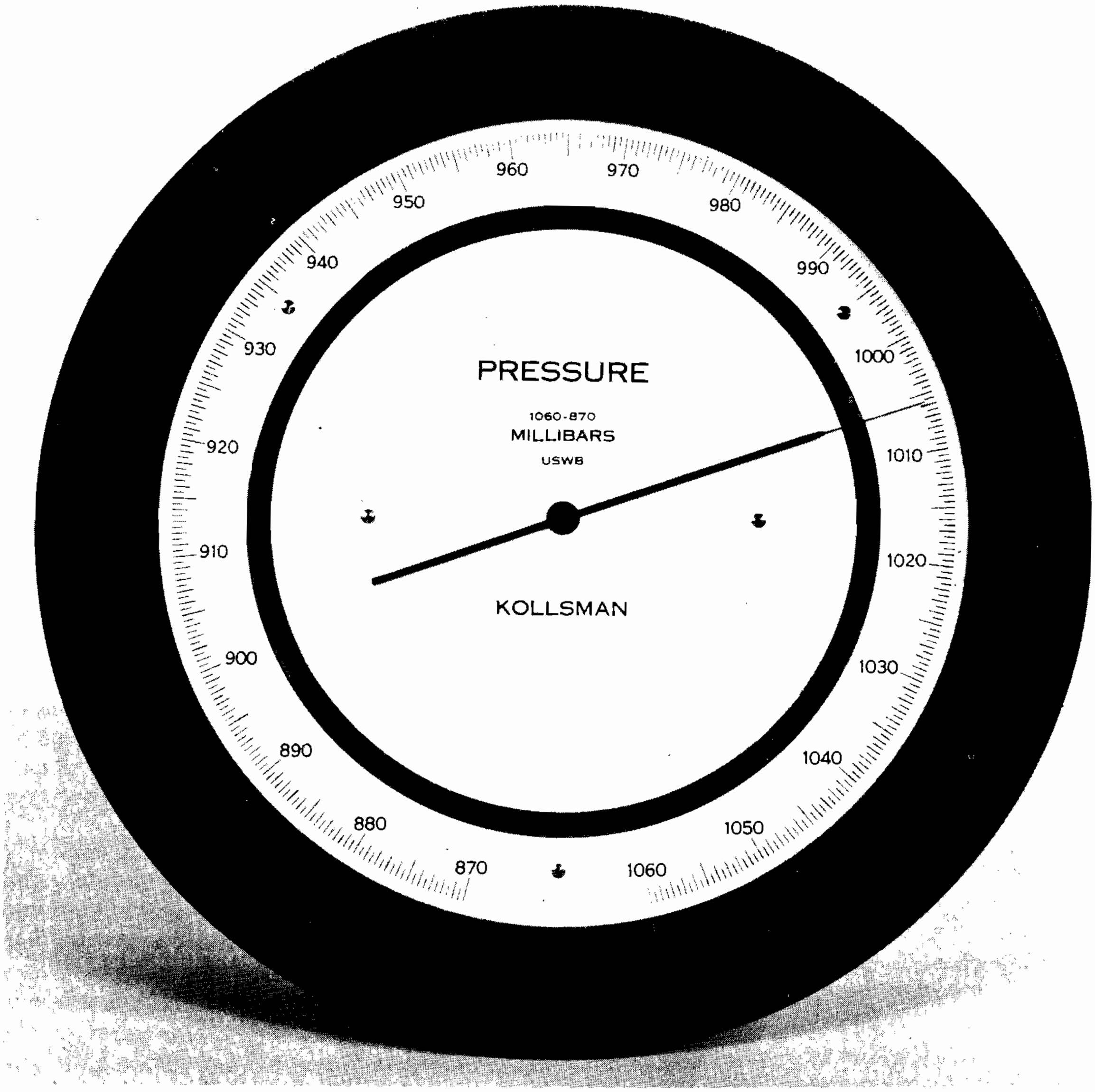

FIGURE 2.3.0. Precision aneroid barometer, panel mounting type, used by the U.S. Weather Bureau.

of a standard mercurial barometer, properly corrected, the aneroid barometer is calibrated so that it yields pressure values directly. As time progresses, aneroid barometers usually drift somewhat from their calibrated condition, hence it is necessary to check them against mercurial barometers periodically, and to apply corrections if necessary. Aneroid barometers are extensively used on shipboard, owing to their freedom from "pumping" (vertical oscillations) which seriously affects the column of mercurial barometers when the ship rolls and heaves in a sea. See secs. 2.8, 2.9, and 2.10 for further information; and sec. A–2.10 for references to literature.

The Military Services have employed some special designs of aneroid barometers which involve special handling procedures, not mentioned above but covered in sec. A–2.21.0, especially sec. A–2.21.0(e).

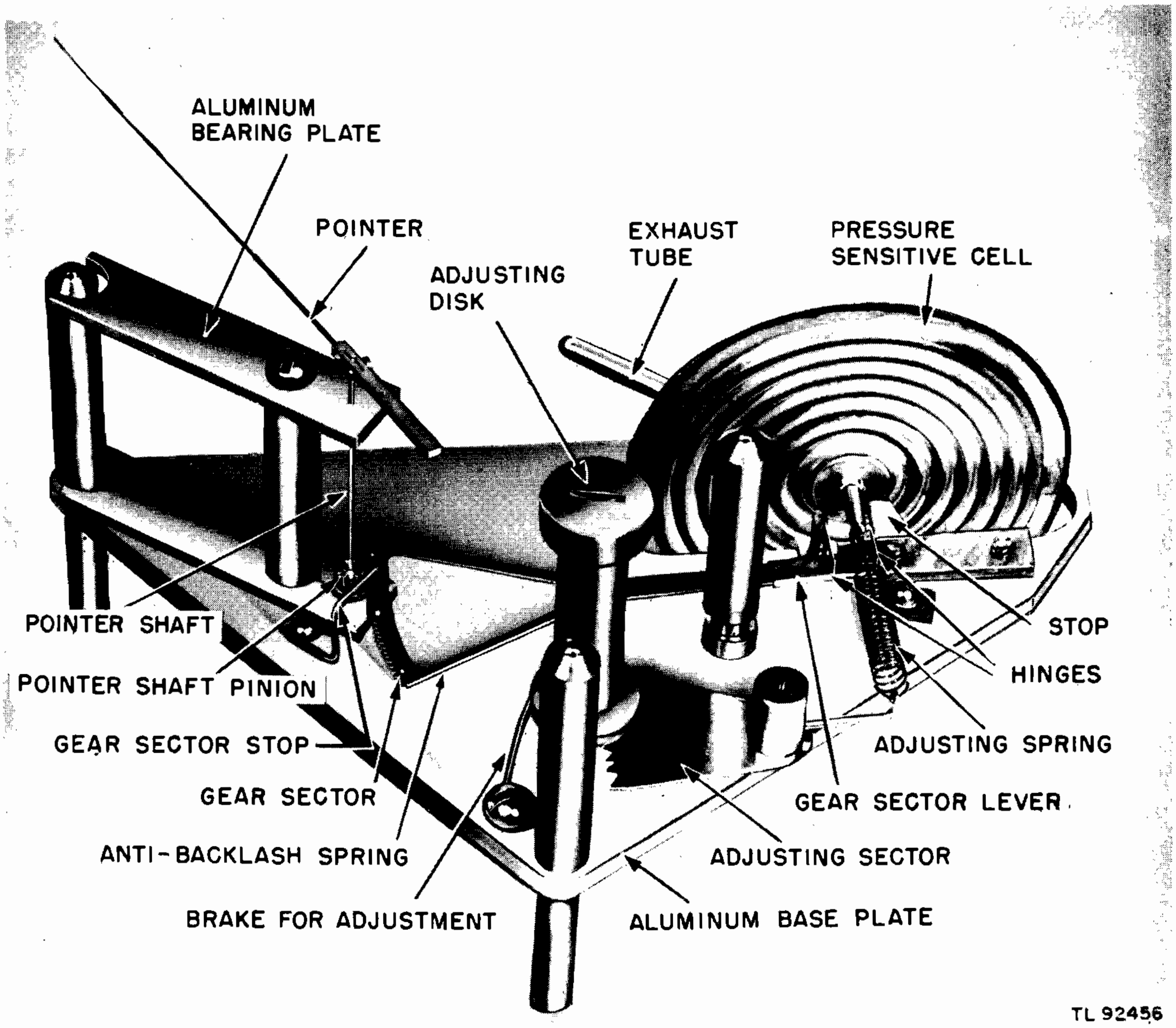

FIGURE 2.3.1. Aneroid mechanism, barometer ML–102–D or ML–316/TM; U.S. Army Signal Corps type used by the U.S. Army and the U.S. Air Force (U.S. Army photograph).

2.4 GENERAL PRINCIPLE OF THE MERCURY BAROMETER AND PROCEDURE FOR READING INSTRUMENT

2.4.0 Introduction

In sec. 2.4.1 below is given a brief account of the general physical principles underlying the operation of the mercury barometer; while in sec. 2.4.2 instructions for reading and correcting mercury barometers are presented. Anyone interested in the basic theory of the Fortin-type or siphon-type (U-tube) barometers, and their corrections, may consult Appendix 1.4.2 in Chapter 12, and the sections on capillarity and imperfect vacuum (secs. 2.7.1 and 2.7.3).

2.4.1 General Principles of the Mercury Barometer

Referring to figs. 2.4.0(B) and 2.5.0 which depict the Fortin-type and figs. 2.4.0(A), 2.6.0, 2.6.1 and 2.6.2 which depict fixed-cistern type of mercury barometers, respectively, it will be seen that the surface of the mercury in the cistern is subjected to atmospheric pressure. Careful examination of that surface in an actual barometer will reveal that it is curved, with domed side upwards. Similarly, a glance at the surface of the mercury in the upper portion of the barometer tube shows it to be more strongly curved, with domed side upwards. The term "meniscus" is used in referring to

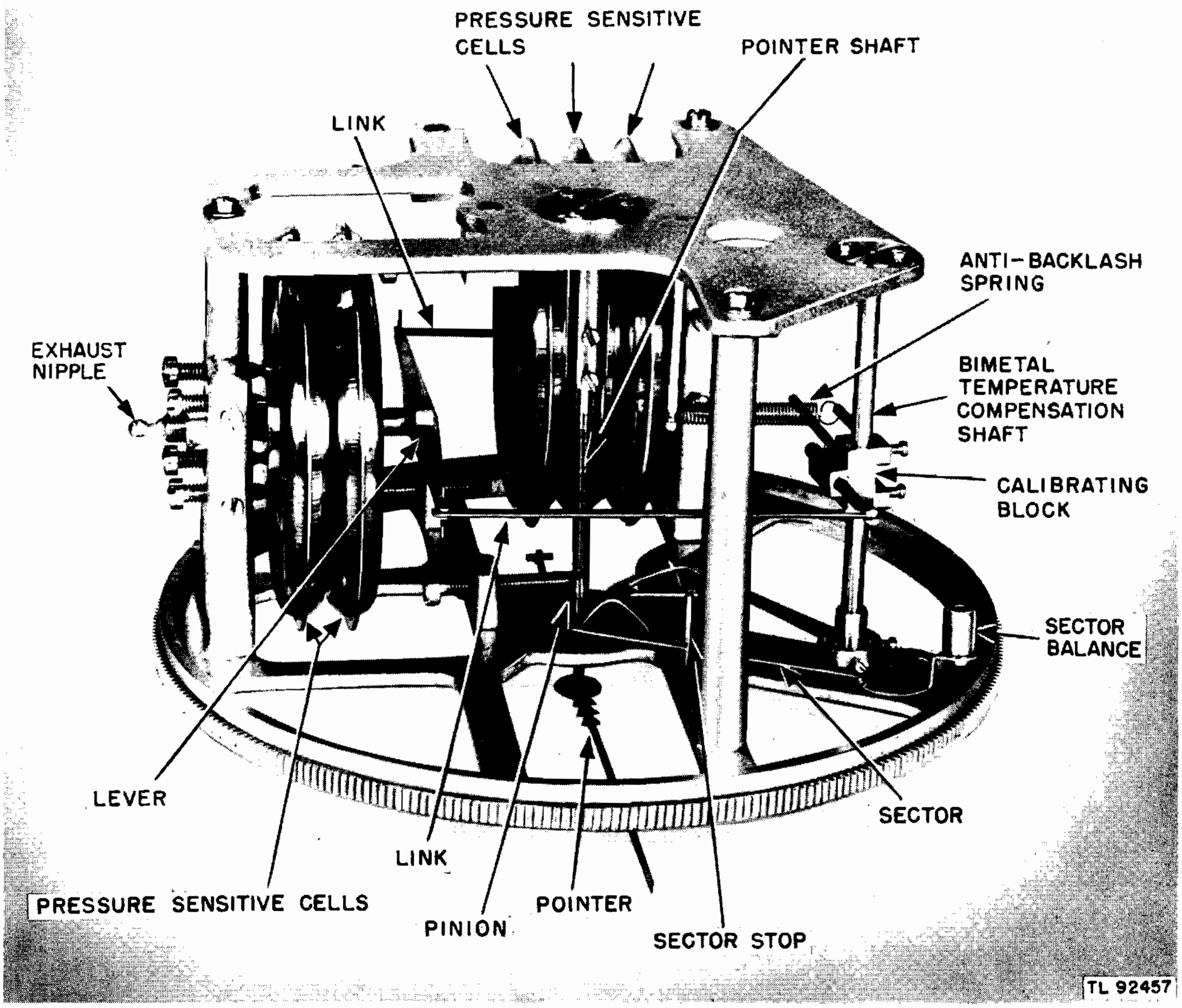

FIGURE 2.3.2. Aneroid mechanism, barometer ML–102–B; U.S. Army Signal Corps type used by the U.S. Army and the U.S. Air Force (U.S. Army photograph).

either of the two curved surfaces just mentioned.

When the glass tube of a mercurial barometer is filled with mercury during the construction of the instrument, the aim is to accomplish the filling in such a manner that a good vacuum is established in the space above the meniscus in the barometer tube. This means that the objective is to prevent water vapor, air, and other gases from getting into the space during the filling process. If the aim were achieved with perfect success, all that would remain in the space above the mercury in the barometer tube would be mercury vapor. Fortunately, the pressure exerted by mercury vapor is small at ordinary temperatures, as shown by the following table:

Temperature (°C.)	*Vapor pressure of mercury (mb.)*
30°	0.0037
20°	0.0016
10°	0.00065
0°	0.00025
−10°	0.000087
−20°	0.000029

Unfortunately, however, it is very difficult to fill a barometer tube without at least a minute mass of air and water vapor being entrapped in the space above the meniscus, thus producing an imperfect vacuum. These gaseous substances, being rarefied, produce a slight downward or back pressure in the tube. Operating in the same direction are the weight of the liquid column and the capillary forces which arise from surface tension of the mercury. Opposed to all of

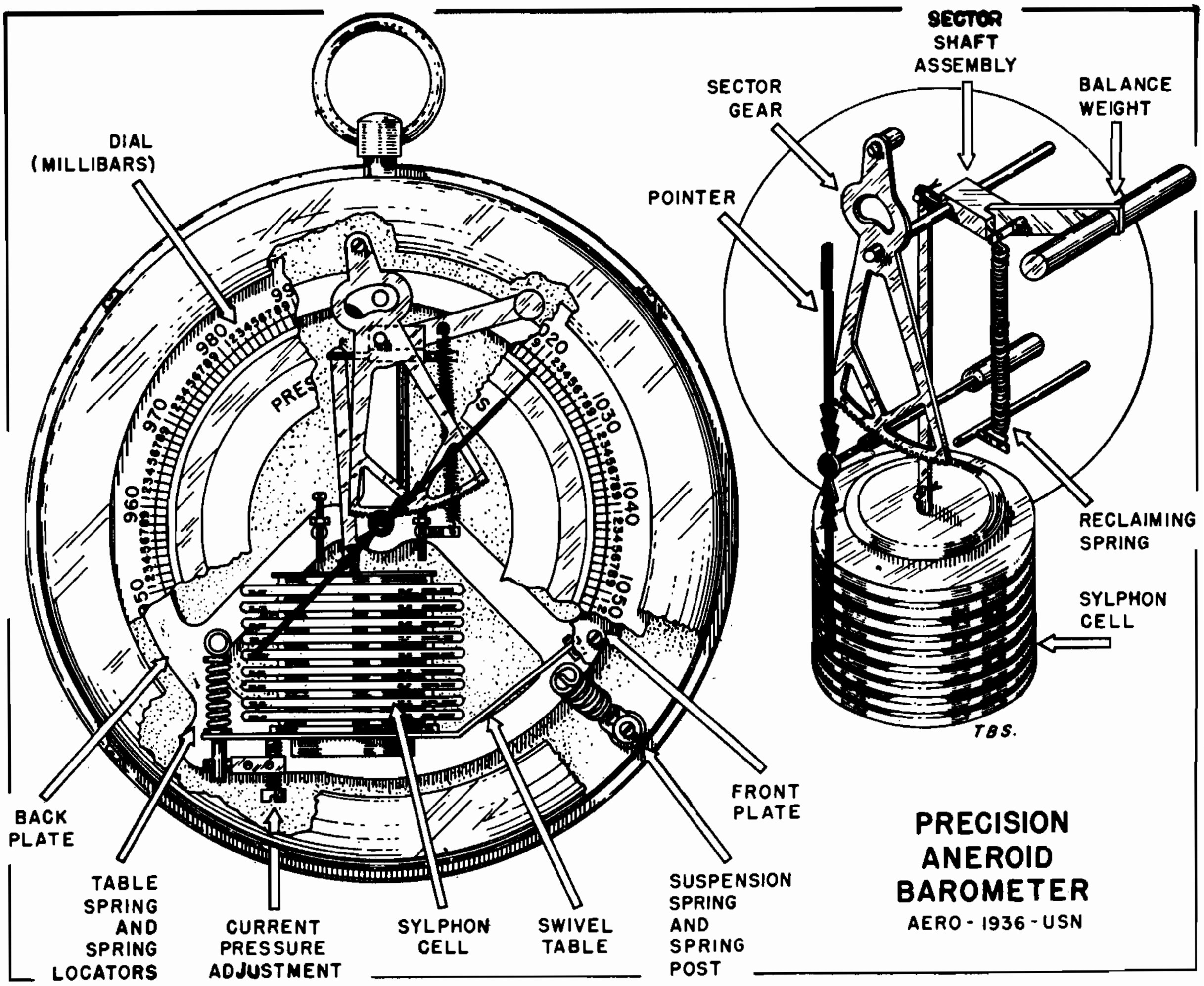

FIGURE 2.3.3. Aneroid barometer, cutaway view showing working parts (design used by U.S. Navy).

these is the pressure of the atmosphere acting upon the surface of the mercury in the cistern and the capillary forces therein.

The principle of operation of the mercurial barometer then is as follows: The atmospheric pressure, which we wish to determine, acts upon the meniscus in the cistern, and is balanced against the sum of (a) the weight of the column of mercury, (b) the capillary forces in the barometer, and (c) the back pressure exerted by such gases and vapors as may be present above the mercury in the barometer tube if there is an imperfect vacuum. Consequently, if a correction is applied to compensate for the capillary forces and the back pressure due to imperfect vacuum, the atmospheric pressure will be gauged by the weight of the column of mercury. This column will be understood to have a height extending from the level of the surface of the mercury in the cistern to the top of the mercury in the barometer tube.

Further information is given in Chapter 12, Appendix 1.4.2 entitled "Basic Principles Relating to Combination of the Corrections of the Fortin-Type Mercurial Barometer for Instrumental Error, Gravity, and Temperature."

2.4.2 Procedure for Reading Instrument

The following procedure is recommended for reading the mercury barometer as a matter of good practice.

2.4.2.0 Preparations.—If the barometer has just been installed or if it has been just previously exposed to a temperature radically different from that prevailing in the neighborhood of its present location, it is

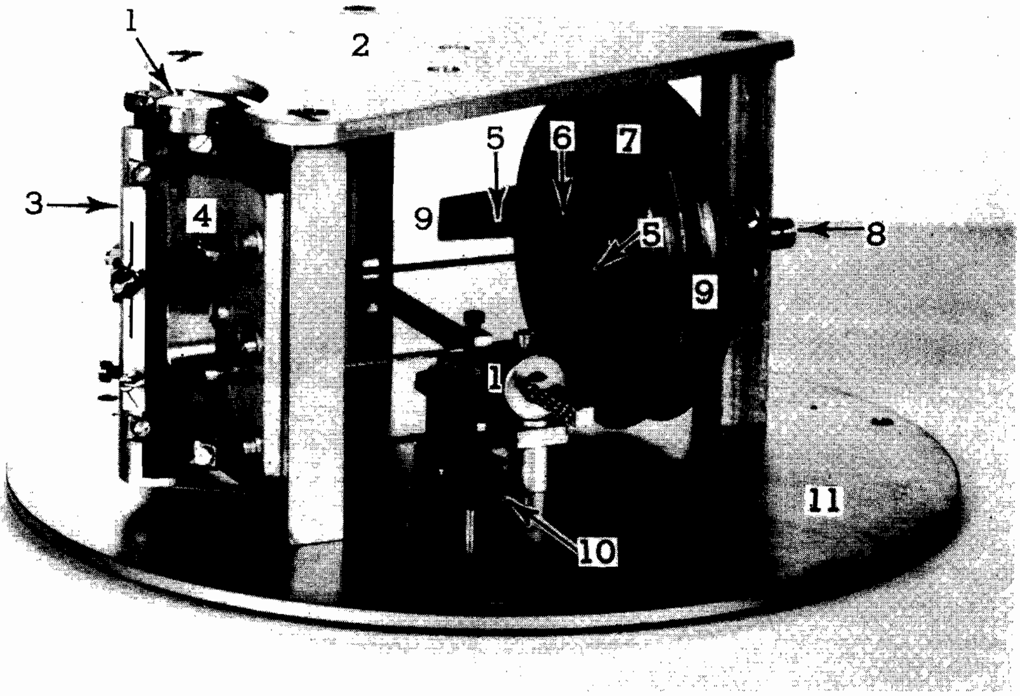

FIGURE 2.3.4. Precision aneroid barometer mechanism, U. S. Weather Bureau type manufactured by Kollsman Instrument Corporation. The parts listed below are identified by number in the illustration:

1. Balance weight
2. Back plate
3. Rocking shaft
4. Rocking shaft mounting plate
5. Needle support for temperature compensating bracket
6. Temperature compensation adjustment screw
7. Pressure cells (capsules)
8. Zero adjusting screw
9. Temperature compensating bracket
10. Sector gear
11. Front plate

desirable to allow sufficient time to permit it to come to equilibrium with its environment, and to enable it to adjust satisfactorily to such internal stresses or imbalances as may exist. In cases where it is urgently necessary to commence readings as soon as practicable after the barometer is installed, or where comparative, standardizing observations are involved, a current of air from an electric fan played on the instrument will help to bring it to temperature equilibrium sooner, usually within 2 or 3 hours. However, mercury barometers used as standard or sub-standard instruments should preferably be allowed to remain hanging undisturbed in their cases for about 1 week or more before highly accurate or precise readings may be derived from them. So far as practicable, the temperature of the environment and of the instrument should be fairly steady for at least several hours in order to secure accurate results. In order to make good observations both at the cistern of the barometer and at the top of the mercury column, it is necessary to have white, diffusely reflecting surfaces behind the instrument in these two areas and to have adequate light shining on (or through) them, to provide suitable contrast against the mercury meniscuses for purposes of setting the vernier and the cistern, as in the case of the Fortin-type barometer.

When getting ready to make an observation with a *marine-type mercury barometer,* the observer should allow the barometer to hang free in its gimbal, with the gimbal

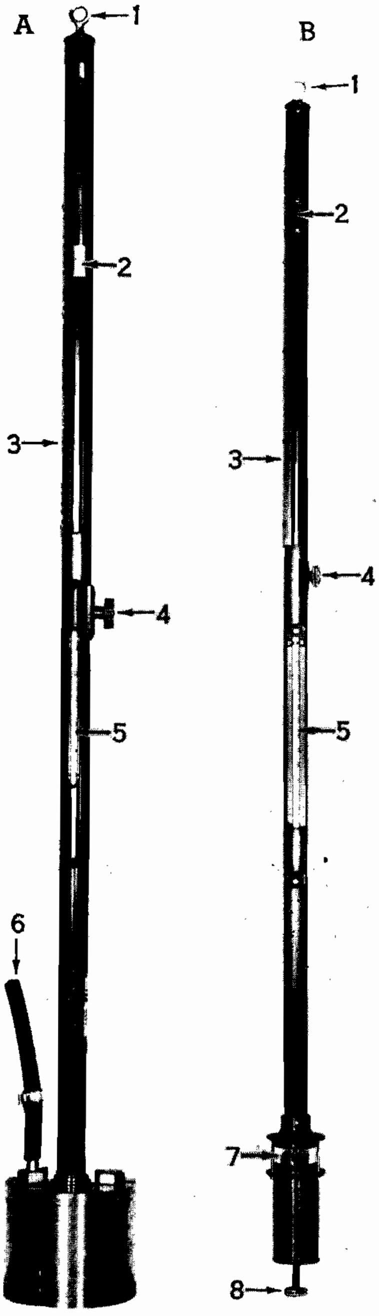

FIGURE 2.4.0. Mercurial barometers. On the left is a Bowen fixed-cistern barometer, on the right a Fortin adjustable-cistern barometer. The parts listed below are identified by number in the illustration.

1. Suspension ring
2. Vernier
3. Scale
4. Vernier adjusting knob
5. Attached thermometer
6. Static-head connecting hose
7. Cistern window
8. Cistern adjusting screw

arm extended in operating position, for at least 15 minutes before the reading is scheduled to begin (see end of sec. 2.2.4.1 regarding pertinent information).

2.4.2.1 Thermometer Reading

Read the attached thermometer, and record the temperature to the nearest 0.5° F. (or 0.2° C.) in the case of barometers of 0.25 inch internal diameter, and to the nearest 1/4° F. (or 0.1° C.) in the case of instruments of greater diameter. When making the reading, stand directly in front of the thermometer and take the correct line of sight to avoid parallax error as illustrated in fig. 2.7.5 (see sec. 2.7.4). If the attached thermometer has a known correction, apply the correction algebraically to the observed reading to obtain the true temperature.

2.4.2.2 Cistern Setting[2]

If the barometer is of the Fortin type, these instructions apply; but if it is of the fixed-cistern type, these instructions are not pertinent.

(A) Turn the adjusting screw which is beneath the cistern (see fig. 2.5.0, also figs. 2.2.2, 2.2.3, and 2.4.0), so as to lower the surface of the mercury in the cistern until it is a slight distance below the tip of the ivory point, say about 1/8 or 1/4 inch, but *never* more than 1/4 inch below the tip.

(B) Next, reverse the direction of turning the adjusting screw and slowly raise the level of the mercury in the cistern until the mercury surface is about 1/16th inch below the ivory point; and then tap lightly with the fingers both the metal portion of the cistern and the metal sheath surrounding the barometer tube in the vicinity of the upper meniscus. (See sec. 2.7.1 and sec. 6.5.5.)

(C) Then, in order to raise the surface of the mercury until it *just* touches the tip of the ivory point, continue turning the adjusting screw in the same direction, an additional amount until the thin background of light between the mercury surface and the tip *just* disappears, while viewing the tip along a horizontal line of sight. Now to

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[2] It is useful to employ a low stool on which to sit while making adjustments of the screw beneath the cistern and while establishing exact contact of the mercury surface with ivory point, since this will tend to improve the precision with which the latter step is performed. It is also useful to make use of a magnifying reading glass to observe the accuracy of the setting with reference to the ivory point and to read the vernier.

check on the setting, observe the point of contact of the mercury surface with the tip of the ivory point by viewing it at an angle of elevation of about 30° above the mercury surface, and determine whether or not the ivory point is making an indentation in the mercury. *When the setting is correct, there should not be more than the slightest dimple where the ivory point makes contact with the mercury surface.* If the mercury surface is bright and the setting is correct, the tip of the ivory point will appear to coincide with its reflected image in the mercury surface.

(D) In case the contact of the ivory point with the mercury produces more than the slightest dimple, it must be considered that the mercury has been raised too high. In that event the entire procedure of setting the cistern must be repeated (as described under paragraphs A, B, and C above), until the criterion given in paragraph (C) has been satisfied. This will necessitate that the mercury surface be lowered a little and then again raised as indicated by the instructions. The proper method of setting the cistern always should involve *raising* the level of the mercury surface up to contact with the tip of the ivory point, *but never lowering* down to the tip once the mercury surface is too high.

2.4.2.3 Vernier Adjustment

(A) Using the fingertips, tap the metal casing of the barometer near the top of the mercury in the glass tube just sufficiently to permit the rounded meniscus at the head of the mercury column to assume its proper equilibrium shape. (Note: The vibration and disturbance of the mercury caused by the tapping on the metal casing tends to overcome excess friction between the mercury and the inner glass wall of the tube which is in contact with the fluid; hence by this means the correction for capillarity which is determined by laboratory calibration under a similar procedure may be expected to be valid. See sec. 2.7.1.) If the barometer is of the *fixed-cistern type,* also tap the metal cistern housing lightly with the fingers at this stage, for a similar reason.

(B) First turn the knurled thumbscrew to raise the vernier above the top of the meniscus, and then lower it very slowly as the lower edge of the vernier gets close to the summit of the mercury column.

(C) Standing steadily in such a position that the level of the eye coincides with that of the top of the column, and assuming a horizontal line of sight towards the white background at this level slowly bring down the vernier by means of the thumbscrew until the lower edges of the vernier at *both* front and back lie on the same line of sight as the top of the meniscus. The correct line of sight is illustrated in fig. 2.7.6 (A). When the line of sight is correct and the setting proper, the lower edges at both front and back of the vernier appear to be coincident with the top of the rounded meniscus, while the line of these edges is tangent to the curved profile of the meniscus at its summit. (Note: Before the final setting of the vernier is attained, a thin slit of light is observable between the top of the mercury column and the lower edges of the vernier. As the vernier is progressively adjusted downward, the slit becomes thinner. By moving the eye a little up and down the vertical height of the slit appears to change. When a line of sight is used which causes the vertical height of the slit of light to appear a maximum, this can be regarded as a suitable one. Finally, the vertical height of the slit in the center reduces to nothing at the top of the meniscus as the line of the lower edges of the vernier become tangent to meniscus at its highest point. At this final condition of the vernier adjustment, it should be possible to observe two small triangles of light in place of the original slit, one on each side of the top of the mercury column. It would be incorrect to cut off the meniscus as illustrated in fig. 2.7.6 (C), or to commit errors of parallax as shown in fig. 2.7.6 (B).)

2.4.2.4 Reading Barometer Scale and Vernier

We present here some preliminary information which it is felt the observer should know, followed by specific instructions under cases (A), (B), and (C) below for reading the vernier and the barometer scale.

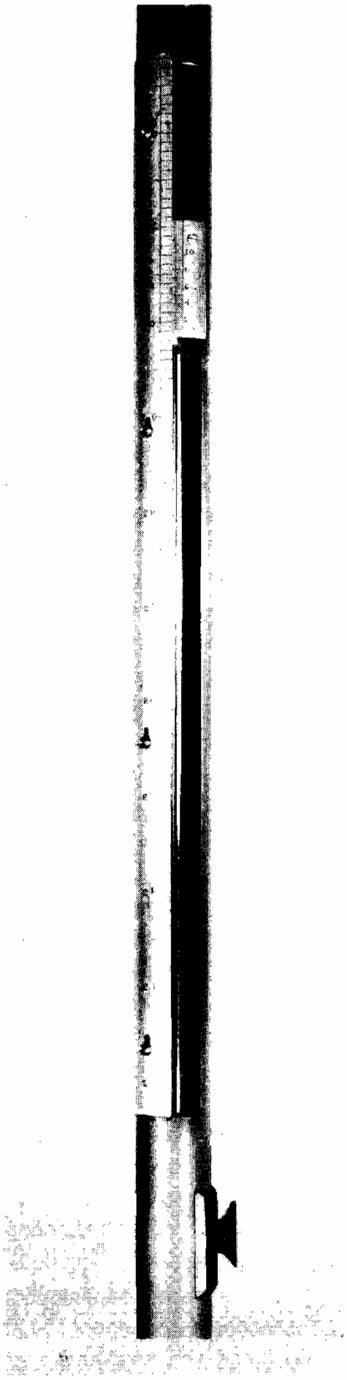
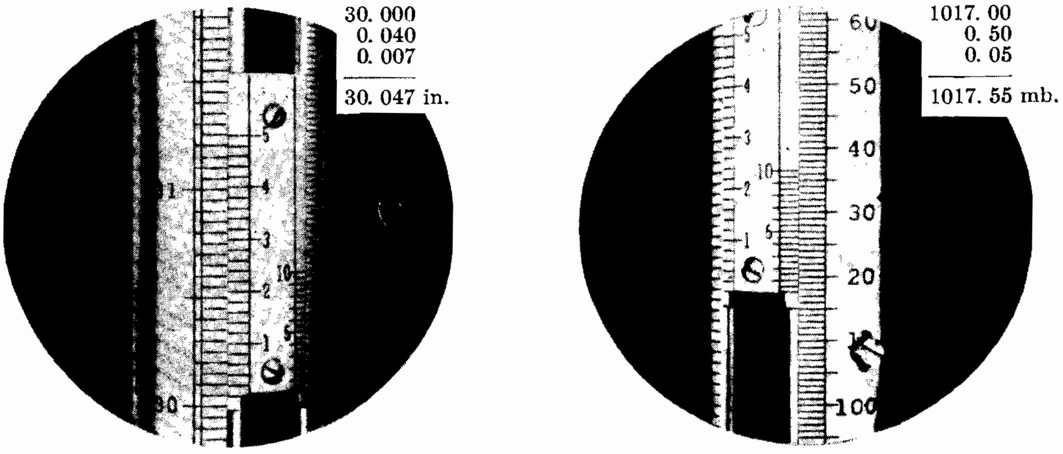


FIGURE 2.4.1. Barometer scale and vernier, Weather Bureau type with 9:10 ratio.

Preliminary information.—The vernier (see figs. 2.4.0 to 2.4.5 (b)) is designed to permit the observer to determine accurately fractional subdivisions of the barometer scale, when reading the height of the column of mercury; and it enables him to ascertain the fractional parts more precisely than he can estimate them by eye. Both the barometer scale and the vernier are uniformly graduated by suitable scale divisions, except that the spacings between the scale divisions of the vernier are generally less than those between the graduation marks on the barometer scale, although other special relationships are used in some designs. The vernier enables the observer to make precise fractional determinations because it is so graduated that a certain convenient ratio exists between the length of one interval of the vernier scale and the length of one interval of the barometer scale. The relationship between the two is usually expressed by pairs of numbers like 9:10, 24:25, 49:50, and 19:20 (see examples in fig. 2.4.2–2.4.4). These pairs of figures can be interpreted as follows: when the barometer scale and the vernier are placed side by side, the linear distance covered by the number of intervals of the barometer scale given in the first figure of the pair is exactly covered by the number of intervals of the vernier given in the second figure. To consider an example such as 9:10, this signifies that 9 successive spacings (or divisions) on the barometer scale occupies a certain distance and that this same distance will be occupied by 10 successive spacings on the vernier. For any specific barometer the observer can easily ascertain the ratio by comparing the barometer scale with the vernier, securing coincidence of distance for whole numbers of intervals on each, and counting the number of intervals of the barometer and vernier scales over this distance. As a rule, the second figure in the ratio is one (1) more than the first figure of the pair; however, other relationships are possible as in the special case of the ratio 19:10. It should be noted that the second figure in the pair is always a convenient submultiple of 100, as this makes it possible to deal readily with decimal fractions of the barometer scale.

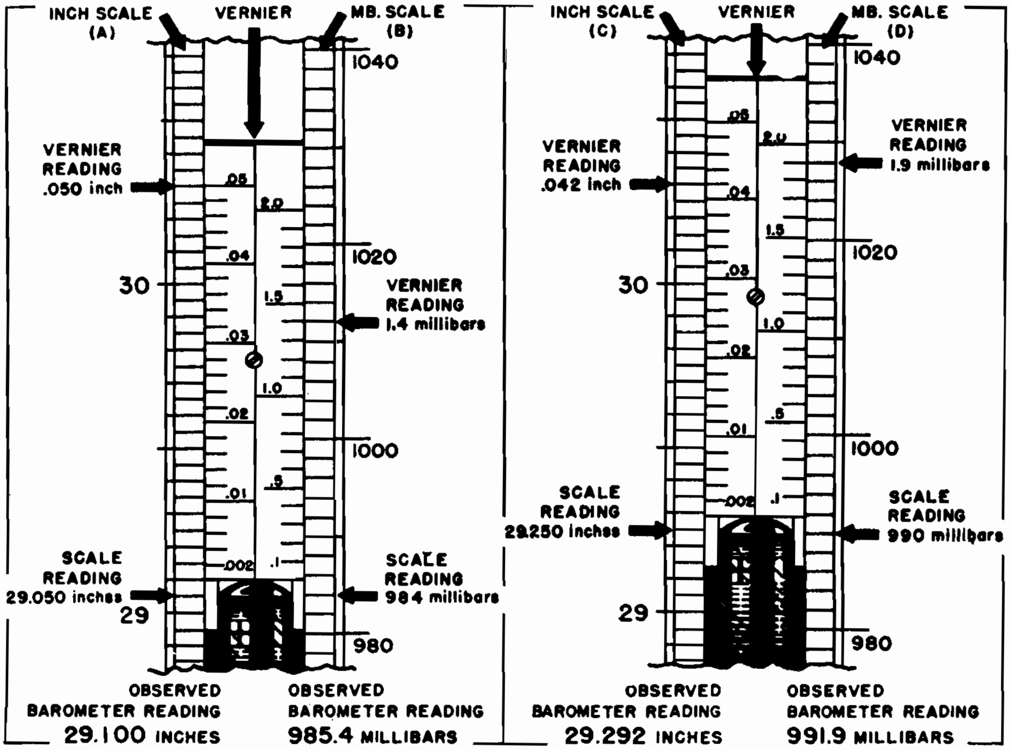
In order to make proper use of the vernier, the observer must know what value should be attributed to one (1) interval of the vernier in terms of the units employed for



24 to 25 Ratio 19 to 20 Ratio

FIGURE 2.4.2(a). Mercurial barometer readings (illustrating readings from the most frequently used Air Force type scale and vernier).

the barometer scale. There are some instruments such as those used by the Navy and sketched in the lower half of fig. 2.4.2 (see also columns 6 and 7 of fig. 2.4.3), where the vernier is labeled directly in the same terms as the barometer scale; however, the other vernier designs merely have figures such as 1 to 5 or 1 to 10, illustrated in the upper half of fig. 2.4.2 and columns 1-5 of figs. 2.4.3, and 2.4.4. In the latter cases the



24 to 25 Ratio 19 to 20 Ratio 24 to 25 Ratio 19 to 20 Ratio

FIGURE 2.4.2(b). Mercurial barometer readings (illustrating readings from the most frequently used Navy type scale and vernier).

observer can readily determine the value which should be attributed to one (1) interval of the vernier in terms of the units used for the barometer scale by application of the following rule: First note the amount of the smallest subdivision engraved on the barometer scale and divide this amount by the highest figure engraved on the vernier (such as 5 or 10); then the quotient obtained by means of this division represents the value which should be attributed to the interval on the vernier from zero (0) to the line properly labeled 1, or the interval from 1 to 2, etc. This may be readily appreciated from the following examples:

(a) In column 1 of fig. 2.4.3, the smallest subdivision engraved on the barometer scale is 0.10 inch, and the highest figure on the vernier is 10. Then, dividing the former by the latter we obtain the quotient 0.10 inch/10 = 0.01 inch, and this signifies that line number 1 on the vernier corresponds to 0.01 inch, line No. 2 on the vernier corresponds to 0.02 inch, line No. 3 corresponds to 0.03 inch, etc., when using the vernier to make the barometer readings as illustrated in the lower half of fig. 2.4.3.

(b) In columns 3 and 4 of fig. 2.4.3, the smallest subdivision engraved on the barometer scale is 0.05 inch, and the highest figure on the vernier is 5. Then, dividing the first of these by the second, we find the quotient 0.05 inch/5 = 0.01 inch, which indicates that line numbered 1 on the vernier corresponds to 0.01 inch, the line numbered 2 corresponds to 0.02 inch, etc., when applying the vernier in the making of barometer readings as illustrated in fig. 2.4.3, lower half. Since the interval from 0 to 1, 1 to 2, etc., on the vernier is further subdivided, either into 5 equal parts as in column 4 or into 10 equal parts as in column 3 of fig. 2.4.3, it is an easy matter to calculate the value to be attributed to the smallest interval of subdivision on the vernier by dividing the 0.01 inch by 5 or 10, depending upon whichever applies, giving 0.002 inch and 0.001 inch, respectively.

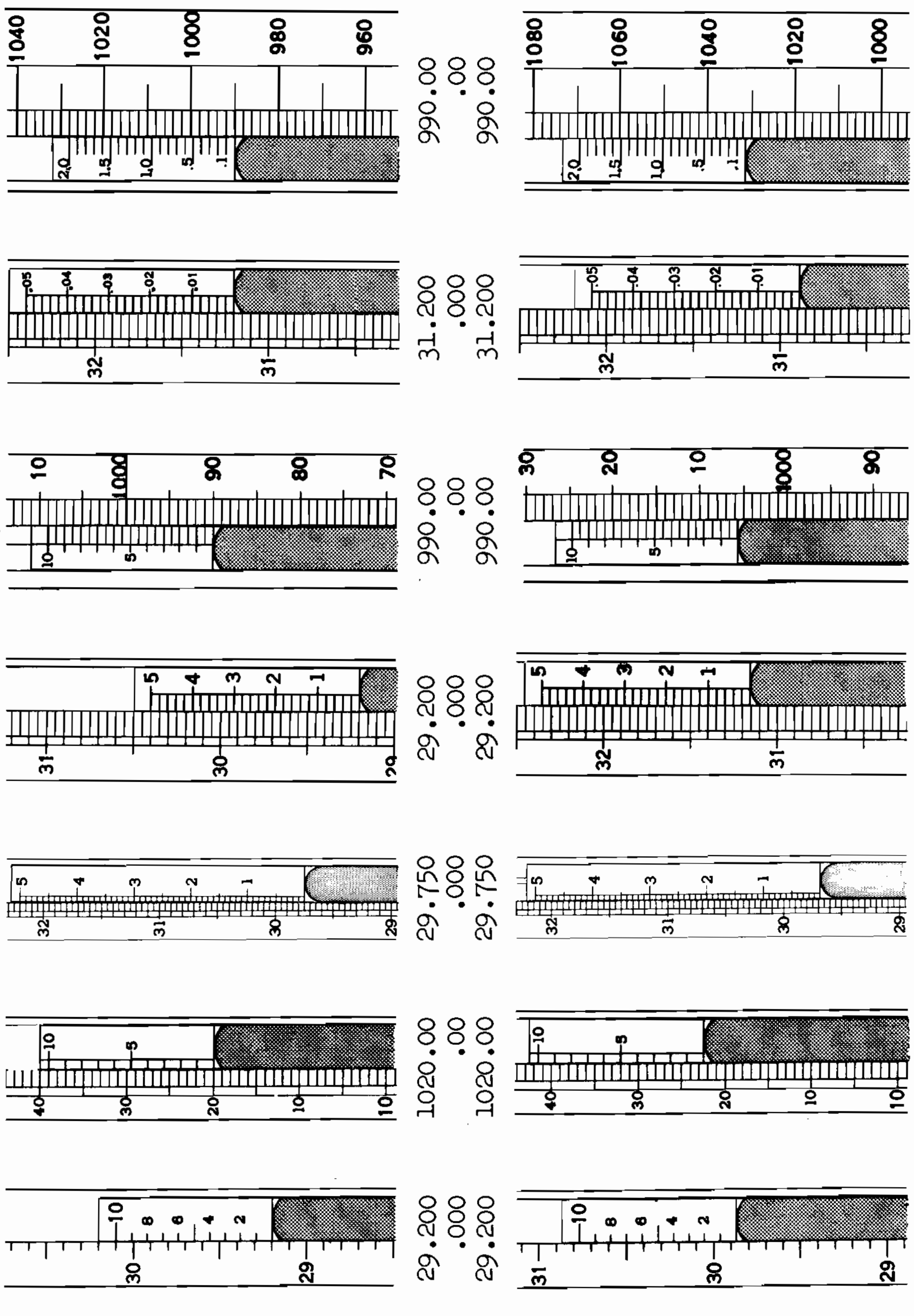
(c) In column 5 of fig. 2.4.3, the smallest subdivision engraved on the barometer scale is 1 millibar, and the highest figure on the vernier is 10. From the quotient of these data we find that 1 mb./10 = 0.1 mb. represents the value which should be attributed to line properly numbered 1, etc., and 0.5 mb. the value to be attributed to the line numbered 5, etc., on the vernier. Since intermediate graduations appear on the vernier half way between the whole-numbered lines, it will be clear that the value to be attributed to the smallest interval between engraved lines on the vernier is 0.05 mb., when using the vernier to determine the fractional part of the barometer reading as illustrated in fig. 2.4.2, upper, right-hand diagram.

The lower sighting edge of the vernier represents the zero line of the vernier, and it is called the "*index*" of the vernier. It should be noted by the observer that the use and reading of the vernier are dependent on whether or not any line or lines of the vernier are aligned (become coincident) with any graduation(s) of the barometer scale, and that if such alignment does not occur in any specific observation an additional step, usually interpolation, is required. Thus the instructions for reading the barometer given below are classified into three cases (A, B, and C) defined as follows: Case (A) involves the condition where the index of the vernier is aligned *exactly* with a graduation line of the barometer scale; Case (B) involves the condition where some line other than the index of the vernier is *exactly* aligned with a graduation of the barometer scale; and Case (C) involves the most common circumstance where none of the vernier lines are aligned with any graduation of the barometer scale.

Instructions

Case (A).—First, observe whether the index of the vernier is *exactly* aligned with a graduation line engraved on the barometer scale. If it is, the reading of the height of the mercury column (termed "barometer reading") is given directly by the value on the scale of the instrument associated with that graduation. Examples are shown in the upper half of fig. 2.4.3.

Case (B).—Second, if the index is *not* exactly coincident with any graduation of the barometer scale, scan the vernier upward and observe whether there is any other line



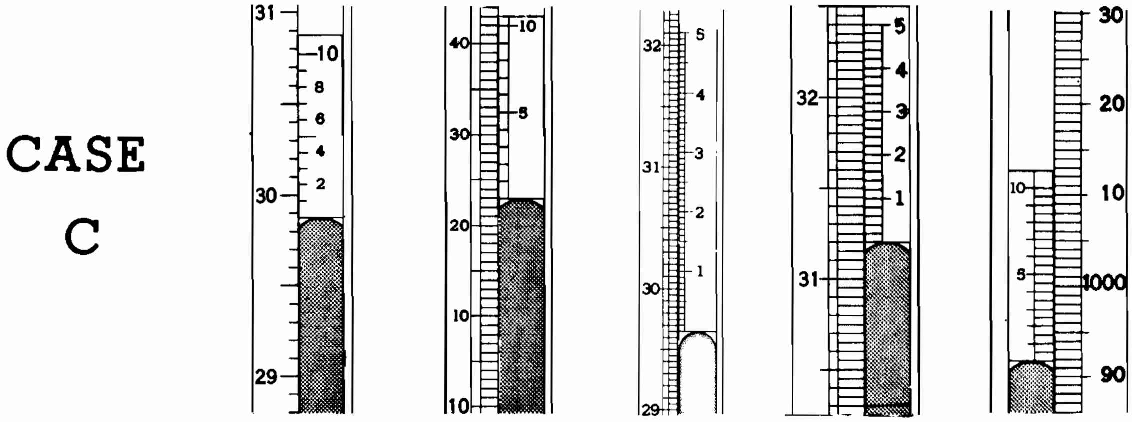
Data	1	2	3	4	5	6	7
Scale-Vernier Ratio	9:10	19:10	49:50	24:25	19:20	24:25	19:20
Service	WB	WB	WB	AF	AF	NAVY	NAVY
Smallest interval	.010 in	0.1 mb	.001 in	.002 in	.05 mb	.002 in	0.1 mb
CASE A							
Scale Reading	29.200	1020.00	29.750	29.200	990.00	31.200	990.00
Vernier Increment	.000	.00	.000	.000	.00	.000	.00
Bar. Reading	29.200	1020.00	29.750	29.200	990.00	31.200	990.00
CASE B							
Scale Reading	29.800	1022.00	29.650	31.150	1005.00	30.850	1030.00
Vernier Increment	.070	0.60	.036	.006	0.65	.038	1.30
Bar. Reading	29.870	1022.60	29.686	31.156	1005.65	30.888	1031.30

FIGURE 2.4.3. Observed barometer readings obtained from various scales and verniers. [See paragraphs (a), (b), and (c) under sec. 2.4.2, (4) "Preliminary Information."]

of the vernier which is *exactly* aligned with a graduation of the barometer scale. If such exact alignment is found for any particular line of the vernier, read the value of that line in terms of the unit of the barometer scale, where the interpretation of the value is in accord with the rule given under "Preliminary Information" and illustrated by examples (a), (b), and (c) above. (Illustrations of this process will be found in fig. 2.4.3, lower half.) Then, by referring to the barometer scale read the value of the graduation which is immediately below the index of the vernier. Finally, add the fractional value obtained from the vernier to the value secured from the barometer scale for the specified graduation; the sum represents the required barometer reading (observed height of the column of mercury), as shown in fig. 2.4.3, lower half. In order to check the final result, the observer should read as accurately as possible the value of the barometer scale at the point where it is intersected by the index of the vernier, estimating the fractional part by eye. When the procedures have been properly carried out, there should be close agreement between the observed reading of the barometer secured in the two ways described above.

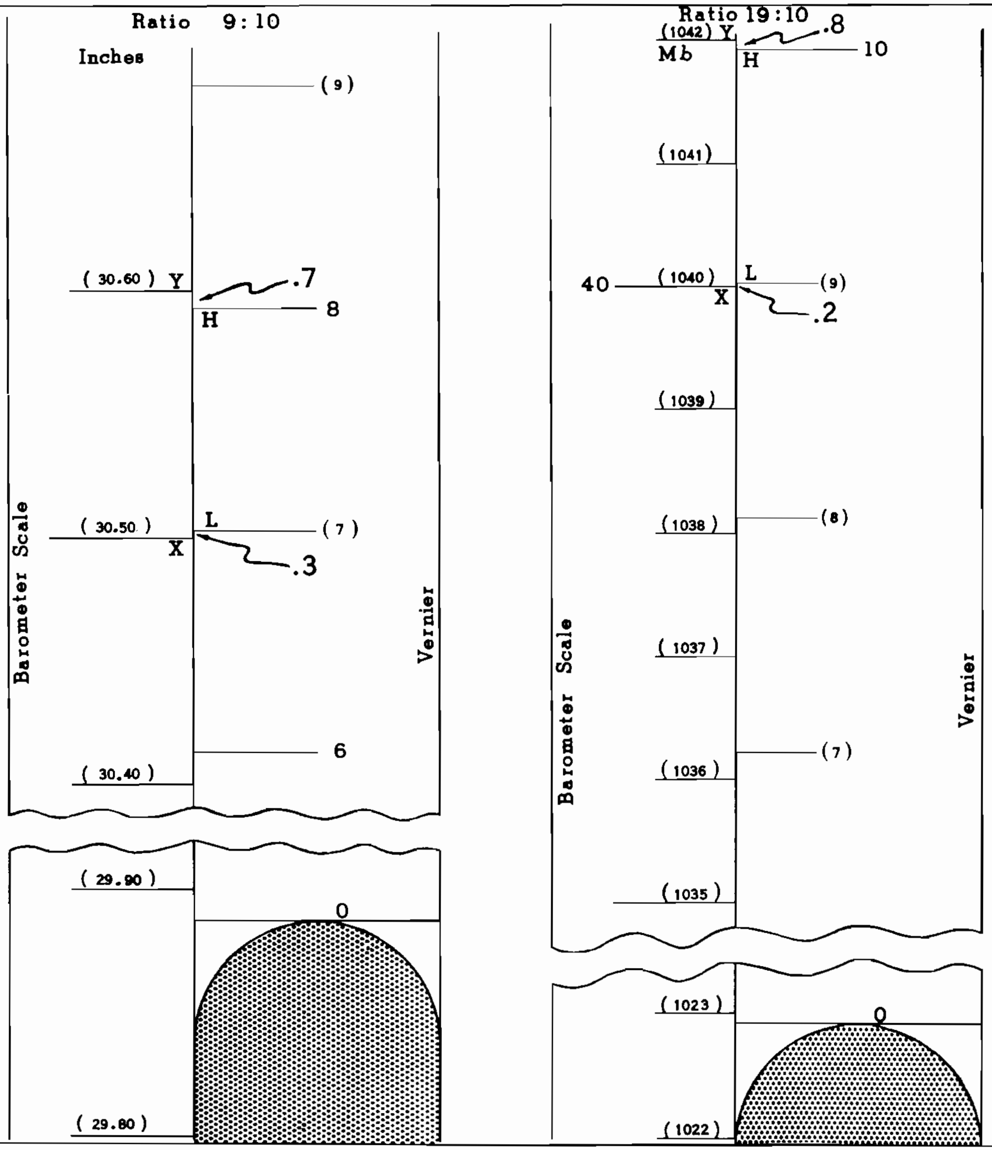
Case (C).—Third, if *neither* of the conditions specified in the first two sentences of Cases (A) and (B) above is satisfied, there exists the condition where no line of the vernier is aligned with a graduation of the barometer scale; hence in this event we have the situation illustrated in fig. 2.4.4, and then the technique indicated in fig. 2.4.5(a) and 2.4.5(b) must be employed. For this situation, it is necessary to scan the vernier upward from the index and find the place where two consecutive vernier lines fall within two adjacent graduations of the barometer scale as shown in figs. 2.4.4, 2.4.5(a) and 2.4.5(b). (An example in detail is described in the next paragraph.) Considering the lower of the two vernier lines just described, the observer should read the value of that line in terms of the unit of the barometer scale, where the interpretation of the value is in accord with the rule given under "Preliminary Information" (see examples (a), (b), and (c) above). This value is generally a multiple of 0.01 inch or 0.1 mb. in the vernier designs illustrated. In order to obtain the next decimal figure, it is

Data	1	2	3	4	5
Service	WB	WB	WB	AF	AF
Smallest Interval	.010 in	0.1 mb	.001 in	.002 in	.05 mb



	1	2	3	4	5
Scale Reading	29.800	1022.00	29.650	31.200	991.00
Vernier Increment	.073	0.92	.002+	.003	.83
Bar. Reading	29.873	1022.92	29.652	31.203	991.83

FIGURE 2.4.4. Observed barometer readings obtained from various scales and verniers. [See paragraphs (a), (b), and (c) under sec. 2.4.2, (4) "Preliminary Information."]



$Q = \frac{XL}{XL + HY}$

$= \frac{0.3}{0.3 + 0.7} = 0.3$

. . . .

Q • [*] =

0.3 • 0.01 = ... 0.003
Line L 0.070
Scale graduation below
vernier index 29.800
Barometer reading 29.873

[*] = Value attributable to one interval of the vernier.

$Q = \frac{XL}{XL + HY}$

$= \frac{0.2}{0.2 + 0.8} = 0.2$

. . . .

Q • [*] =

0.2 • 0.1 = ... 0.02
Line L 0.90
Scale graduation below
vernier index 1022.00
Barometer reading 1022.92

[*] = Value attributable to one interval of the vernier.

FIGURE 2.4.5(a). Enlarged vernier illustrating procedure for estimation of fractional part of barometer reading.

$$Q = \frac{XL}{XL + HY}$$

$$= \frac{0.5}{0.5 + 0.5} = 0.5$$

. . . .

Q • [*] =

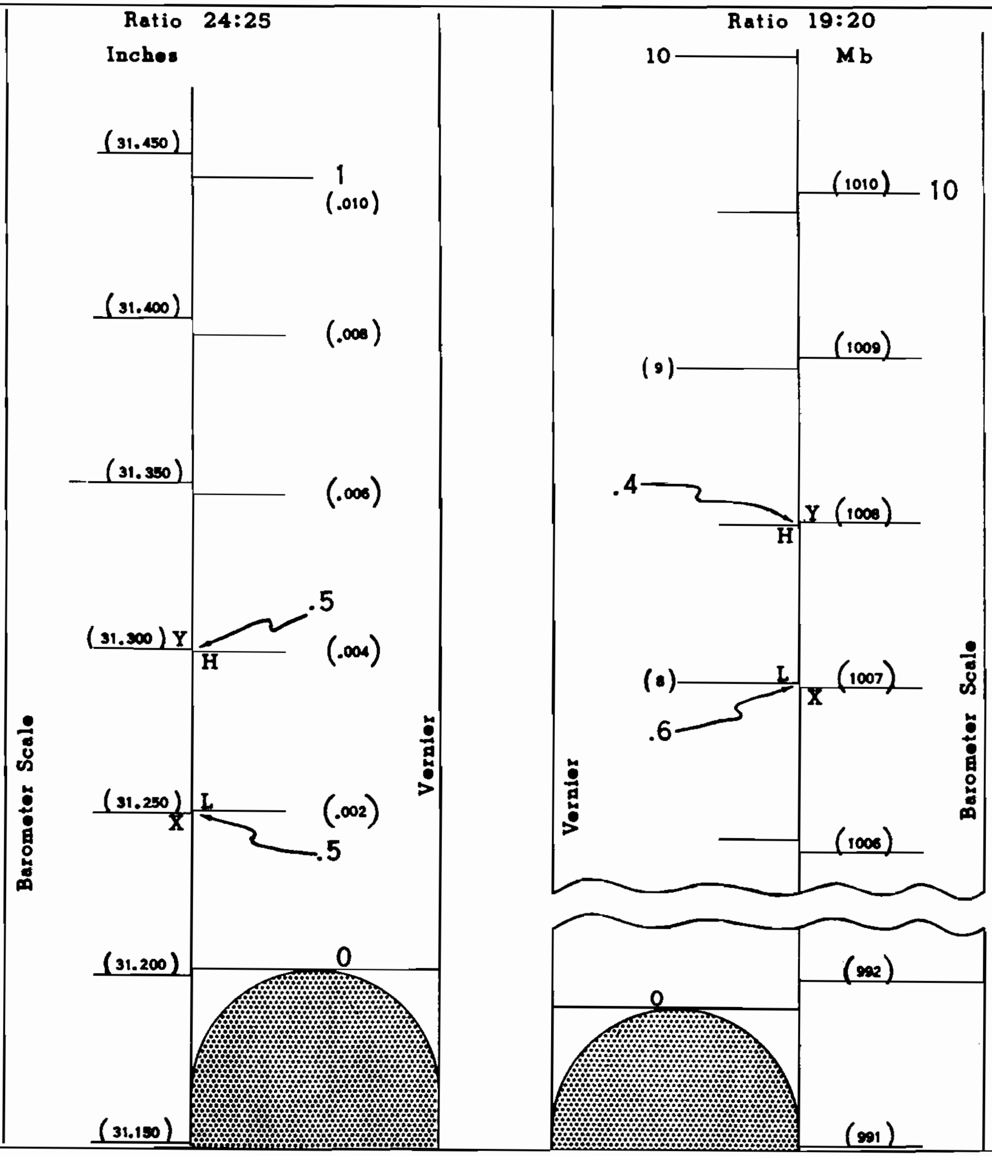
0.5 • 0.002 = ... 0.001

Line L 0.002

Scale graduation below vernier index 31.200

Barometer reading 31.203

[*] = Value attributable to one interval of the vernier.



$$Q = \frac{XL}{XL + HY}$$

$$= \frac{0.6}{0.6 + 0.4} = 0.6$$

. . . .

Q • [*] =

0.6 • 0.05 = ... 0.03

Line L 0.80

Scale graduation below vernier index 991.00

Barometer reading 991.83

[*] = Value attributable to one interval of the vernier.

FIGURE 2.4.5(b). Enlarged vernier illustrating procedure for estimation of fractional part of barometer reading.

necessary to make use of the procedure depicted in fig. 2.4.5(a) and 2.4.5(b). To this end the observer must consider the *difference* in distance between the two consecutive vernier lines and the two adjacent graduations of the barometer scale being compared, and then estimate the fractional part of this difference occupied by the space between the lower scale graduation and the lower vernier line under consideration. Next, it is necessary to express this as a decimal in terms of the unit of the barometer scale by taking that estimated fractional part of the value attributable to *one* interval of the vernier. Then, the observer must read the value of the graduation on the barometer scale which is immediately below the index of the vernier. Finally, he must add together the whole value thus secured from the barometer scale and the two data determined from the vernier, thereby obtaining the sum which represents the required barometer reading. In order to check the final result, the observer should read as accurately as he can the value of the barometer scale at the point where it is intersected by the index of the vernier, estimating the entire decimal part by eye. Close agreement should be thus obtained if the complete procedure has been properly carried out.

Example

In order to endeavor to make the procedure clear by means of the sketches in figs. 2.4.5(a) and 2.4.5(b) the letters *L-H* denote the two vernier lines which fall within the two adjacent graduations of the barometer scale denoted by the letters *X-Y*. Then the difference in distance between the two consecutive vernier lines and the two adjacent graduations of the barometer scale is represented by the sum $(XL + HY)$, where XL denotes the distance between the lower graduation X and the lower vernier line L, while HY denotes the distance between the upper vernier line H and the upper graduation Y. Now the quotient $XL/(XL + HY)$ represents the estimated fraction; for example such as $0.3/(0.3 + 0.7) = 0.3$. Suppose that the value attributable to one interval of the vernier is 0.01 inch, then the decimal equivalent of the estimated fractional part is 0.3 of 0.01 inch, or 0.003 inch. If the value of the reading of the lower vernier line L were say 0.070 inch, the combination of these two data would yield 0.073 inch as the total result obtained from the vernier. To continue the example, if the value of the graduation on the barometer scale which is immediately below the index of the vernier were say 29.800 inches, the sum $(29.800 + 0.073)$ inches, or 29.873 inches, would represent the required barometer reading.

2.4.2.5 Applying Corrections to Observed Reading of Mercury Barometer to Obtain Station Pressure

In order to obtain the station pressure in inches of mercury or in millibars it is always necessary to apply appropriate corrections to the observed reading of the mercury barometer determined in accordance with sec. 2.4.2.4 above. Stations operated by the U.S. Government under conditions where the instructions of this manual are in effect will generally be provided with a copy of Form WBAN 54–3.3.1 (Barometer Correction Card) pertaining to the particular mercury barometer supplied to the station. This form is illustrated in Chapter 3, sec. 3.3, and it shows how certain corrections pertinent to a given barometer are listed. At fixed land stations, all or some of the corrections may be regarded as constant; and when all are treated as constant they are added algebraically, the result being indicated on the line labeled "Sum of Corrections." One of the corrections often included in Form WBAN 54–3.3.1 is the so-called "Correction for Reduction from H_z to H_p," also known by the term "Removal Correction." (For definitions of terms and references to other sections where additional material is given, see sec. 2.4.2.6 "Supplementary Information regarding barometer corrections.") The instructions for applying the corrections to the observed reading of the mercury barometer in order to obtain the station pressure depend upon whether the barometer is of the Fortin or the fixed-cistern type, upon whether the station is at a fixed location or is mobile, and upon whether the "Correction for Reduction from H_z to H_p" is constant or variable.

Each correction has its appropriate algebraic sign (+ or —); and therefore when an instruction states that "a correction should be applied" this should be interpreted as signifying that a correction marked with a plus (+) sign must be added to the quantity to be corrected and that a correction marked with a minus (—) sign must have its absolute value subtracted from the quantity to be corrected.

(I) *Instructions for application of corrections in case the barometer is of the Fortin-type and the station has a fixed location.*—In this case, the "Sum of Corrections" as given on Form WBAN 54–3.3.1 must first be applied to the observed reading of the barometer; and then the "Correction for Temperature" (see Chapter 5) must be applied to the result obtained from the first operation. (See examples in figs. 5.2.1 and 5.2.2.) Thus, in ordinary meteorological practice, the quantity obtained by the algebraic addition of the barometer reading, the "Sum of Corrections," and the "Correction for Temperature" is considered to represent the "station pressure" for routine purposes. However, for special scientific work where a high degree of absolute accuracy is required, greater refinement of results is obtainable through the use of the methods of calculation consistent with equations (1), (2), or (3) of sec. 5.1 (see also Appendix 1.4.2). When the "Correction for Reduction from H_z to H_p" varies with the outdoor temperature (i.e., when a "variable removal correction" is required as outlined in Chapter 4), the Sum of Corrections varies likewise, and the value of this Sum of Corrections under such conditions must be taken from the data on the reverse side of Form WBAN 54–3.3.1. Since the Sum of Corrections is composed of the algebraic sum of the correction for instrumental errors, the correction for gravity, and the "removal correction," one may replace the Sum of Corrections by these items combined in any valid manner for the purpose of determining the station pressure, as illustrated in fig. 5.2.2. (For further details see sec. 2.4.2.6.)

Reverting to the process described in the first sentence of the previous paragraph, a more convenient method of accomplishing the objective is to add algebraically the "Sum of Corrections" and the "Correction for Temperature," thereby producing a "Total Correction Table," one form of which is illustrated in sec. 5.4. When such a table is available, the "Total Correction" obtained from it should be applied to the observed reading of the mercury barometer, in order to secure more simply the same result as would be obtained by following the instructions in the first sentence of the previous paragraph.

It will be noted that the "Correction for Temperature" and the "Total Correction" depend upon the observed readings of both the attached thermometer and the barometer (see Tables 5.2.1–5.2.3, and sec. 5.4).

Note: The errors that may result from the foregoing procedures are partially discussed in sec. 5.1 and Appendix 1.4.2.

(II) *Instructions for application of corrections in case the barometer is of the Fortin-type and the station is mobile.*—Observers at mobile stations such as those mounted on trucks or where the mercury barometer is moved from place to place so as to be subjected to a different force of gravity at different locations must take account of the local value of gravity at each location. In that case, the "Correction for Gravity" must be determined in accordance with the instructions given in Chapter 3. The correction so found must be entered tentatively on Form WBAN 54–3.3.1 on the line labeled "Correction for Gravity" (or Reduction from Local to Standard Gravity).

After the proper "Correction for Gravity" has been entered on Form WBAN 54–3.3.1 as outlined in the previous paragraph, the observer should follow the instructions given above under the heading "(I) Instructions for Application of Corrections in Case the Barometer is of the Fortin Type and the Station Has a Fixed Location." That is, the instructions under (I) are relevant for the obtainment of station pressure, provided that the "Gravity Correction" included in Form WBAN 54–3.3.1 is appropriate to the current location of the barometer.

(III) *Instructions for application of corrections in case the barometer is the fixed-cistern type.*—In this case the procedure for applying the corrections is illustrated by the examples shown at the end of sec. 5.3. *If the* station is mobile, as for example a ship moving from place to place, the "Gravity Correction" (K_g) is determined at each location in accordance with the provisions of Chapter 3 (see sec. 3.1).

Before it is possible to apply the corrections, it is necessary to know certain quantities relating to the fixed-cistern barometer. These are defined in sec. 5.3 in terms and symbols as follows:

"Instrumental correction, K_i"
"Barometer constant, b"
"Reference temperature, t_r"

For each observation, the observer must also obtain the following two data: "Observed reading of barometer, B" and "Attached thermometer reading, t."

In lieu of detailed instructions at this point, it is suggested that the user of the barometer refer to the examples at the end of sec. 5.3 for guidance. When a "Removal Correction" is necessary, it should be applied as a final step.

2.4.2.6 Supplementary Information Regarding Barometer Corrections

Aneroid barometers are not subject to the same corrections as mercury barometers; for example, a gravity correction *never* applies to the aneroid instrument.

The corrections which properly apply to mercury barometers may be listed as follows, together with references to sections and chapters where additional information can be secured:

(A) *Correction for instrumental errors, including scale errors and capillarity.*—(This correction is shown on Form WBAN 54–3.3.1 for the given barometer. It is generally determined in the instrument laboratory before the barometer is shipped to the station. The correction is ascertained in the laboratory by means of a calibration; that is a comparison of the readings of the given barometer against those of a standard barometer properly corrected. With reference to the subject of barometer comparison see Chapter 6, secs. 6.0–6.5.3; and the Annex to Chapter 6. Also, see secs. 2.7.1 and 2.7.3 for general information regarding capillarity and imperfect vacuum, respectively. Essentially, the correction under consideration is a composite, including the following possible elements; correction for inaccurate setting of the zero point of the barometer scale with reference to the scale graduations taken as a whole; correction for error in the subdivision of the scale in the portion calibrated; correction for error in the adjustment of the sighting edge of the vernier to the zero line of the vernier; correction for errors of capillarity; correction for imperfect vacuum; etc.)

(B) *Correction for gravity.*—(This correction is also sometimes termed the "Correction to reduce from local to standard gravity." At fixed stations it is always shown on Form WBAN 54–3.3.1 for the given location of station and altitude above sea level. The method of determining the correction for gravity is described in Chapter 3. Appendix 1.4.2 contained in Chapter 12 presents the general theory underlying the gravity correction pertinent to all mercury barometers. By consulting sec. 2.7.5 the reader can gain an idea of the reason for the necessity of this correction.)

(C) *Removal correction.*—(Another term used is "Reduction from H_z to H_p." This correction only applies if the station elevation, H_p, is different from the actual elevation of the zero point of the barometer, H_z. It is a correction to reduce pressure from the latter to the former. When the difference $H_z - H_p$ is relatively small, the "removal correction" may be considered as a constant; but when the difference is large, say over 50 feet, it will be variable, depending upon the observed outdoor temperature. In cases where the removal correction is constant, it is shown as an entry on Form WBAN 54–3.3.1; however, in cases where the removal correction is variable it is usually tabulated on the back of the form, or on a separate card or sheet of paper. Chapter 4 provides instructions for computing the removal correction, while Chapter 7 contains additional material pertaining to the computation of variable removal corrections in situations where the difference $H_z - H_p$ is relatively large.)

(D) *Residual correction.*—(This is a correction intended to overcome errors of an instrumental nature which are manifested by the barometer after it is installed at a station removed from the laboratory where it was originally calibrated. Therefore, the residual correction must take account of the errors above and beyond those allowed for by the "correction for instrumental errors, including scale errors and capillarity" described under (A) above. It amounts to a correction for *change* in the instrumental errors from the time that item (A) was determined in the laboratory until the barometer is checked at the station. Among the causes which may explain the appearance of such errors is the possibility that small air bubbles formerly adhering to the inner wall of the barometer tube have become dislodged by the movement of the mercury, perhaps during shipment; hence if the bubbles rise to the space above the meniscus in the tube, the back-pressure in the "vacuum space" changes, thus producing a variation in the error for imperfect vacuum. The "residual correction" is determinable at the station where the barometer is installed only on the basis of precise comparative readings between the given instrument and another barometer which has itself been standardized and checked after its return to the laboratory or site of the standard barometer. Therefore, the "residual correction" will only be included on Form WBAN 54–3.3.1 when and if such comparative determinations have been made at the station; provided that two or more sets of comparisons obtained at different times permit the earlier results to be corroborated. Chapter 4 contains a little information on the subject of "residual correction" and secs. 6.5–6.5.9 describe the appropriate procedures. See the Annex of Chapter 6 and secs. 6.0–6.4 for further information.)

(E) *Correction for temperature.*—(This is governed by the reading of the attached thermometer and is different for the fixed-cistern barometer than for the Fortin type barometer. With regard to the theory of the temperature correction for the latter type, see Appendix 1.4.2; and for general information on the subject see sec. 2.7.4. Chapter 5 contains the instructions for obtaining the correction and gives more details. In the case of Fortin-type barometers, the reader should refer to the instructions in sec. 5.2, and note that Table 5.2.1 yields the correction when the barometer scale is true at 62° F., and Tables 5.2.2 and 5.2.3 yield the correction when the scale is true at 32° F. In the case of fixed-cistern barometers, sec. 5.3 should be consulted, especially the examples given at the end of that section.)

2.5 FORTIN-TYPE MERCURY BAROMETER

In this type, a pointer made of non-corrodible material such as ivory or stainless steel projects down from the roof of the cistern (see fig. 2.5.0). The tip of this pointer is called by various synonymous names, particularly index point, zero point, or ivory point (the latter in case the pointer consists of ivory). The cistern is so constructed that the level of the mercury within may be lowered and raised by turning a thumb screw beneath the cistern. Before the height of the mercury column can be determined, it is necessary first to lower the level of the mercury in the cistern below the zero point and then to raise it until the tip of the pointer just touches the surface of the mercury in the cistern. As the tip and the mercury just make contact, a dimple of minute size which is just barely perceptible appears in the surface of the liquid. The observer must use care to avoid having the pointer dip more deeply than indicated by this criterion, while at the same time he should see that no air space is visible between the tip and the surface. A clean mercury surface will enable the observer to achieve these objectives more readily; for, under these conditions when the contact is exact the tip of the pointer will appear coincident with the image of the tip produced by reflection in the surface. Prior to the final adjustment of the cistern screw the metal sheath of the barometer is tapped in order to assure that the mercury meniscus has assumed a consistent shape (see sec. 2.7.1); then the setting is checked to see that the contact of the tip of the index point with the mercury is correct; otherwise a re-adjustment is necessary. It is recommended that a standard tapping procedure be employed as indicated in secs. 2.4.2, 2.7.1, and 6.5.5.

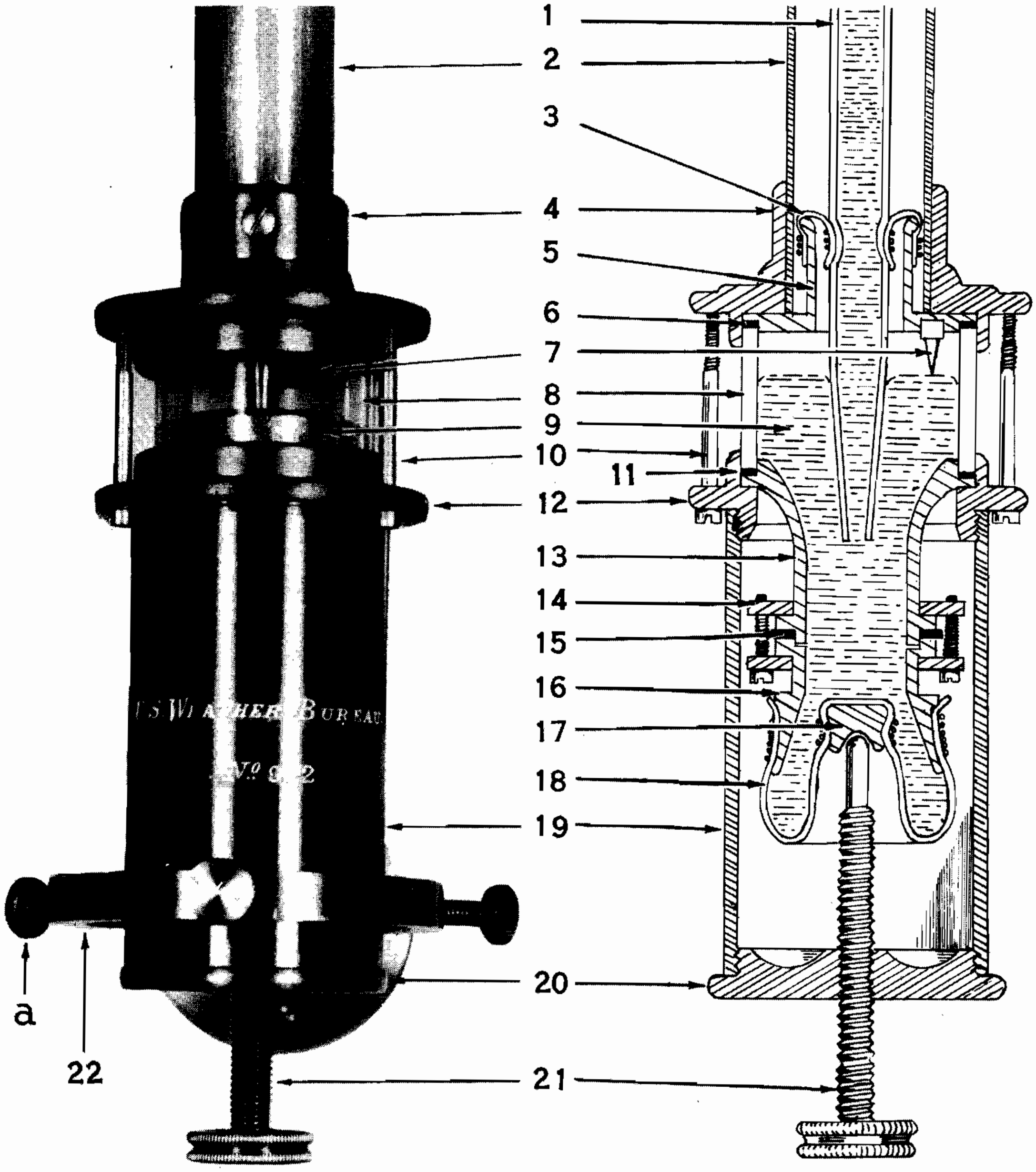


FIGURE 2.5.0. Fortin-type mercurial barometer cistern, showing exterior and cross section views. The parts listed below are identified by number in the illustration.

1. Glass tube
2. Brass casing
3. Leather joint
4. Top flange
5. Flanged cylinder
6. Leather gasket
7. Ivory point
8. Glass cylinder
9. Mercury
10. Long screws
11. Leather gaskets
12. Lower flange
13. Upper curved wooden cylinder
14. Split-ring clamp
15. Leather gasket
16. Lower curved wooden cylinder
17. Wooden bearing
18. Leather bag
19. Cistern housing
20. Screw cap
21. Adjusting screw
22. Centering ring; centering screw (*a*).

The "zero point" represents the zero (starting point) of the scale of the barometer. If the zero point does not just make contact with the mercury, an error results. Also, if the pointer is not properly fixed with reference to the scale of the barometer, an error is present. The latter, called "the index error," is usually thought of as being combined with errors in the graduation of the scale; and the combined error is determined by calibration against a standard barometer. The "correction for scale errors" is the term used for the correction to overcome constant errors from these sources.

Large-bore, Fortin-type barometers are generally used as standard or sub-standard barometers for calibration purposes. When they have a good vacuum and have an accurately graduated scale, they are capable of yielding precise readings, so long as they are maintained under uniform temperature conditions and care is taken with the adjustment of the level of the meniscus in the cistern to the zero point. See Annex A–2.2 for a summary review.

2.6 FIXED-CISTERN TYPE BAROMETER

The fixed-cistern barometer contains a given mass of mercury which, if changed in amount, would make the readings of this instrument unrepresentative. No adjustment of the mercury level in the cistern to the zero of the scale is necessary for this type of instrument. However, the inability to observe the level of the mercury meniscus in the cistern introduces a problem which is solved by using a contracted scale for the barometer, owing to reasons explained below. See figs. 2.6.0—2.6.2.

A condition which must be satisfied for the reliable operation of the fixed-cistern barometer is that the cross-sectional areas of the mercury in the barometer tube and in the cistern must be uniform over the vertical range of movement of the meniscus in the tube and cistern, respectively.

Additional information regarding fixed-cistern barometers is given in sec. A–2.4 which discusses briefly some of the advantages and disadvantages of this type of instrument.

It is obvious that if the volume of the mercury remains constant, a rise of the mercury in the barometer tube will be accompanied by a proportionately smaller fall in the cistern of larger cross-sectional area. In addition, it is clear that the actual increase in height of the mercury column is the sum of the rise in the tube plus the fall in the cistern. Since the total volume of mercury remains constant when the temperature remains unchanged, the increase of volume of mercury in the tube due to a rise in the tube is equal to the decrease of volume of mercury in the cistern due to the corresponding fall. It follows that this equality of volume change leads to the relationship: (rise of mercury in tube, r) × (cross-sectional area of interior of tube, a) = (fall of mercury in cistern, F) × (cross-sectional area of interior of cistern, A).

That is: $ra = FA$,

hence $F = r\frac{a}{A}$.

Now, at constant temperature, the height (R) of the mercury column measured from the top of meniscus in the cistern to the top of meniscus in the barometer tube *after the rise* is equal to the height (R_o) of the column *before the rise plus* the amount of the rise (r) in the tube *plus* the amount of the fall (F) in the cistern.

That is, $R = R_o + r + F$,

and substituting for F from the preceding equation, we get

$$R = R_o + r + r\frac{a}{A}$$

or

$$R = R_o + r\left(1 + \frac{a}{A}\right),$$

which yields

$$R = R_o + r\left(\frac{A + a}{A}\right).$$

Let us take a specific case; namely, the one in which $a/A = 1/50$; then $(A + a)/A = 51/50$. Suppose that in this instance the scale of the barometer is graduated on a contracted basis, so that 51 divisions now have the length occupied by 50 divisions on the original scale. Then if r_c represents the rise as indicated on the contracted scale, it

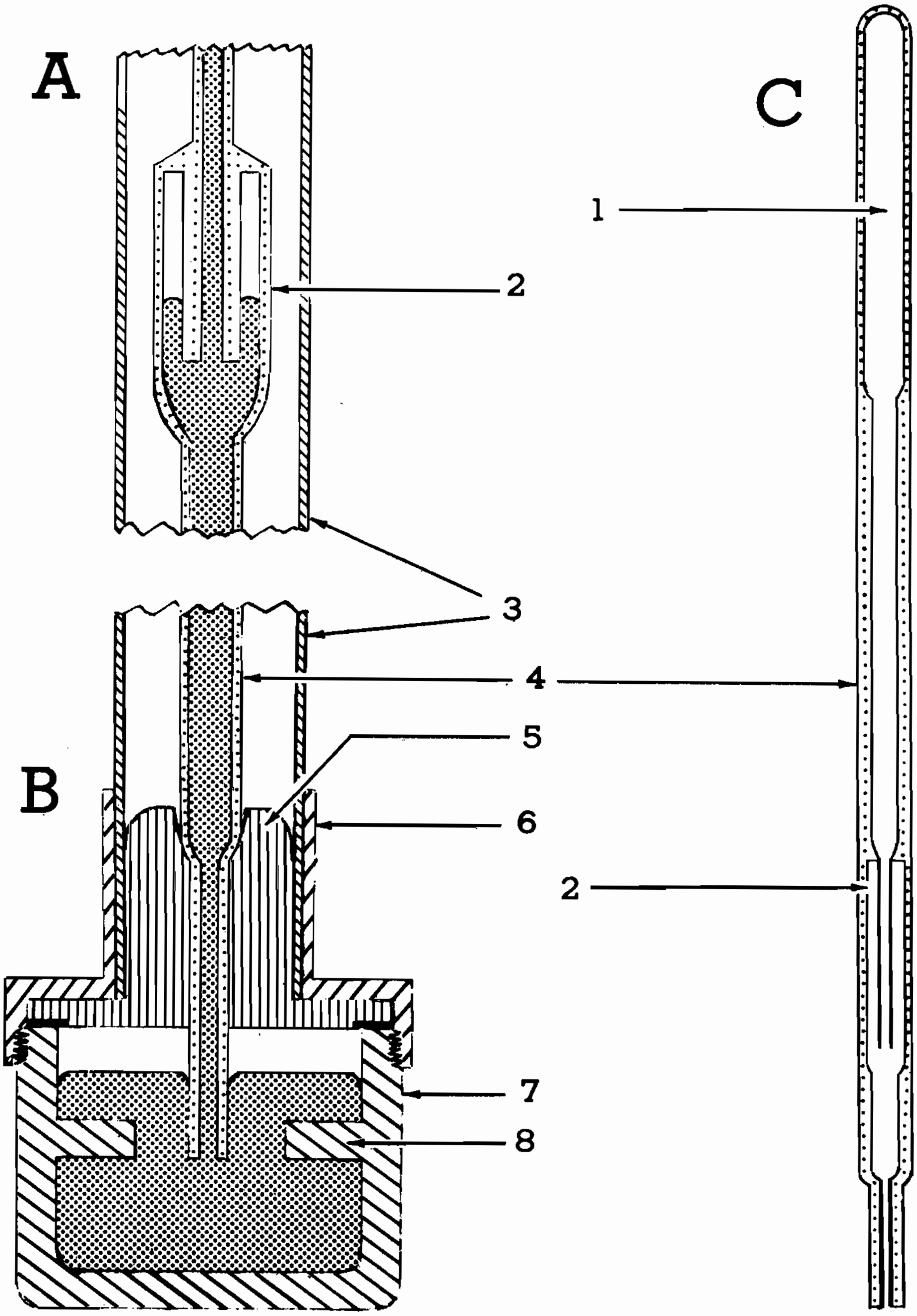


Figure 2.6.0. Cross section of a fixed-cistern barometer: *A*. Enlargement of an air trap. *B*. Enlargement of a cistern. *C*. Glass barometer tube. Integral parts: 1. Upper chamber of uniform bore in which the meniscus of the mercury in the tube moves up or down as the pressure varies, the height of the column being measured to the top of the meniscus. 2. Air trap. 3. Brass tubular shield. 4. Glass mercury tube. 5. Porous boxwood cistern roof. 6. External flange. 7. Mercury cistern. 8. Internal flange to damp out oscillations of mercury when barometer undergoes any accelerations as when carried about or on shipboard.

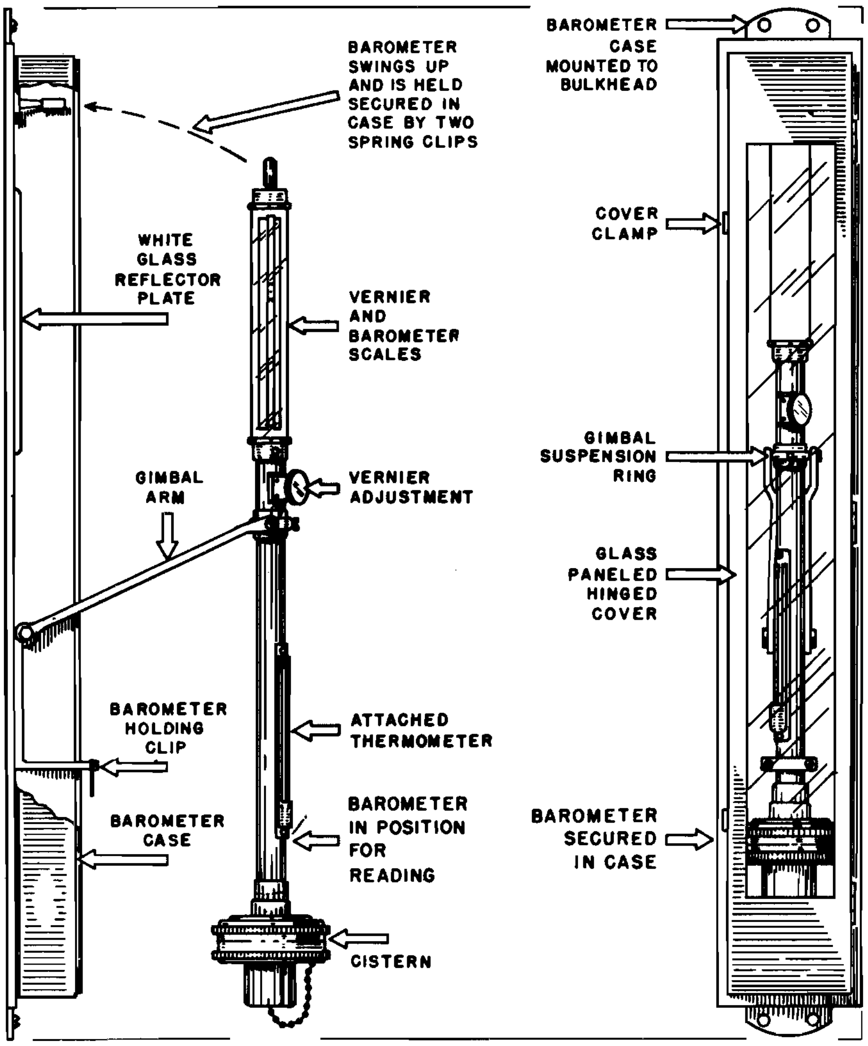


FIGURE 2.6.1. Fixed-cistern barometer showing case and gimbal mounting. Design used by U.S. Navy.

is evident that $r_c = r(51/50)$. Thus, in general, if the contracted scale is graduated in such a manner that

$$r_c = r\left(\frac{A+a}{A}\right),$$

it follows from the preceding equation that

$$R = R_o + r_c.$$

This can be interpreted to signify that if we knew the true height of the mercury column before the rise in the tube (R_o), the true height of the mercury column after the rise in the tube (R) is obtained by adding algebraically to R_o the apparent rise of mercury in the tube (r_c) as observed on the contracted scale, at constant temperature. The same principle applies to a fall of mercury in the tube accompanied by a rise in the cistern, since r_c is then a negative quantity. From the foregoing, the practical reason for use of the contracted scale on the fixed-cistern barometer becomes evident.

The fixed-cistern barometer must be calibrated in the laboratory against a large-bore, high-quality standard barometer. A series of readings is made on both instruments, covering a wide range of pressure at constant temperature. This series yields true heights of the mercury column, R, based on the precise standard readings and values obtained simultaneously of the readings, r_c, of the contracted scale of the fixed-cistern barometer. The exact values of R_o and $(A + a)/A$ are unknown in general, but it is

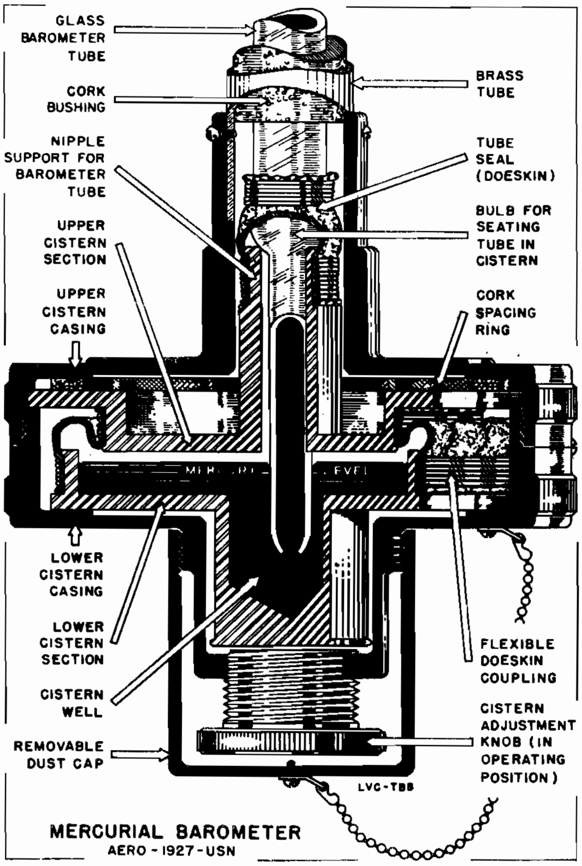


FIGURE 2.6.2. Cutaway view of fixed-cistern of mercurial barometer design used by U.S. Navy.

apparent from the previous equations that if these are constants at the given temperature, we can write the following linear relationship between the readings:

$$R = R_o + kr_c$$

where k = constant (usually very nearly equal to unity). The constant k is introduced to allow for a possible variation of the actual value of the ratio $(A + a)/A$ from the value of the ratio used by the manufacturer in the process of graduating the contracted scale.

From the series of readings of R and r_c at constant temperature, the values of the constants R_o and k pertinent to that temperature may be evaluated in accord with the last equation. In order to provide for the contingency of temperature change, it is necessary to have calibrations consisting of similar sets of readings of R and r_c at various known values of instrumental temperature.

In Chapter 5, sec. 5.3, there is presented a practical procedure for evaluating the temperature correction of fixed-cistern barometers, in which use is made of the Fortin-type barometer temperature-correction tables.

2.7 FACTORS INFLUENCING THE ABSOLUTE ACCURACY OF MERCURY BAROMETERS

2.7.0 Introduction

Mercury and other liquid barometers are affected by a number of elements which govern the absolute accuracy of a given reading. Among these, one may consider errors in the graduating of the scale or its length, including erroneous positioning of the scale with respect to the zero (ivory) point; error in the adjustment of the sighting edge to the zero line of the vernier; error due to capillarity; error due to imperfect vacuum, etc. Generally speaking, the aggregate of these errors is substantially constant, provided the vacuum is of good quality, and hence it is possible to determine a single correction to overcome these instrumental errors by means of a calibration of the given barometer against a standard barometer.

Careful consideration is necessary with regard to the specification of the conditions under which a single correction is valid. Consider the departure of the actual readings of individual scale graduations from the true linear distances of those graduations as would be measured from the zero of the scale on an absolutely accurate linear measuring device. Certain conditions must be satisfied: (1) the mean of those departures over the entire scale must not exceed a small constant index error close to zero; (2) the magnitude of the departures of individual scale graduations as stipulated above must remain within an acceptable small tolerance, which is usually of the order of a fraction of the readability error of the instrument; and (3) the algebraic sum of the errors due to capillarity, imperfect vacuum, and vernier scale imperfections should not vary by more than a small tolerance from an acceptable small constant quantity.

Errors due to temperature and gravity can be corrected on the basis of fundamental considerations (see Ch. 3, 5 and Appendix 1.4.2).

Errors due to friction or failure of the barometer to be truly vertical are more or less variable and may be minimized by observance of good practices. Another source of error lies in "pumping," which is manifested as an oscillating motion of the mercury, usually during periods of strong wind gusts. This phenomenon is also observed in the case of mercurial instruments mounted on shipboard, where oscillating, pitching or rolling movements of the vessel cause difficulties not easy to overcome. In the remainder of section 2.7, general discussions are presented regarding the various sources of error outlined above, and the possible steps which may be taken to avoid or make due allowance for them. Only by such measures may the required absolute accuracy be approached.

2.7.1 Capillarity, Cleanness of Mercury, and Friction

In the following a discussion of introductory character is given first with regard to the basic effects of capillarity and pollution of the mercury on the indications of barometers and manometers containing this liquid. Owing to the needs of observers, the first portion of the treatment of the subject is presented from an operational viewpoint. Mention is made of the apparent influences of "friction" and "stickiness" of the mercury in some instruments, effects which are especially noticeable when the liquid or the glass containing-wall has become fouled. While the observer may employ some remedial measure, such as vibration of the instrument, to overcome these effects, often termed "frictional" in common parlance, the reader is cautioned against holding to the view that they are indeed caused merely by friction between the liquid and the solid containing-wall of the tube or cistern. As a matter of fact, rather involved physical and chemical considerations are required to provide valid explanations in full detail of the causes of the apparent frictional effects, of the forces which determine the "capillary correction" ("capillary depression"), and of the factors which govern the shape and curvature of the head of the mercury column. For these reasons, the more involved technical considerations are deferred for presentation to the latter part of the discussion, which covers certain important theoretical relationships pertaining to capillary effects, surface tensions, etc. For those concerned with the deeper aspects of these subjects, additional information is given in Appendix 2.7.1.

By referring to fig. 2.7.1 the reader may gain a concept of the "capillary depression" (*C*), which is regarded as the "correction for capillarity" made use of in the "Barometer Correction Card," Form WBAN 54-3.3.1. Table 2.7.1 gives indications of how the value of *C* varies with bore of the tube, height of the meniscus, and surface tension of the mercury.

The shape of the meniscus (domed surface of the mercury directed upward) is a result of capillarity. This is manifested at the boundary surfaces of liquids where they make contact with solid walls, and is a phenomenon that depends upon surface tension of the liquid. When the liquid is mercury, the capillary action depresses the level of the top of the mercury surface below what it would be if surface tension were absent. (Note: This is opposite to the action of water in contact with ordinary glass.) While the capillary action is present both in the barometer tube and in the cistern of the mercurial instrument, it will be observed that the effect is much more pronounced in tubes of small diameter than in larger vessels. In tubes whose diameter exceeds one inch, the amount of depression of the level of the top of the mercury surface owing to capillarity is practically negligible.

For present purposes one may focus attention on the force of surface tension which acts on the domed surface of the mercury along the ring where the liquid makes contact with the tube or cistern. This force is directed outward and inclined somewhat downward, depending upon the angle of contact. By resolving this force in the downward direction, one obtains the resultant capillary force which must be taken into account in deducing the atmospheric pressure from the balance of forces opposing it in the barometer. The simplest method of determining the correction for capillarity is by a calibration in which the readings of the given barometer (usually of small bore) are related to the readings of a large bore, standard comparison barometer capable of yielding precise data. One may think of the resultant downward capillary forces as equivalent to the weight of the mercury in the volume extending from the actual surface of the meniscus to the higher level which the upper boundary of the mercury would assume in a horizontal plane if surface tension were absent. The term "capillary depression" is used in referring to the height from the top of the domed surface of the meniscus to the level which the upper mercury boundary would assume in the absence of surface tension. On the other hand, the term "meniscus height," usually denoted by *h*, is employed to represent the height of the apex of the meniscus with reference to the plane of the ring of contact of the mercury with the glass. This ring will be understood to be the circle or curved line on the inside surface of the glass along which the liquid just touches the solid.

Since it is desirable that the correction for capillarity yielded by calibration always be valid, it is important that the capillary depression remain essentially constant. Certain factors operate to cause variations in the capillary depression, hence it is advisable to take steps which will eliminate significant amounts of the variations. From the experimental standpoint of one who observes the barometer meniscus daily, it will be noted that when the pressure rises, the meniscus in the tube at first tends to bulge upward more than before; and when the pressure falls, the reverse is true. That is, there may be a temporary accommodation of shape of the meniscus to the change in pressure which permits mercury to flow from cistern to tube or the reverse, without slipping of the circle along which the liquid surface makes contact with the container.

In order to eliminate these effects, the barometer should be tapped with the fingers before and after every setting. Such tapping is desirable both on the barrel of the barometer near the top of the mercury column in the tube and on the cistern, since friction acts in both places. The effect of the tapping is to overcome friction, allowing the exposed mercury surfaces to slip along the walls of tube and cistern, respectively, and causing the meniscus in each place to assume its normal shape. When the frictional effects are overcome, the correction for capillarity found during calibration should be applicable during the time of the observation.

Another set of factors involved in this connection is the change of cleanness of the mercury and of the walls of the cistern or barometer tube. Thus, an atmosphere which carries pollution into the cistern, especially under moist conditions, may cause the mercury and the cistern to become dirty, and produce a thin film of oxide on the meniscus. The mercury in the cistern then loses its brilliant surface. In some cases, it is possible for the foreign matter to adhere to the tip of the point in the cistern of a Fortin-type barometer. This will impair the reliability of the instrument, for it renders difficult the obtainment of a proper zero setting. The metals lead, tin, and zinc may alloy themselves with the mercury, causing it to become foul. This has the effect of soiling the interior of the cistern and producing a deviation of the density of the liquid from that assumed for clean mercury.

A significant effect of contamination in the mercury is to alter the shape of the meniscus so that instead of being domed upward it may become nearly flat. This is serious, inasmuch as the corrections found for capillarity and scale errors during the calibration under conditions of clean mercury and normal curved meniscus will not be valid after the surface of the meniscus has become relatively flat.

To summarize: capillary depression of the mercury, both in the cistern and tube, is determined by the surface tension and the bore of the tube. Surface tension varies with temperature of the liquid and with the impurities in the liquid, on its surface, and on the walls of the container. The effect of capillarity is normally observed by the height of the meniscus which is usually related to the angle of contact of mercury with container wall, unless accommodation to changing pressure modifies the shape of the meniscus. In order to maintain the validity of the calibration, to overcome friction, and to secure the formation of the most stable meniscus in the cistern and tube, tapping of the barometer before and after each setting is necessary. It should be noted that continued marked deviation of the shape of any meniscus from normal, particularly excessive flattening of the meniscus due to pollution of the mercury, is an indication of the need to have appropriate steps taken regarding the replacement or cleaning of the barometer. For pertinent information on this subject see the Annex, sec. A–2.14. "Effects of Impure Mercury, and Procedures for Cleaning It," and sec. A–2.17.1, "Cleaning of Fortin Barometers."

Gould and Vickers[3] have published very useful tables giving the capillary depression as a function of bore of tube (*D*) and meniscus height (*h*) for three different values of the surface tension (*S*) of mercury. Those tables are reproduced here as figs. 2.7.0(A) and 2.7.0(B).

It should be noted in using the tables that mercury which is exceptionally clean has a surface tension of about 500 dynes per cm. at 20° C., for the case of mercury in a vacuum; whereas mercury which is slightly contaminated has a surface tension of about 400 dynes per cm., also at 20° C.[3] Different values of the surface tension have been cited by various authorities,[4] [5] and a few data for clean mercury in a vacuum are here given: thus, at 25° C., $S = 484$ dynes/cm.; at 50° C., $S = 479$ dynes/cm.; and at 75° C., $S = 474.5$ dynes/cm.

It may be considered with respect to the mercury in the barometer tube assumed to be in a reasonable state of cleanness that the surface tension at ordinary room temperature will be of the order of 450 to 475 dynes per cm., for routine purposes.

Kistemaker[6] has determined in a somewhat indirect manner that mercury at about 18° C., when in contact with *undried air* at atmospheric pressure, indicated an effective surface tension of about 430 dynes/cm.

The data presented in figs. 2.7.0(A) and 2.7.0(B) are useful for obtaining the capillary depression pertinent to mercury manometers and standard U-tube barometers, also for cistern-siphon barometers. However, the capillary correction for regular station Fortin barometers and fixed-cistern barometers is determined by calibrating these instruments by means of a large bore standard barometer which itself has an appropriate correction applied for the capillary depression.

Since mercury tends to become more or less fouled with age when it has a surface exposed to moist atmospheric air which carries a certain amount of pollution, and since the condition of the walls of glass or other containers with which the mercury comes into contact may change in some respects (such as by acquiring a minute deposit of impurity where the mercury meniscus moves over the inner wall or by undergoing some change in regard to the film of substance that it might adsorb), the effective surface tension of the mercury in barometers generally varies with age. This change is doubtless different within the barometer tube than in the cistern. Therefore, the capillary depression of a barometer usually suffers some variation as its service life increases. In addition, the wetting of glass by mercury is not entirely negligible, especially if the mercury becomes fouled. Owing to friction capillary depression depends somewhat upon whether the mercury is rising or falling due to changes in ambient atmospheric pressure. Effects of electrification due to motion of the mercury over glass, and even slight traces of impurities can cause large variations in the surface tension of mercury and, hence, in the capillary depression, especially in small-bore tubes. Likewise, the capillary depression can be greatly reduced by the effect of moisture.[7]

Irregularities in the glass of barometer tubes can cause errors in observations of the meniscus, due to refraction.[7]

Another source of error stems from the fact that the ring of contact of the mercury meniscus in the barometer tube may become

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[3] F. A. Gould and T. Vickers, "Capillary depression in mercury barometers and manometers," Jour. Sci. Instruments, vol. 29, pp. 85–87 (1952). Acknowledgment is due to the authors and to the publishers for their kind permission to reproduce the tables.

[4] C. Kemball, "On the Surface Tension of Mercury," Trans. Faraday Soc., vol. 42, pp. 526–537 (1946).

[5] R. S. Burden, "Surface Tension and the Spreading of Liquids," Cambridge University Press, 2d Edition, (1949).

[6] J. Kistemaker, "On the volumes of mercury menisci and the surface tension of mercury deduced from them," Physica, vol 11, pp. 270–276 (1945).

[7] W. Cawood and H. S. Patterson, "The capillary depression of mercury in cylindrical tubes and some errors of glass manometers," Trans. Faraday Soc., vol. 29, pp. 514–523 (1933).

Bore of tube (mm)	Meniscus height (mm)											Bore of tube (mm)
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	
(Surface tension 400 dynes/cm)												
8	0.054	0.108	0.162	0.214	0.265	0.315	0.363	0.409	0.453	0.494	0.533	8
10	.029	.058	.087	.115	.143	.170	.196	.222	.247	.270	.292	10
16	.006	.011	.016	.022	.027	.032	.037	.042	.047	.052	.056	16
22	.001	.002	.003	.004	.005	.006	.008	.009	.010	.010	.011	22
(Surface tension 450 dynes/cm)												
1	5.2	9.3	12.6									1
2	1.32	2.56	3.65	4.54								2
3	0.573	1.134	1.662	2.149	2.582	2.958	3.263	3.517				3
4	.314	0.623	0.921	1.205	1.471	1.715	1.936	2.131	2.302	2.444	2.563	4
5	0.193	0.384	0.570	0.750	0.923	1.086	1.238	1.378	1.505	1.619	1.720	5
6	.128	.254	.379	.500	.617	0.729	0.836	0.937	1.030	1.117	1.196	6
7	.088	.176	.263	.348	.430	.510	.587	.661	0.730	0.794	0.855	7
8	.063	.126	.189	.250	.310	.368	.424	.478	.530	.579	.625	8
9	.046	.093	.138	.183	.228	.271	.313	.353	.392	.429	.464	9
10	0.035	0.069	0.103	0.137	0.170	0.202	0.234	0.264	0.294	0.322	0.349	10
11	.026	.052	.078	.104	.128	.153	.177	.200	.223	.245	.265	11
12	.020	.040	.059	.079	.098	.117	.135	.153	.170	.187	.203	12
13	.015	.030	.045	.060	.075	.089	.104	.117	.131	.144	.156	13
14	.012	.023	.035	.046	.058	.069	.080	.090	.101	.111	.120	14
15	0.009	0.018	0.027	0.036	0.045	0.053	0.062	0.070	0.078	0.086	0.093	15
16	.007	.014	.021	.028	.035	.041	.048	.054	.060	.067	.072	16
17	.006	.011	.016	.022	.027	.032	.037	.042	.047	.052	.056	17
18	.004	.008	.013	.017	.021	.025	.029	.033	.036	.040	.044	18
19	.003	.006	.010	.013	.016	.019	.022	.026	.028	.031	.034	19
20	0.003	0.005	0.008	0.010	0.013	0.015	0.017	0.020	0.022	0.024	0.026	20
21	.002	.004	.006	.008	.010	.012	.014	.015	.017	.019	.020	21
22	.002	.003	.005	.006	.008	.009	.011	.012	.013	.015	.016	22
(Surface tension 500 dynes/cm)												
8	0.072	0.143	0.215	0.286	0.354	0.421	0.485	0.547	0.607	0.663	0.716	8
10	.040	.080	.120	.159	.197	.235	.272	.308	.342	.375	.407	10
16	.009	.017	.026	.034	.043	.051	.059	.067	.075	.082	.090	16
22	.002	.004	.006	.008	.010	.012	.014	.016	.018	.020	.021	22

FIGURE 2.7.0(a). Capillary depression (C, in mm.), as a function of bore of tube (D) and meniscus height (h), in mm. The depression data given in the body of the table are expressed in mm. of mercury at 20° C. under standard gravity. (Source of data: article by F. A. Gould and T. Vickers, "Capillary depression in mercury barometers and manometers," Jour, Sci. Instruments, vol. *29*, pp. 85–87, (1952). Reprinted by permission.) (Continued in fig. 2.7.0(b).)

Bore of tube (mm)	Meniscus height (mm)										Bore of tube (mm)
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	
(Surface tension 400 dynes/cm)											
8	0.533	0.569	0.603	0.633	0.660	0.684	0.705	0.723	0.737	0.749	8
10	.292	.314	.333	.352	.369	.384	.398	.410	.421	.430	10
16	.056	.060	.065	.068	.072	.076	.079	.082	.084	.086	16
22	.011	.012	.013	.014	.014	.015	.016	.016	.017	.018	22
(Surface tension 450 dynes/cm)											
1											1
2											2
3											3
4	2.563										4
5	1.720	1.807	1.881	1.942							5
6	1.196	1.266	1.329	1.384	1.431	1.470	1.503				6
7	0.855	0.910	0.961	1.006	1.047	1.082	1.112	1.137	1.157		7
8	.625	.668	.708	0.744	0.777	0.807	0.833	0.855	0.874	0.890	8
9	.464	.498	.529	.557	.584	.608	.630	.649	.665	.679	9
10	0.349	0.375	0.399	0.422	0.443	0.462	0.480	0.495	0.509	0.522	10
11	.265	.285	.304	.322	.338	.354	.368	.380	.392	.402	11
12	.203	.218	.233	.247	.260	.272	.283	.293	.303	.311	12
13	.156	.168	.180	.190	.200	.210	.219	.227	.234	.241	13
14	.120	.130	.139	.147	.155	.163	.170	.176	.182	.187	14
15	0.093	0.101	0.108	0.114	0.120	0.126	0.132	0.137	0.141	0.146	15
16	.072	.078	.083	.089	.093	.098	.102	.106	.110	.113	16
17	.056	.061	.065	.069	.073	.076	.080	.083	.086	.088	17
18	.044	.047	.050	.054	.057	.059	.062	.064	.067	.069	18
19	.034	.037	.039	.042	.044	.046	.048	.050	.052	.054	19
20	0.026	0.029	0.030	0.032	0.034	0.036	0.037	0.039	0.040	0.042	20
21	.020	.022	.024	.025	.027	.028	.029	.030	.031	.032	21
22	.016	.017	.018	.020	.021	.022	.023	.024	.024	.025	22
(Surface tension 500 dynes/cm)											
8	0.716	0.766	0.813	0.855	0.894	0.929	0.961	0.989	1.013	1.031	8
10	.407	.436	.464	.491	.517	.542	.563	.582	0.600	0.615	10
16	.090	.097	.104	.110	.116	.122	.128	.133	.138	.142	16
22	.021	.023	.025	.026	.028	.029	.031	.032	.033	.034	22

FIGURE 2.7.0(b). Capillary depression (*C*, in mm.), as a function of bore of tube (*D*) and meniscus height (*h*), in mm. The depression data given in the body of the table are expressed in mm. of mercury at 20° C. under standard gravity. (Source of data: article by F. A. Gould and T. Vickers, "Capillary depression in mercury barometers and manometers," Jour. Sci. Instruments, vol. *29*, pp. 85–87, (1952). Reprinted by permission.)

irregular when the instrument is tapped, thereby causing the meniscus to depart from the ideal and symmetric conditions assumed in the theory on which the tables are based.[8]

Mercury under certain conditions varies in its tendency to stick to the glass containing-wall of the barometer tube or cistern, even if the wall is apparently clean. When the ambient pressure increases, and the mercury rises, the meniscus height (h) may increase due to this adhesive action, thus causing a decrease in the angle of contact and therefore a change in the curvature of the top of the meniscus; whereas when the ambient pressure decreases and the mercury falls, the reverse effects occur.[9] As a consequence of these phenomena, the capillary depression is not a single valued function of meniscus height (h) for a barometer tube of given bore.

It is of interest at this point to consider the forces which tend to resist displacement of the liquid mercury relative to the solid containing-walls (e.g., glass) of the barometer tube or cistern. Although tapping of the barometer has been suggested in the foregoing as a means of overcoming the effects of friction, it should not be inferred that friction is the only or even the predominant force that tends to resist such displacement. One may conceive of a force which has this tendency and acts as though it were analogous to *static friction;* i.e., a force due to friction which acts on one body in contact with another *just before* relative sliding motion between them starts. The force of static friction is normally greater than that of sliding friction, the latter being the force which must be applied to maintain the motion after it has attained a uniform relative velocity (v) and depends upon the value of v. If there is a force analogous to static friction pertaining to the sliding motion of mercury relative to glass, it must have the nature of a viscous resistance or drag, i.e., a force which tends to oppose the sliding motion of a fluid over a solid surface in intimate contact, and which depends upon the viscosity of the fluid. Normally the magnitude of viscous drag of a smooth surface is proportional to the relative velocity when v is sufficiently small; hence one might therefore infer that it should be of null value when $v = 0$. However, when the meniscus changes its shape as an accommodation to pressure variations before the mercury slips vertically over the surface, shearing motion occurs in the liquid a short distance from the solid wall, and yields a viscous drag which is capable of being transmitted to the boundary wall like a frictional force. Without such shearing motion or turbulence in the mercury relative to the wall, it is difficult to see how the resisting force can be of this nature.

By a careful consideration of the phenomena of surface chemistry and physics, it is possible to explain much of the behavior of the menisci in barometers and manometers without any need to invoke forces which are frictional in character, although the reaction of the menisci to varying ambient atmospheric pressures may make it seem plausible that such is the nature of the forces involved. To this end it is necessary to introduce the concept of *interfacial tension* of a solid surface in equilibrium with some other substance, either gaseous or liquid. Interfacial tension must be regarded as equivalent to *"free surface energy";* and it is analogous to surface tension, which is the related concept applied to the surface of a liquid in equilibrium with a gas, usually its own vapor. The interfacial tension therefore is the free surface energy associated with unit area of the interface between the given solid surface and the other substance in equilibrium with the solid, depending on the phase of the substance. Let capital S represent surface tension, or interfacial tension in general; then suitable subscripts (s, g, l,) may be employed to indicate the combination of the phases under consideration, referring to solid, gaseous, and liquid, respectively. Thus, S_{sg} denotes the interfacial tension of a solid surface in equilibrium with a gas (or vapor); and S_{sl} denotes the interfacial tension of a solid surface in equilibrium with a liquid. The foregoing entities are not to be confused with S_{lg} which refers to the surface tension of a liquid in equilibrium with a gaseous substance, which must be specified.

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[8] R. Whytlaw-Gray and N. Teich, "The mercury meniscus in precision measurements on gases," Trans. Faraday Soc., vol. 44, pp. 774–783 (1948).

[9] A. W. Porter, "Capillary ascent or depression of liquids in cylindrical tubes," Trans. Faraday Soc., vol. 29, pp. 702-707 (1933).

The foregoing concepts may be applied to the mercury barometer in the following manner: (a) S_{sl} refers to the interfacial tension between the solid glass containing-wall and the adjoining bulk liquid mercury; (b) S_{sg} pertains to the interfacial tension between the solid wall and the gaseous substance, for example, mercury vapor probably mixed with rarefied air as contained above the meniscus in the tube, or air mixed with mercury vapor as contained above the meniscus in the cistern; and (c) S_{lg} represents the surface tension of the liquid mercury in the meniscus surface, dependent upon the contiguous gaseous substance overlying the meniscus and upon films of adsorbed substances or contaminants that might lie on it.

From an operational point of view the values of S_{sl}, S_{sg}, and S_{lg} should be regarded as the weighted mean values which obtain along a horizontal circle in the immediate vicinity of the ring of contact of the meniscus with the inside glass wall of the barometer tube or cistern, as the case may be. The right-hand portion of fig. 2.7.1 illustrates schematically the sort of contact which exists at a typical mercury in glass meniscus (see also fig. 2.2.5).

Now if one considers as a base of reference the ring or line of contact of the meniscus with the solid wall, such as the tube or cistern, it will be apparent that the interfacial tension S_{sg} is pertinent to the glass *immediately above* the line of contact, where the gas is mercury vapor or air in the case of the barometer; while the interfacial tension S_{sl} is pertinent to the same solid *immediately below* the line of contact where the liquid is mercury. Then, $(S_{sg} - S_{sl})$ is the instantaneous vertical force on the liquid per unit length of line of contact at the boundary wall, due to the indicated interfacial tensions. If there is a film of any substance adsorbed or coated on an area of the boundary wall over which the mercury moves, this can have a strong effect on the values of S_{sg} and S_{sl} pertinent to that area, and in general the film will influence their respective values in *different* degrees, thus affecting their difference.

The effect of changes in the specified difference with vertical position of the ring of contact can be most readily grasped from a consideration of the two following examples, in both of which the mean value of $(S_{sg} - S_{sl})$ at a given initial position of the ring of contact is assumed to be −270 dynes/cm.: in Case (1) the mean value of the difference which applies at a position of the ring 0.01 mm. higher is assumed to be −250 dynes/cm., while in Case (2) the mean value of the difference at the same position is assumed to be −290 dynes/cm.

These negative quantities may be considered as providing the downward component of capillary forces which yield the convex upward meniscus and the capillary depression observed in the mercurial barometer.

Under the conditions of Case (1), the vertical advance of the ring of contact by 0.01 mm. would be attended by the encountering of a weaker downward component than applied at the initial position due to the change in the interfacial tension difference with height in the tube. The effect of this would be like a decrease in frictional force along the surface, if any existed. Thus, in Case (1) the angle of contact of the mercury would more nearly approach 90°, the apex of the meniscus would rise slightly less than the amount (0.01 mm.) by which the ring of contact rose, and both the capillary depression (pertinent "correction for capillarity") and the meniscus height (h) would undergo a decrease.

On the other hand, under the conditions of Case (2), the vertical advance of the ring of contact by 0.01 mm. would find the mercury at the meniscus subjected to a stronger downward component of surface tension force than existed at the initial position. The encountering of such a stronger component would have an effect like that of an increase in frictional force, if any existed. Hence, in Case (2) the angle of contact would depart more than previously from 90°, the apex of the meniscus would rise slightly more than 0.01 mm. which was the vertical displacement of the ring of contact, while both the capillary depression and the meniscus height (h) would show increases.

Considerations similar to those given in the foregoing with respect to cases of advancing menisci may be applied to those of receding menisci.

In order to investigate the causes of this behavior it is necessary to consider the variations of the forces that act on the mercury column due to interfacial tensions, and to ascertain how those forces will determine the angle of contact, depending on the surface tension of the mercury. Although angle of contact A, shown in fig. 2.7.1, seems convenient, it is conventional and advantageous to treat the supplement of angle A, designated here by Θ, where $\Theta = (180° - A)$. It may be observed that Θ represents the angle of contact measured from the solid wall contiguous with the bulk liquid to the tangent to the meniscus extending toward the gaseous substance from the point of contact of the liquid with the solid.

According to the classical theory pertaining to the meniscus (see Appendix 2.7.1) the following equation, referred to hereafter as relationship (i), governs the angle of contact, provided that equilibrium exists between the interfacial and surface tensions that act on the liquid along any element of its line of juncture with the solid where the three phases coexist:

$$(S_{sg} - S_{sl}) = S_{lg} \cos \Theta = -S_{lg} \cos A. \quad \text{(i)}$$

(*Note*: The symbol S, denoting the surface tension of the mercury, is employed later to represent S_{lg} for simplicity; and these two symbols may be used interchangeably.)

When S_{sg} is greater than S_{sl}, the force $(S_{sg} - S_{sl})$ is oriented normal to the juncture line (ring of contact) along the surface of the solid, and is directed toward the portion of the surface where the solid and gas phases are contiguous; while in the case when S_{sg} is less than S_{sl}, the force is in the opposite direction, that is, toward the portion of the surface where the solid and liquid phases are contiguous.

If D denotes the diameter of the ring of contact of the mercury with the circular inside wall of the barometer at the location of the meniscus, then πD is the length of the ring of contact (circumference of the circle), and hence the product $\pi D(S_{sg} - S_{sl})$ represents the *total force* due to surface tensions acting on the liquid at the meniscus in a direction normal to the ring of contact and parallel to the inside wall. It follows that by virtue of the foregoing relationship (i), the same total force is given by the product $\pi D(S_{lg} \cos \Theta)$ when equilibrium exists at the meniscus. In the typical mercury barometer this total force due to capillarity is directed vertically downward, since $(S_{sg} - S_{sl})$ is generally negative owing to the fact that S_{sg} is ordinarily less than S_{sl} for the case where the solid is glass, the liquid is mercury, and the gaseous substance is mercury vapor and air. The effect of this downward force is to produce a *capillary depression* in the mercury barometer; that is, it acts to pull the level of the mercury at the convex meniscus below what it would be if the meniscus were perfectly flat. On the other hand, if one employed pure water in the glass tube, the term $(S_{sg} - S_{sl})$ would be positive, the force would pull the liquid upward, and this would cause the column of water to exhibit a *capillary rise;* that is, the level of the concave water meniscus would be higher than that of a perfectly flat meniscus.

A consideration of the equilibrium relationship, (i) above, reveals that the algebraic sign of the term $(S_{sg} - S_{sl})$ will determine the sign of $\cos \Theta$. As previously pointed out, in the case of mercury in glass as in ordinary barometers the quantity S_{sg} is less than S_{sl}, and therefore $\cos \Theta$ is negative under ordinary conditions; but it is possible to employ such a type of glass (e.g., quartz) and to fill the barometer tube with mercury by such a process (e.g., prolonged distillation or boiling of the liquid) that the value of $\cos \Theta$ is either zero or slightly positive (see sec. A–2.19). It is obvious from trigonometric considerations that when $\cos \Theta$ is negative as it is in field barometers, the value of the angle Θ must lie between 90° and 180°. Experience shows that the value of this angle in the barometer tube consisting of lead glass will normally lie within the range of about 100°–140° (average about 125°) when the bore of the tube is 0.25 inch, although values outside of this range are possible. Since the angle designated by "A" in fig. 2.7.1 is the supplement of Θ, one has $A = (180° - \Theta)$, hence these data imply that the angle A will generally fall within the range from 80° to 40° (average 55°) for this bore. However, it should be noted that if the barometer *is not* tapped the angle will depend upon the type of glass, the impurities, if any, on its inside surface over the working area, the impurities on the meniscus, and the rate of rise or fall of the mercury column.

The surface tension of liquid mercury in equilibrium with its own vapor or with air containing some of that vapor is always positive and generally has a value of about 450–480 dynes/cm. at ordinary room temperature. By virtue of relationship (i) pertaining to equilibrium conditions at the meniscus, one finds that the quantity $\pi D(S_{sg} - S_{sl}) = -\pi DS \cos A$. Therefore when equilibrium exists, the right-hand member of this equation must be recognized as the equivalent of the left-hand member, which, as previously indicated, represents the total force due to capillarity acting vertically on the liquid at the meniscus in the barometer tube. A somewhat similar relationship will apply in the cistern.

While it is difficult to measure the quantities S_{sg} and S_{sl} directly, it is possible to determine their *difference* on the basis of experimental measurements of the capillary depression (or rise) of the ring of contact in the case of a U-tube barometer or manometer, one leg of which has a very large bore and the other a small bore, both of known dimensions. The latter sizes have to be taken into account together with the specific weight of the mercury in computing the difference. In general the quantities S_{sg} and S_{sl} are much larger than S, but the absolute value of their difference is smaller. Under some conditions of barometric operations there may be fairly large changes of S_{sg} relative to S_{sl} or vice versa, and these can have important effects on the accuracy of the data obtained from the instrument. Some concept of the order of magnitude of such changes may be inferred with the aid of relationship (i). For example, suppose that normally the angle A in fig. 2.7.1 is 55°, but further suppose that in a particular case the ring of contact falls on a deposit of impurity within the glass tube such that it causes the angle A to become 80°, under the condition where $S = 475$ dynes/cm. Thus, when $A = 55°$, $\cos A = 0.5736$, and $-S \cos A = -475\ (0.5736)$ dynes/cm., i.e., $(S_{sg} - S_{sl}) = --272.5$ dynes/cm.; but when $A = 80°$, $\cos A = 0.1736$ and $-S \cos A = -475\ (0.1736)$ dynes/cm., i.e., $(S_{sg} - S_{sl}) = -82.5$ dynes/cm. Clearly, the change from -272.5 to -82.5 dynes/cm. represents a relative shift that could affect the results significantly.

Since it is largely the ratio of the differences $(S_{sg} - S_{sl})$ to the bore of the tube, D, which controls the capillary depression (see equations below), it will be principally the variation of that difference which governs the variation of the capillary depression. Since the value of S, i.e.,(S_{lg}), is not likely to vary appreciably within a matter of a few hours or days in the case of normal barometer operations, one may employ relationship (i) as a means of inferring the variations of $(S_{sg} - S_{sl})$, for the cosine of the angle of contact may be regarded as proportional to this difference, the angle being determinable by observation. By virtue of the foregoing considerations the variations of the cosine of the angle of contact may be used as an approximate index of the variations of the capillary depression. Experience shows that the angle of contact varies with the motion of the mercury relative to the glass, and is dependent upon whether the fluid is advancing or receding. It follows logically from these facts that the capillary depression manifests the phenomenon of hysteresis; that is, the capillary depression will not be the same for motion of the meniscus in either direction but will depend upon whether it is upward or downward.

The causes of this hysteresis can be sought in the factors which are capable of producing different (relative) changes or rates of change in the values of S_{sg} and S_{sl}, depending upon the speed and direction of motion of the meniscus with respect to the glass walls. Effects on S_{sg} and S_{sl} of such variations in speed and direction of the meniscus will naturally be determined by the conditions that exist at the interface between the solid and the liquid, and between the solid and the gaseous substances, respectively, in contact within the barometer. It is necessary to envisage these conditions from a microscopic viewpoint, and to consider how they will vary if the mercury advances on the one hand, or recedes on the other.

From this viewpoint the interfaces may be regarded as being covered by numerous thin regions, probably of irregular area and size, in the form of a patchwork such that the chemical constituents in neighboring areas are different. Thus, the interface between the solid glass wall and gaseous substances above the meniscus in the barometer tube may have some areas occupied with a film of air adsorbed on the glass; but other areas may have a film of condensed mercury vapor and some may have a film of adsorbed condensed water vapor (if the mercury or tube contains moisture). However, it is possible for some of the areas to be bare, that is, free of any film, especially if the vacuum in the tube is of excellent quality; although the glass itself in these areas may be covered with foreign chemical impurities. On the other hand, the interface between the solid glass wall and the bulk liquid mercury below the meniscus may have thin regions of diversified composition containing air, water vapor, or chemical impurities. The source of the impurities may be deposits such as those crystallized out of the glass constituents, or oxides produced by the reaction of oxygen with base metals and other materials contained in the mercury. Within the cistern where it is possible for sulfur gases, water vapor, and other pollutants such as gaseous hydrocarbons to enter, the impurities may consist of sulfides and other types of chemical compounds which can have a serious effect on the surface phenomena. As has been shown by Langmuir (see Appendix 2.7.1), a film of adsorbed substance is often only one molecule in thickness; hence it does not require very much mass of such a foreign material in the form of a film to have a profound influence on the capillary properties. From a microscopic point of view the glass surface will have irregularities and inhomogeneities; i.e., portions with more or less roughness, with distinct texture and perhaps composition, which will serve to cause frictional resistance to the motion of the mercury, enhance the effect of the liquid viscosity, and provide microtopographic features (like hills and valleys) that tend to anchor the deposits of foreign chemical impurities, films of adsorbed substances, etc.

On the basis of the foregoing considerations it can be visualized that when the ring of contact of any mercury meniscus advances or recedes it is likely to encounter somewhat different conditions in respect to surface micro-chemistry and -physics. In other words, the configurations and extents of the thin regions occupied (or unoccupied) by the various chemical substances on the interface will not be the same above and below the ring of contact; and moreover the actual physical area, including the surface roughness, will not be equal to the area projected on a circular cylinder. From this standpoint one may envisage that the actions of the meniscus on the chemical substances within the thin regions which it encounters will vary with the direction, speed, and angle of attack of the liquid boundary relative to those regions; while the exact character of the interaction will depend on the chemical composition of the substances involved and the microphysical structure of the surface.

A few examples will suffice to indicate the reasonableness of the foregoing conclusions. Thus, when the meniscus advances upward into the area where glass is exposed, the liquid will engulf any condensed mercury films which it encounters; whereas when it meets films of adsorbed air, it may entrap some, leaving them behind, but it may also sweep some ahead, thereby either removing the film and adding the contents to the air volume already present in the space above the meniscus, or yielding additional film of air to the glass at a higher level. For this reason one might expect that the exposed portion of the glass just left by a receding meniscus will have relatively smaller total areas occupied by films of air than the exposed portion of the glass ahead of an advancing meniscus for which the exposure has been prolonged. Another important contrast occurs with respect to bare spots, for while such regions may be present on the glass above the meniscus contiguous to the vacuum space in the barometer tube, they cannot exist below the level of the meniscus. The situation with regard to foreign chemical impurities is very involved, since some of them may adhere to the meniscus surface and under certain conditions be transferred to the *solid-*

liquid interface, or vice versa, depending on the chemical nature of the substances encountered in the vicinity of the ring of contact.

Again, with regard to the effects of speed of the meniscus relative to the glass wall, it seems likely that in cases where the mercury accelerates (as when slippage occurs following a sharp pressure rise) the advancing meniscus will act to entrap air films more extensively than in cases where the progress is slow and steady.

In addition, thermodynamic factors play a role; e.g., on areas of the tube wall which have suffered marked relative cooling or which have interior scratches there is likely to be greater deposition of condensed vapors than elsewhere.

Now that a number of cases have been cited in support of the view that conditions above and below the meniscus are not the same from a microscopic viewpoint, one can proceed with a consideration of the effect of these matters on the free surface energies at various portions of the interfaces. The free surface energy associated with any element of area within an interface will largely depend upon the pair of chemical constituents which face one another and coexist on the opposite sides of the element; e.g., glass versus condensed mercury vapor, air versus bulk liquid mercury, admixed air and mercury vapor versus glass or mercury liquid, etc.

Thus, the existing temperature and pressure together with the chemical composition of the pair of constituents which face on any such area will determine the interfacial tension pertinent to the area. Accordingly, across a boundary (juncture line) between two such areas having different constituents within any interfacial surface, such as along the inside glass wall of the tube, there will be associated a definite difference of interfacial tension. At a common point of intersection of three areas having different constituents there will be associated three sets of differences of surface tension or interfacial tension, depending on the direction chosen. Along the ring of contact of the meniscus one finds three interfaces which meet on this common line of juncture; and therefore one will have three sets of differences of surface tension or interfacial tension normal to this line, depending on the pairs of interfaces considered.

In connection with the problem of providing a physical explanation of the capillary depression and its hysteresis, the direction of most immediate interest is the vertical, particularly with regard to the determination of the relevant interfacial tension difference. To this end especial attention must be given to the differences in interfacial tension that would be found along short vertical line segments lying on the inside surface of the glass wall and cutting across the ring of contact of the meniscus. One might envisage that for every infinitesimal element of the ring of contact there will exist a corresponding difference $(S_{sg} - S_{sl})$ as measured along the line segment passing vertically through the center of the element.

When the mercury in the vicinity of an advancing or receding meniscus moves over a film of some foreign substance adsorbed or deposited on the solid (glass) surface, the interfacial tension of the film relative to the mercury may be regarded as a force acting in a direction opposite to that of the motion of the mercury whereas the interfacial tension of the solid relative to the film may be considered as a force acting in the reverse direction, tending to resist removal of the film due to the reaction. The behavior of the film subjected to the action of the contending forces, that is, whether it will remain adhering to the solid or become adsorbed on the liquid surface sliding over the boundary wall, depends largely on the relative magnitudes of the two interfacial tensions specified. When the conditions are such that the film is removed by the moving mercury, this requires the expenditure of work ("work of adhesion"), from which there results a commensurate upward or downward force which acts to resist the motion of the mercury. Thus, in cases where the film is not equally distributed all around the line of contact of the meniscus, the force under consideration will not be uniform along this line, and therefore the line itself may become somewhat irregular instead of forming a perfect horizontal circle in the vertical tube (or cistern). On this basis it can be seen that the tapping of a barometer to secure equilibrium conditions at the menisci will sometimes induce the removal of a film from either the solid or the liquid interface owing to the effects of the motion of the mercury under the existing interfacial tension differences; and in some cases a meniscus subjected to such action will depart from its previous shape, perhaps becoming less rather than more symmetrical, showing a wavy line of contact, as sometimes happens when the instrument is vibrated or jarred. Under these circumstances the departure of the line of contact from a perfect ring cannot be entirely attributed to differences in friction (or viscous drag) along the line.

Sometimes there exists a thin layer of air from a bubble clinging to the inside glass wall of the barometer tube or cistern; and under some conditions it may be dislodged or suffer slippage, as favored by the motion of mercury. In this manner the air may sometimes rise to the top of the mercury. Depending on the changes in ambient pressure, the responding movement of the mercury meniscus over the glass surface at varying speeds will give rise to different rates of entrapment of air or sweeping action, as the case may be. Thus, irregularities may develop with respect to the configuration of the ring of contact and to the chemical nature of the materials lying on either side of it.

By virtue of the foregoing considerations it is to be expected that the value of the difference $(S_{sg} - S_{sl})$ will vary with position on the inside wall of the barometer tube or cistern, particularly as affected by the vertical and horizontal distributions of the patchwork of thin regions or films, depending upon their composition. One may summarize the reasons for these distributions as follows: Microscopic irregularities and chemical inhomogeneities will often exist on the inside of the glass wall; and these will offer certain areas favorable or unfavorable in different degrees for the adsorption of various substances, such as air, water vapor, oxides or sulfides of chemical impurities, etc. Adsorbed molecules on the surface of the glass will have characteristic mobilities, depending mainly upon their chemical constitution and upon that of the underlying surface, as well as on the temperature. In other words, the molecules of some substances can move over the surface with more or less facility and speed if they encounter favorable conditions, and they must finally come to equilibrium. In this manner, the concentrations of such substances are capable of varying with location of the area on the glass, depending on the distribution of the temperature of the latter, and the other relevant factors. While most often the thickness of film thus adsorbed is only that of one molecule, such an amount is sufficient to have a most significant effect on the value of the difference $(S_{sg} - S_{sl})$ pertinent to the line of contact on the given area.

Most profound changes in the difference $(S_{sg} - S_{sl})$ and in the capillary depression are manifested when the ring of contact, usually in the cistern but sometimes in the tube, moves onto or off of an area of the glass wall where chemical impurities have become coated to a significant degree; e.g., due to adhesion of a film of oxide or sulfide of metals, whose source is generally atmospheric pollution or substances originally contained as amalgams in the mercury. The range of types of pollutants which may reach the interior of the cistern is relatively large in some regions, especially those having heavy exhausts attended by high moisture contents, as from industrial sources. Under these circumstances, the chemical composition of the deposits on the glass can have an important effect on the interfacial tension difference and hence on the related capillary depression.

Hysteresis of the angle of contact as manifested by a change in the angle with change in direction of motion of the mercury meniscus may be regarded as due primarily to the variation in the value of $(S_{sg} - S_{sl})$ with this direction, depending upon whether the meniscus is advancing or retreating. It appears probable that the hysteresis is affected to a lesser extent by changes in the direction of the viscous drag on the mercury and by microscopic changes in the roughness of the surface over which the meniscus moves, whether up or down. One may infer from relationship (i) that hysteresis of the angle of contact is generally associated with hysteresis of the capillary depression; and thus the variation of $\cos \Theta$ (or $\cos A$) with direc-

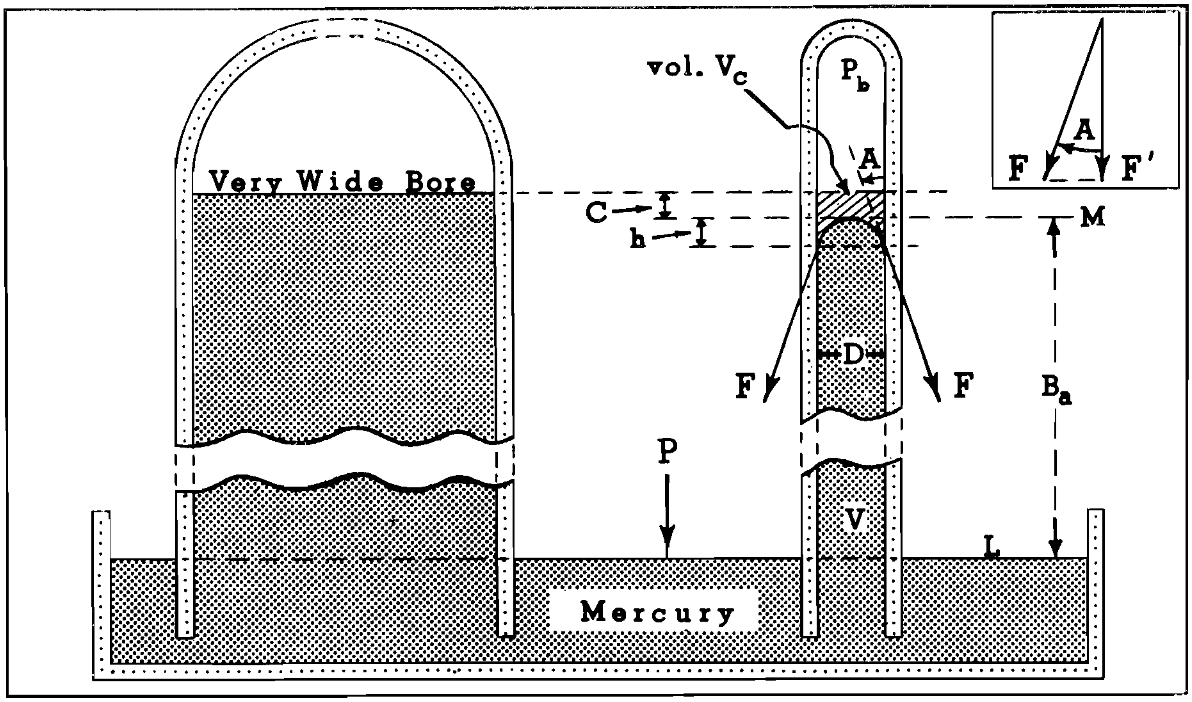

FIGURE 2.7.1. Capillary depression of column of mercury in barometer tube

$$F = \pi DS \tag{1}$$

$$F' = \pi DS \cos A = \rho V_c g \tag{2}$$

$$P_b \pi D^2/4 + \rho V g + \pi DS \cos A = P\pi D^2/4 \tag{3}$$

$$P_b \pi D^2/4 + (B_a + C)\ (\rho g \pi D^2/4) = P\pi D^2/4 \tag{4}$$

$$P_b + (B_a + C)\ \rho g = P \tag{5}$$

C = capillary depression, cm.; linear amount by which the summit of mercury column is depressed purely by capillary forces due to surface tension acting at the mercury meniscus

h = meniscus height, cm.; vertical distance from summit of meniscus to plane of ring of contact

B_a = actual height of column of mercury, cm.; vertical distance from surface of mercury in cistern to summit of meniscus

P_b = back pressure in vacuum space due to residual gases and mercury vapor, dynes/cm.^{2}

V = volume of mercury in tube above surface of mercury in cistern, cm.^{3}

V_c = volume of mercury equivalent to capillary depression, cm.^{3}

F = force exerted by surface tension S along ring of contact, dynes, where F is understood to be tangential to surface of mercury

F' = downward component of F, dynes
P = atmospheric pressure, dynes/cm.^{2}
g = acceleration of gravity, cm./sec.^{2}
ρ = density of mercury, grams/cm.^{3}

D = inside diameter of barometer tube, cm.
S = S_{lg} = surface tension of mercury in equilibrium with the gaseous substance overlying the liquid in the closed tube, dynes/cm.
A = angle of contact = $(180° - \theta)$. See text, eq. (i).

tion of motion of the meniscus or with time is most often a reflection of a corresponding variation in the pertinent capillary depression or correction.

Fig. 2.7.1 is designed to show some of the main principles and relationships involved in the capillary depression of mercury. It is possible to measure the capillary depression pertaining to a given barometer tube by comparing the height to which the mercury rises in that tube with the height to which the mercury would rise in a tube of very wide bore (for example, having one and one-half inches inside diameter or more), provided that the back pressure in the space above the menisci is brought to a very low value by means of a vacuum pump and that both heights are measured with the aid of a highly precise scale with negligible error. The capillary depression thus measured is designated by C in fig. 2.7.1. In the small bore barometer tube the meniscus makes an angle denoted by A, and therefore the surface tension of the mercury on glass, S, acting on the ring of circumference πD produces a force F inclined at the indicated angle to the wall of the tube. (See equation (1) and the inset figure in the upper right-hand corner.) The vertical downward component of F, designated by F', is given by equation (2). This relationship shows that F' is equivalent to the weight of the mercury whose volume is indicated by V_c, which is the volume of the space above the meniscus in the small-bore tube to the level of mercury in the wide-bore tube, provided that the back pressure is negligible. Equation (3) indicates the condition determined by equilibrium of all dynamical forces involved. Thus, on the left-hand side of equation (3) the first term shows the downward force due to the back pressure; the second term shows the weight of mercury in the small-bore tube; and the third term indicates the downward component of the force due to the surface tension; while on the right-hand side the balancing force due to atmospheric pressure acting on the surface of the mercury in the cistern is given.

Equation (4) indicates the balance of dynamical forces pertaining to the wide-bore tube, in which case the meniscus is so nearly flat that the angle of contact A for this tube is practically 90 degrees; hence, the cosine factor is essentially zero and is absent from equation (4). In other words, $F' =$ zero (0), with respect to the wide-bore tube shown. Finally, equation (5) which stems from equation (4) indicates how the capillary correction (C) applies.

It is proved in works on surface tension[10] that in the case of a single curved surface (such as a meniscus, a liquid drop, or an air bubble in a liquid) existing as an interface between two phases (e.g., between liquid and vapor) there is established a difference of pressure between the two sides of the interface. The effect of the free surface energy due to the forces of interaction between the molecules involved in the system encompassing the interface is to produce an excess of pressure on the concave side of the interface. This is commonly attributed to the effect of surface tension. If the principal radii of curvature of the interface surface are denoted by r_1 and r_2, it has been demonstrated[10] that the excess of pressure on the concave side due to the above-specified effect is given by the equation

$$\text{pressure excess} = S(1/r_1 + 1/r_2),$$

where $S =$ surface tension between the liquid and the gaseous substances overlying its surface.

Suppose that the meniscus is symmetric about a vertical axis, and represents a surface of revolution. Then for such a surface r_1 and r_2 are equal and have a common value, say b, which denotes the radius of curvature of the apex portion of the meniscus. Under this condition the excess pressure on the concave side owing to the free surface energy is expressed by the quantity $2S/b$. As may be seen from fig. 2.7.1, the pressure immediately below the meniscus in the small-bore tube is equal to $(P - \rho g B_a)$; while the pressure immediately above the meniscus is P_b. By virtue of the excess pressure on the concave side as specified above, it follows that

$$(P - \rho g B_a) - P_b = 2S/b.$$

Therefore,

$$(P - P_b) = 2S/b + \rho g B_a.$$

By substituting equation (5) of fig. 2.7.1 in the last expression, it is easily found that

$$C = 2S/\rho g b.$$

At this stage it is of interest to contemplate an experiment different from the one depicted in fig. 2.7.1; namely, an experiment involving a sealed glass bell jar on whose base plate there rests a deep wide dish of mercury from which there emerges a vertically held tube of small bore, open at both upper and lower ends. Let it be supposed that

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[10] F. H. Newman and V. H. L. Searle, "The General Properties of Matter," Fifth Edition, London, Edward Arnold (Publishers) Ltd., 1957.

the gaseous substance under the bell jar consists exclusively of mercury vapor in equilibrium with the liquid mercury, so that air and other foreign gases or vapors are kept out. Under these conditions the density of the mercury vapor is proportional to the saturation vapor pressure of the mercury at the given temperature and inversely proportional to the absolute temperature. Let the density of the mercury liquid be denoted by ρ, and the density of the mercury vapor by ρ'. In this case, S represents the surface tension of the liquid mercury at an interface above which lies the saturated vapor in equilibrium with the liquid. Now the meniscus in the tube will exhibit a depression with reference to the prevailing level of the mercury surface in the dish. If C denotes the capillary depression of the top of the meniscus with respect to this level, it may be shown by reasoning similar to that presented above that

$$C = 2S/(\rho - \rho')gb$$

where b is the radius of curvature of the concave side of the apex portion of the meniscus.

It is convenient to introduce the parameter termed the "capillary constant," denoted by a, and defined for the experiment last described, by the expression

$$a^2 = 2S/(\rho - \rho')g.$$

However, in the experiment depicted in fig. 2.7.1, it would be proper to define the "capillary constant" by the expression

$$a^2 = 2S/\rho g.$$

Thus, in the case of either experiment,

$$C = a^2/b.$$

Blaisdell[11] has performed a set of calculations based on the theory of capillary depressions and has published convenient extensive tables giving the dimensionless quantity (C/a) as a function of the two dimensionless variables $(D/2a)$ and (h/a), where D = inside diameter of the tube and h = meniscus height. With the aid of these tables, if a, D, and h are known, one can ascertain C within the range covered by the tabulated data.

Somewhat similar calculations were performed many years earlier by Bashforth and Adams[12] covering the range of data pertinent to tubes of smaller bore than covered by Blaisdell.

The capillary depression data compiled by Gould and Vickers[3] were based on the theoretical calculations of Blaisdell;[11] and Bashforth and Adams.[12] See figs. 2.7.0(A) and 2.7.0(B).

In the foregoing discussion most of the considerations dealt with barometers and manometers whose mercury is in a reasonable state of cleanness. It is of interest, also, to consider the effect of fouling of the mercury which is more serious in the case of the fixed-cistern barometer than in that of the Fortin barometer. This is more or less exemplified in fig. 2.7.2. From this diagram one sees that when the mercury in the cistern becomes fouled, the meniscus in the cistern tends to be flatter (as *L'L'*) than when it was clean (as *ABC-DEF*), and there is more mercury contained within the cistern, at the same temperature and ambient pressure, when it is badly fouled than when it was clean. Therefore, the level of the meniscus M' in the fouled condition is apparently lower than the level of the meniscus M in the clean condition even though the temperature and pressure are the same in the two cases. This change between M and M' does not reflect precisely the change in height of the mercury column from h_c in the clean case to h_f in the fouled case. This is one of the difficulties with the fixed-cistern barometer. On the other hand, with regard to the Fortin barometer, it is possible to observe the mercury in the cistern and to adjust the level of the mercury meniscus to the ivory point, thus taking account, in large measure at least, of the condition of the mercury, although the capillary depression may be different than when the mercury was clean. Finally, if the mercury is observed to be fouled, this indicates the need for cleaning or replacing the instrument.

The causes of fouling of the mercury in barometers is due to at least several causes, including: (a) deposit of pollutants from the atmosphere on the mercury surface; (b) oxidation of the mercury where exposed to air; (c) formation of amalgams by the solu-

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[11] B. E. Blaisdell, "The Physical Properties of Fluid Interfaces of Large Radius of Curvature," Journal of Mathematics and Physics, vol. 19, pp. 186–245 (1940), Cambridge, Mass.

[12] Bashforth and Adams, "Capillary Action," Cambridge (1883).

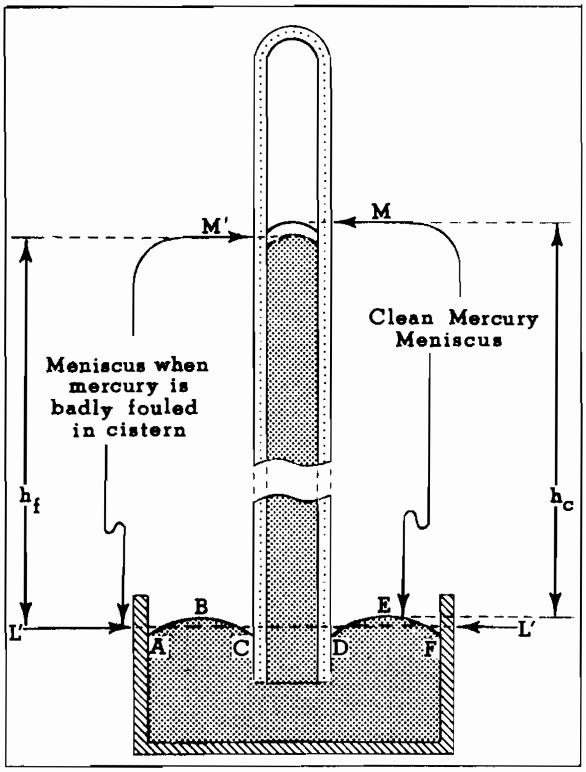

FIGURE 2.7.2. Decrease in readings of a fixed-cistern barometer as a result of fouling of mercury in cistern. (Temperature of instrument and atmospheric pressure assumed constant.) h_c = height of column with clean mercury; h_f = height of column after mercury is fouled.

tion of metals transported to the mercury as a result of deposit of pollution containing such substances; (d) formation of amalgams wherever the mercury dissolves metal constituents of the glass or other materials with which the mercury comes into contact; (e) formation of foreign compounds on the surfaces of the mercury and exposed glass cistern owing to the chemical interactions with gases, water vapor, and other substances which enter the cistern (e.g., the combination of sulfur containing materials or gases, base metals, and water vapor is particularly effective to produce fouling); (f) release of water vapor and/or air bubbles from the inner walls of the glass tube where they have been lodged, thus permitting the contents to react with the mercury and any substances held in suspension or deposited within the system; and (g) effects of electrical discharges within the barometer tube. With respect to the last item, it has been found that when mercury moves over (at least some) glass surfaces electrification is produced, especially if the mercury is agitated, which might be the case when the barometer "pumps" owing to the influence of vibrations and pressure changes within the structure due to strong wind gusts.[13]

The electrical conductivity of the glass, and the nature and concentration of the impurities within the mercury or deposited on the inner walls of the glass have a profound effect in modifying the degree and extent of electrification due to separation of opposite charges in barometers. It is believed that if the tube is a poor electrical conductor, more of such separation of opposite electrical charges can occur, leading to a greater frequency and intensity of electrical discharges in the tube, with the adverse consequence that there is likely to be more fouling in such a case than if the tube had been a good electrical conductor.

Fouling of the mercury and changes in the angle of contact which occur as the mercury meniscus accommodates to variations in ambient atmospheric pressure are capable of producing very significant alterations in the effective capillary constant (a). In support of this conclusion, laboratory investigations have revealed that the capillary constant of mercury is not always the same, and that a spread over values from 5 to 10 percent apart can occur in regard to this parameter for a given instrument, with a corresponding variation of about 40 percent in the capillary depression, as shown by Kistemaker.[14] The latter investigator has developed a laboratory method of determining the capillary constant pertaining to any given manometer, which appears to be capable of yielding results within a fairly close degree of approximation.[14]

Tables published by Blaisdell,[11] and Bashforth and Adams[12] may then be employed to ascertain the capillary depression corresponding to any value of the capillary constant (a) thus determined experimentally. This involves matters of considerable importance in precision manometry.[8] [14] However-

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[13] E. N. Da C. Andrade, "Barometric Light," Encyclopaedia Britannica, 14th Edition, vol. 3, p. 129 (1929).

[14] J. Kistemaker, "The capillary depression of mercury and high precision manometry," Physica, vol. 11, pp. 277–286 (1945).

ever, in the case of U-tube barometers, including the cistern-siphon type (see the Annex of Chapter 2), it is not generally feasible to determine the capillary constant (a) as proposed by Kistemaker; hence, one must employ tables of the capillary depression such as those given in figs. 2.7.0(a) and 2.7.0(b). It is important to note that in connection with U-tube manometers and barometers, the capillary depression (C) pertaining to the two menisci must be applied with proper regard to algebraic signs; thus, suppose the upper meniscus has a measured height of H units above the lower meniscus, then the capillary depression pertinent to the upper meniscus must be added to H, while the capillary depression pertinent to the lower meniscus must be subtracted in order to determine the proper result.

2.7.2 Verticality

It is essential that the mercurial barometer be suspended vertically. If the barometer does not hang plumb when a reading is made, errors occur in the data. One source of error is common to the fixed-cistern and the Fortin-type barometers, when not vertical, and this arises because the observed reading, being on a slant, is not the same as the vertical distance between horizontal planes tangent to the top of the meniscus in the barometer tube and in the cistern, respectively. In particular, if the long axis of the barometer tube deviates from the vertical by an angle A when the observed reading of the barometer is r, the correction to overcome this error is $-r(1 - \cos A)$. As an example, if the observed reading, r, were 30 inches when the angle A was 0.5° ($\cos 0.5° = 0.9999619$), the correction necessary would be $-30(1 - 0.9999619) = -0.0011$ inch (equivalent to about -0.037 mb.). If the angle A was 1.0° ($\cos 1.0° = 0.9998477$), the correction necessary would be $-30(1 - 0.9998477) = -0.0046$ inch (equivalent to about -0.16 mb.).

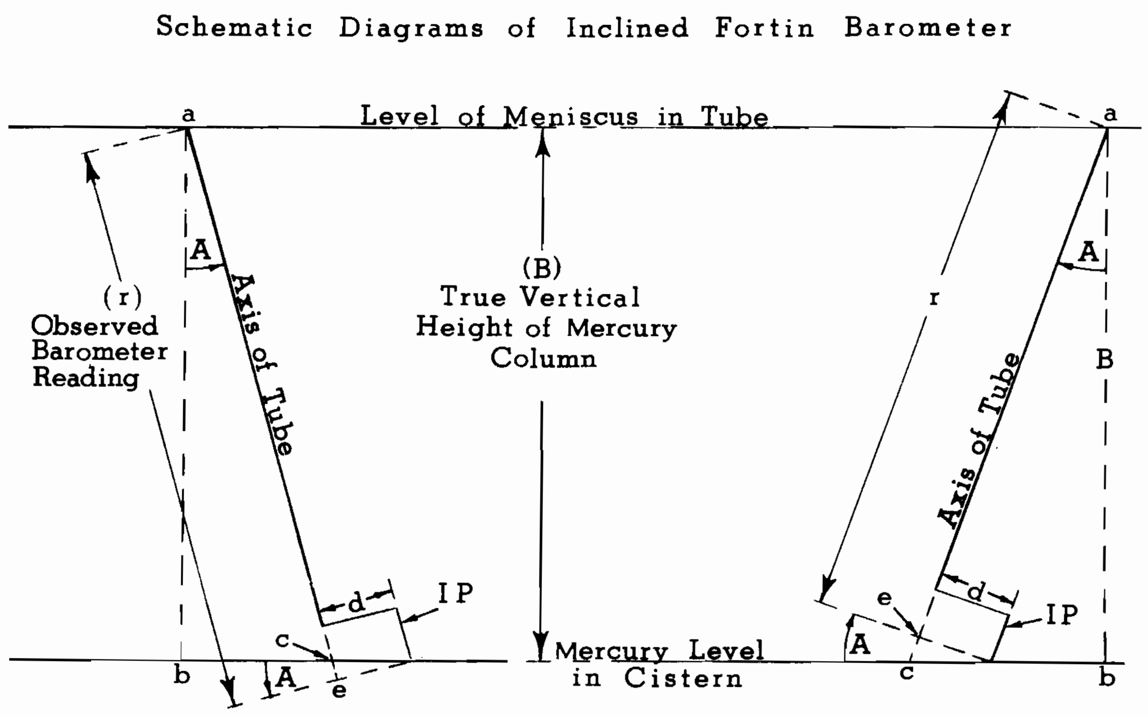
The Fortin-type barometer is subject to another source of error when out of plumb. This arises from the fact that the index point (zero point, or ivory point) is not aligned on the axis of the barometer tube (see fig. 2.7.3). Let the distance of the index point be represented by d. Suppose the barometer were pulled away from the vertical towards the index point until the angle of deviation were A. Then, an additional correction amounting to $-d \sin A$ would have to be applied to overcome the error connected with the eccentricity of the index point when the barometer is out of plumb; and the total correction is as follows:

$$-r(1 - \cos A) - d \sin A.$$

To contrast with this, if we suppose the barometer to be pulled from the vertical towards a direction on the opposite side of the index point, the additional correction is $+d \sin A$, yielding a total correction of $-r(1 - \cos A) + d \sin A$. As examples, suppose $d = 0.5$ inch, with $A = 0.5°$, then $d \sin A = 0.5''(0.0087265) = 0.0044$ inch (0.15 mb.); and with $A = 1.0°$, $d \sin A = 0.5''(0.0174524) = 0.0087$ inch (0.30 mb.).

Fig. 2.7.3 illustrates the two possible cases where the ivory point lies in the same vertical plane as the vertical line (ab) and the axis of the barometer tube (ae) when the instrument is displaced to either side. The formulas for the corrections in the two cases are given by equations (4) in fig. 2.7.3, where the correction compensates for the error due to the inclination, under the assumption that the point designated by "a" in the figure lies at the intersection of the axis of the barometer tube and the observer's line of sight when observing the meniscus in the tube. An additional error, not taken into account, arises owing to the fact that the point where the observer's line of sight is tangent to the meniscus in the tube may not be at the same level as the point where a horizontal plane would be tangent to the meniscus. In such an event the point designated by "a" in fig. 2.7.3 would not necessarily represent the two points described in the previous sentence; and there would be some additional effect due to change of the capillarity correction from that appropriate in the case where the barometer tube is vertical.

Considering the various possible orientations of the barometer tube when displaced from the vertical, it may be seen that if the displacement is at right angles to the plane depicted in fig. 2.7.3, the error due to the



(1) $\overline{ce} = d \cdot \tan A = d \cdot \sin A / \cos A$

(2) $\dfrac{B}{\cos A} = \overline{ac} = r - \overline{ce}$	(2) $\dfrac{B}{\cos A} = \overline{ac} = r + \overline{ce}$

Substituting (1) in (2), we get

(3) $B = r \cdot \cos A - d \cdot \sin A$	(3) $B = r \cdot \cos A + d \cdot \sin A$
(4) Correction $= (B - r)$ $= -r(1 - \cos A) - d \cdot \sin A$	(4) Correction $= (B - r)$ $= -r(1 - \cos A) + d \cdot \sin A$

FIGURE 2.7.3. Correction $(B - r)$ necessary to apply to Fortin barometer reading r in order to compensate for the effect of lack of verticality when the ivory point is off the axis $\overline{ae}$ in plane of the diagram; where $\overline{ae}$ is axis of barometer tube and IP is ivory point.

off-center location of the index point, viz $\pm d \sin A$, would be virtually eliminated. Therefore, if it is necessary to consider readings from a Fortin-type barometer pulled away from vertical, preference should be given to those readings which obtain when the deflections of the index point are at right angles to the plane passing through the center lines.

If the barometer hangs freely so that its movements are limited by a ring support surrounding the cistern and the barometer swings to and fro, it is necessary at time of observation to steady the instrument by holding the cistern against the ring support in a direction at right angles to the abovementioned plane.

Modern ring supports come equipped with centering screws. These screws should be carefully screwed up so as to gently clamp the barometer cistern when the barometer hangs in a true vertical position. In order to test the verticality, the cistern should be adjusted so that the index point just makes contact with the surface of the mercury, and the barometer should be rotated. If the contact remains the same throughout a rotation, the plumbness of the instrument is verified.

2.7.3 Imperfect Vacuum

Back pressure on the meniscus in the barometer tube is small and practically negligible if due only to mercury vapor (see sec. 2.4.1). However, if water vapor, air, or other gases are trapped in the space above the meniscus, giving an imperfect vacuum, the back pressure may be significant (see fig. 2.7.4). It does not take much water vapor to have a serious effect, since it may condense when compressed in the space, thus yielding liquid water. It will be clear that this occurs owing to the rise of the mercury in the tube as the atmospheric pressure increases. When condensation occurs, equilibrium between the liquid water and its vapor yields the saturation vapor pressure (see fig. 2.7.4 B). Inasmuch as this increases rapidly with temperature, it can produce an important error (see Table 7.6.1). Air trapped in the space also increases in pressure with increase in temperature. Errors from these causes are difficult to correct, and hence mercurial barometers which have significant amounts of water vapor and air contained in the barometer tube are unsatisfactory for giving precise indications of pressure. Owing to these reasons, special precautions are necessary when handling these barometers, to prevent water vapor and air from getting up the tube. If a very small amount of air and water vapor (insufficient to condense) is present in the space above the mercury in the barometer tube, a correction for the back pressure which it exerts is usually determined by calibration in the laboratory at room temperature. It follows that under these conditions the effect of the slightly imperfect vacuum may be allowed for, provided that the subsequent deviations of instrument temperature from the laboratory room temperature are not large.

The effects on the back pressure of a significant amount of foreign gaseous substances in the space above the mercury meniscus in the barometer tube can be calculated by means of the gas laws. Thus, if one assumes the perfect gas law as applied to a single component, unsaturated gas, the back pressure will be directly proportional to the product of the absolute temperature and the mass of the gas entrapped in the space, while it will be inversely proportional to the volume of the gas (see the fifth paragraph of Appendix 7.1). An ascent of mercury in the tube will reduce the volume, thereby causing an increase in the back pressure, as may be seen from Diagram (A) in fig. 2.7.4, which illustrates this effect for various assumed constant temperature conditions, provided that the gas remains unsaturated. In cases where new quantities of gaseous substances are released from along the inner walls of the barometer tube and rise to the top of the mercury, they add to the mass of entrapped gas and therefore will produce a proportionate increase in the back pressure. This fact helps to explain how some mercury barometers over a course of years develop a need for more and more positive corrections to overcome this effect, if they suffer from such release of gaseous materials, usually in the form of small bubbles.

By referring to fig. 2.7.4, the reader may readily determine the seriousness of the influence of an imperfect vacuum on the absolute accuracy of a mercury barometer. Diagram (A) of the figure shows that even though the error due to imperfect vacuum may be, say, about 0.2 mb. at a barometer reading of 27 inches, the error may attain to about 0.4 mb. at a reading of 31 inches, owing to the compression of dry air or unsaturated air which is assumed to be present in the upper portion of the tube.

Diagram (B) of fig. 2.7.4 is designed to show the effect of water vapor when contained in the vacuum space and compressed to such a degree that condensation occurs, under the assumption that the temperature

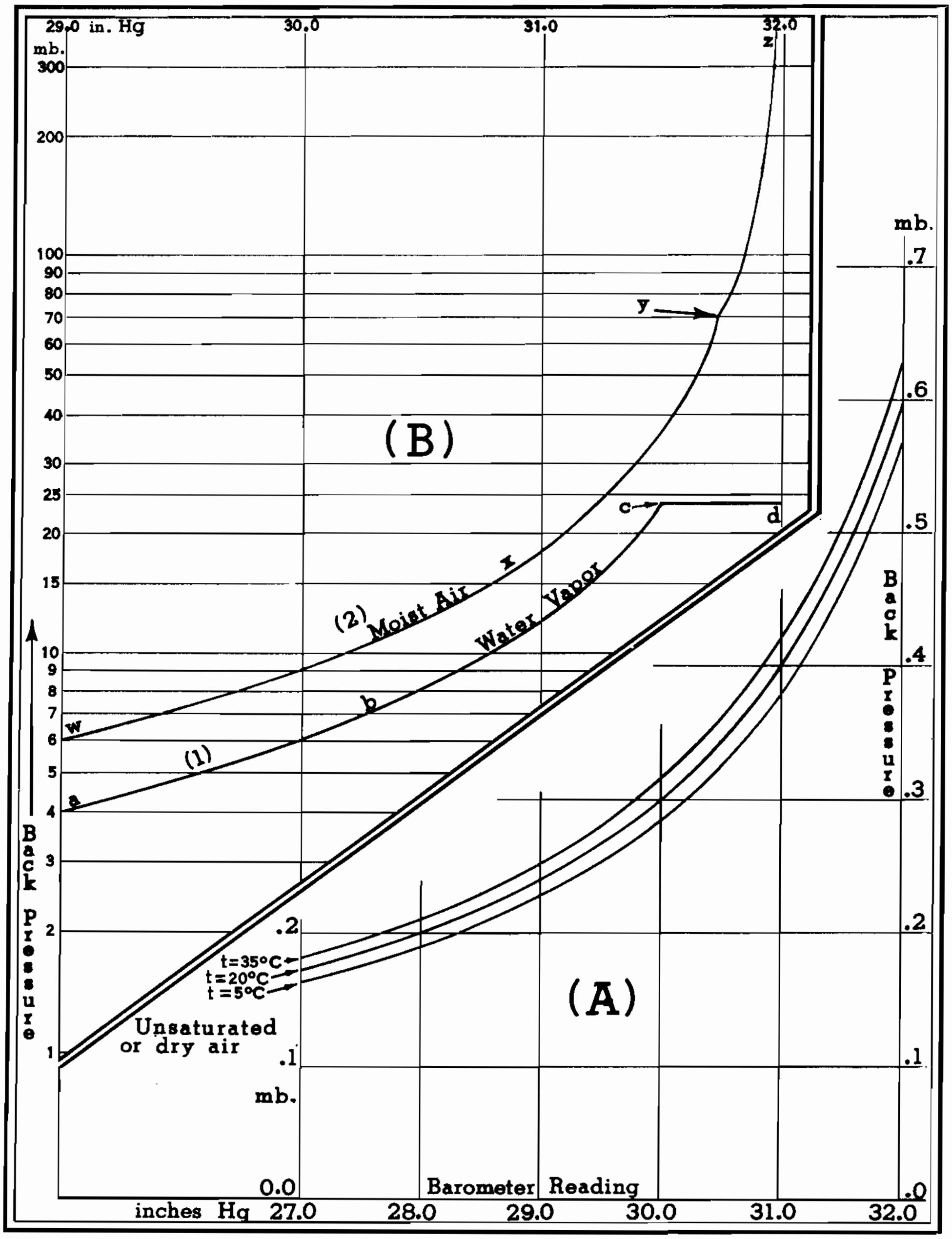


FIGURE 2.7.4. Diagrams (A) and (B) showing back pressure due to imperfect vacuum, as a function of barometer reading. (A) Dry or unsaturated air in vacuum space at several indicated temperatures, where top of tube is at a reading of 34 inches. (Ordinate scale linear.) (B) Two cases of very defective barometers at a constant temperature of 20° C., where the top of the tube is at a reading of 32 inches. (Ordinate scale logarithmic.) (1) Curve *abcd* pertains to pure water vapor, unadmixed with air, in the vacuum space; segment *ab* to *c* refers to unsaturated vapor; *c* designates point at which condensation of vapor begins as barometer reading increases; and horizontal line *cd* pertains to condition where water vapor is saturated. (2) Curve *wxyz* pertains to moist air in vacuum space; segment *wx* to *y* refers to unsaturated air; *y* designates point at which condensation of vapor begins as barometer reading increases; and segment *yz* pertains to air saturated with water vapor.

remains constant at 20° C. The ordinate of Diagram (B) is given on a logarithmic scale partly in order to permit the reader to envisage the effect of changing the mass of enclosed gaseous material and the temperature. For example if the mass of water vapor assumed to exist in the space were doubled, the curve designated as (1) would be raised to ordinate values of twice the amount indicated to the left of the point at which condensation begins; while if the temperature were raised to 30° C., the ordinate level of the straight line segment *cd* would increase to 42.43 mb., as may be found from the data in Table 7.6.1. For the condition corresponding to the horizontal line *cd*, liquid water would exist in the space above the mercury in the tube, and therefore the ordinate pertaining to the line *cd* would increase rapidly as the instrument becomes warmer, owing to the variation of saturation vapor pressure of water with temperature. In addition, if the mass of water vapor in the space were increased beyond that shown in Diagram (B), the location of the point *c* or *y* at which condensation begins would be moved to the left of where it is shown on the chart; that is, the condensation would be initiated at a lower barometer reading; hence the above-mentioned effect of temperature would be experienced more often.

Curve (2) in Diagram (B) illustrates the possible consequences of having a mixture consisting of dry air and water vapor in the space. For comparative purposes it is assumed that the amount of water vapor pertaining to curve (2) is the same as for curve (1). In this case, assumed to occur at a constant temperature of 20° C. (68° F.), the condensation of the water vapor would begin at point *y*. Therefore, the conditions corresponding to the curve *yz* involve the presence of liquid water as well as saturated water vapor above the meniscus. Consequently, this portion of the curve would shift upward with increase of temperature, thus producing even greater errors than shown, due to back pressure.

From the foregoing facts one may clearly discern the strong objections to permitting significant amounts of water vapor to get into the space above the meniscus in the tube.

Further information relating to air and moisture in barometer tubes is given in secs. A–2.17.2 and A–2.17.3.

2.7.4 Temperature of Mercury Column and Barometer Scale

As was previously indicated, once provision is made for the corrections mentioned above, the atmospheric pressure is gauged by the weight of the column of mercury. This depends upon (1) the height of the column, (2) the density of the mercury, and (3) the local acceleration of gravity; hence these are factors which must be taken into account. (See Appendix 1.4.2.)

Temperature affects both factors (1) and (2), since increase of temperature expands the mercury and the scale of the barometer. An expansion of the mercury decreases its density; and at the same time an expansion of the scale causes a decrease in the number of scale graduations extending from its zero to any mark at a fixed absolute height above the zero. A decrease of temperature will produce the reverse effects. Thus, in general, the apparent height as observed on the scale will deviate from the true calibrated barometer height, owing to temperature changes. There is always some fixed temperature at which the scale yields true units of length for which it was graduated. At other temperatures, lower or higher than this fixed value, the scale reading is subject to a correction.

The thermometer attached to the barometer gives indications which are used to judge the temperature of both the mercury and the scale. From the reading of the attached thermometer, and of the apparent height of the mercury column as observed by means of the scale, a correction for temperature may be found (see Chapter 5). The purpose of this temperature correction, when applied algebraically to the observed height of the column, is to yield the true height which the column would have if all of the mercury were at a standard temperature of 32° F. (0° C.) Thus, the above correction is designed to provide both for the density of the mercury and the length of the scale as affected by temperature change.

When a reading of the attached thermometer is used, the assumption is made that the reading is truly representative of the average temperature of the column of mercury and of the barometer scale. The assumption will not be fulfilled under two conditions: (a) if the temperature of the immediate environment of the barometer is changing rapidly with time; or (b) if there are steep horizontal and vertical gradients of temperature in proximity to the barometer.

Under condition (a), the temperature of the column of mercury and of the barometer scale will lag behind the temperature indicated by the readings of the attached thermometer. In that event, the correction for temperature deduced on the basis of the latter readings will be erroneous. For example, if the temperature of the air surrounding the barometer increases at the rate of 2° F. per hour, the error may approach 0.001 inch of mercury (0.034 mb.) for this reason. If the barometer is moved from one extreme of temperature to another (as from outdoors in winter to heated quarters, or vice versa), the lag of the actual temperature of mercury column and barometer scale behind that of the attached thermometer will be considerable (for example, as much as 0.013 inch of mercury, or 0.44 mb., for a lag of 5° F.). To avoid this kind of error, at least 2 hours should be allowed to elapse before using the barometer after it has been moved from one extreme of temperature to another. However, should it be necessary for emergency reasons to secure readings sooner, the barometer should be fanned or exposed to the current of air from an electric fan for say 5 or 10 minutes before the readings are made. In the case of use of the data for precision comparison barometry, the ventilation current to which the instrument is exposed should be continued at least 1–1/2 hour before reading, under steady environmental conditions as regards temperature.

Under condition (b), the presence of steep or irregular horizontal and vertical gradients of temperature near the barometer will generally cause the attached thermometer to give unrepresentative indications with respect to the mercury column and barometer scale. For example, in a highly-heated, small, closed room the temperature in the upper half may be considerably more than in the lower half. If the vertical temperature gradient is not uniform, as is possible in these circumstances, the attached thermometer, even though in the middle of the barometer, will not yield the required average temperature. Thus, a discrepancy of 1° F. in the reading will produce an error in pressure of the order of 0.003 inch of mercury (0.1 mb.). Similarly, if the temperatures at the front and back of the barometer are markedly different, as might be the case in mounting the instrument on a wall relatively hot or cold compared to room conditions, significant errors may be expected owing to the fact that the attached thermometer on the front of the instrument is not representative for the entire column and scale.

The reasons indicated above justify the limitations given later with regard to the location of the barometer; namely, neither to place the instrument where it will be above or directly exposed to radiators or ventilation ducts nor where drafts of cold or hot air can strike it from doors, windows, or other sources. For similar reasons, the exposure of the instrument should be free from the direct rays of the sun, and radiant heat from stoves, heaters, or other warm objects. Since heat radiating from the observer's body will affect the attached thermometer faster and to a greater degree than it will the mercury column and barometer scale, it is necessary for the observer to read the attached thermometer before setting and reading the barometer.

In reading the attached thermometer, the observer must take care to place his eye on the correct line of sight as illustrated in fig. 2.7.5, in order to avoid parallax errors which would be committed if incorrect lines of sight are assumed.

2.7.5 Gravity

The weight of any mass at rest, such as that of a column of mercury, is proportional to the local acceleration of gravity (g). Gravity increases with increase of latitude, and decreases with increase of altitude above mean sea level (see Chapter 3). Since

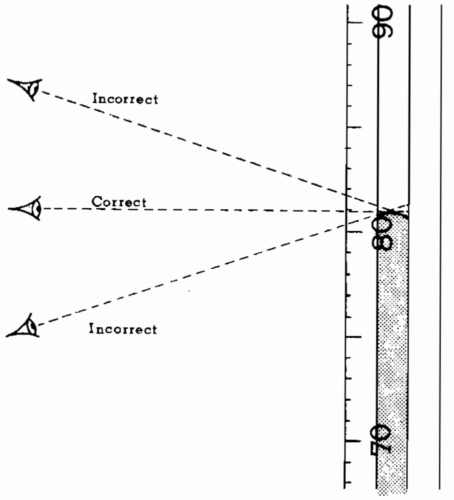


FIGURE 2.7.5. Parallax errors in reading thermometers. The sketch shows a correct reading of 81° F., and erroneous readings of approximately 80° F., and 82° F. owing to the eye being below and above the level of the top of the liquid column respectively.

g is not everywhere the same, it is necessary to apply a correction for gravity, depending upon the location, as described in Chapter 3. When the scale readings are in "millibars," this correction has the effect of giving the actual pressure in terms of units which reflect the true weight of the column of mercury in the given locality for which the correction is valid. When the barometric scale is graduated in inches or millimeters, the correction, when applied to the reading, is designed to give the barometric height in inches or millimeters, respectively, which would be observed if the barometer were subjected to standard gravity. "Standard gravity" as here intended is defined as the constant value of the acceleration of gravity 980.665 centimeters per second per second (cm./sec.^{2}). This has been adopted as standard gravity for barometry both by the International Committee on Weights and Measures and by the World Meteorological Organization. Corrections for gravity are constant for fixed land stations, but vary with location in the case of mobile stations and ships. Aneroid barometers do not require a correction for gravity since they are calibrated with respect to pressure data based on mercurial barometer readings corrected for temperature, gravity, and all combined instrumental errors (see Appendix 1.4.2).

2.7.6 "Pumping" and Swinging of Barometer

The material in this sub-section is of most concern to observers who have occasion to use barometers on board ships.

By virtue of the adverse effects of pumping and swinging on mercury barometers, as described below, the modern tendency is to employ carefully calibrated aneroid barometers on board ships in lieu of the mercury instruments for regular observation at sea, provided the aneroid barometer is connected to a static pressure head (note the next to the last paragraph in this section and also sec. 2.11.1). For background information pertinent to the present subject, the reader is referred to sec. 2.11.1 which presents a discussion regarding the effects of wind. These effects give rise to the variability of pressure within structures, such as buildings and ships where the measurements are made. When the wind is strong, gusty, and turbulent, variations in the wind speed produce relatively significant fluctuations of pressure inside the structure, as may be seen by studying the table of data given in sec. 2.11.1. Since the gusts and lulls of the wind are generally recurrent with considerable frequency, these fluctuations may become fairly rapid. The mercury in the barometer tube responds to such variations in pressure by oscillating vertically, while its inertia tends to cause persistence of the motion. Such vertical oscillatory motion of the liquid column of the barometer is termed "pumping." Violent fluctuations of pressure may also cause vibrations of the indicating mechanism of aneroid instruments. Pumping of barometers creates difficulties with regard to accurate reading of the instruments, and precise observation of the meniscus. The surface of the mercury, both in the tube and cistern, may become ill-defined or malformed, when the oscillations are rapid and violent, thus causing uncertainty in the measurements. Fortunately, when the conditions are mild, the pumping motions reveal themselves as little more than changes in the curvature of the mercury meniscus.

In the case of mercury barometers on board ship, some other contributory factors to the phenomenon of pumping must be considered. Primarily, there are the effects which stem from the rolling, pitching, yawing, and vibration of the vessel, since these motions tend to increase the pumping. Among the causes which operate in such cases are (a) the vertical accelerations as the ship passes over a series of long waves, and (b) the swinging of the mercury barometer on its gimbals as the ship rolls, heaves, and yaws. Contributing to the more pronounced degree of pumping possible on board ship than on land are the following circumstances: (1) the wind force is usually greater over the stormy sea lanes where the ships ply than over land; and (2) the forward motion of the ship provides an added component to the relative air speed, especially in a headwind. Moreover, the installation of the barometer in the chartroom on the deck of the vessel places it in a position where the open exposure makes it especially susceptible to the pressure effects of airflow. Thus, we may conclude that pumping on board ship can be very serious as a source of errors, and as a condition which makes it difficult to secure accurate readings. In order to alleviate this situation, fixed-cistern barometers for use aboard ships are constructed so that the bore of the tube is relatively small over much of its length, except near the top where the meniscus occurs and near the entrance to the cistern. By the use of a capillary constriction in the tube, such that the bore is about 1/32 inch for a length of approximately 17 inches, the vertical oscillations of the mercury are hampered. (Note: Other bore diameters such as 0.1–0.4 mm. depending on the length have also been used for the capillary portion of the tube in marine barometers.) But one of the objectionable consequences of such a design is that the barometer readings tend to lag behind the pressure, under conditions of steady rise or fall. Therefore, the size of the constriction must be limited by the need to achieve a happy compromise between the two aspects: to damp out the pumping adequately, and to prevent the lag from becoming excessive. It is generally considered that a satisfactory compromise is reached when the lag coefficient is about 240 seconds. (The significance of this lag coefficient may be grasped from the following experiment: if the barometer were suddenly introduced into a chamber having a constant pressure different from that to which the instrument was subjected, the difference between the barometer reading and the ambient pressure in the chamber would reduce to 1/2.718 of its initial value in the time stipulated by the lag coefficient, 240 seconds. From the theory it may then be deduced that the difference will fall to 10% of its original value in a time interval 2.3 times as long, namely 552 seconds; and to 1% of its original value in a time interval 4.6 times as long, namely 1104 seconds.)

The existence of lag coefficients contributes to errors as may be seen from the examples below. Generally, marine barometers have a lag coefficient ranging between about 240 and 540 seconds. For example, consider a case with the lag coefficient 420 seconds, where the pressure is *falling* steadily at the rate of 2 mb. per hour. Then, because of lag, the barometer reading will be *too high* by about 7/30 mb. However, if the pressure is *rising* steadily at the same rate, the reading will be *too low* by the same amount.

Swinging of the marine barometer on its gimbals arises owing to effects of inertia of the instrument and friction of the gimbal ring. These effects develop by virtue of the motions of roll, pitch, and yaw of the ship. As previously stated, such swaying motion of the barometer will cause pumping of the mercury column. Not only does this motion cause difficulties in the making of readings, but it acts to produce errors for two other reasons as now explained. First of all, the barometer is inclined away from the vertical during most of its oscillation; hence the reading of the barometer scale along the average slanting direction is *greater* than the true vertical, projected height of the mercury column, which is determined by the atmospheric pressure and therefore is the desired reading. Secondly, the swinging of the barometer on its gimbals gives rise to a centrifugal force per unit mass having a component directed vertically downward, and this component is added to the local acceleration of gravity. The effect of this added component is to cause the apparent height of the mercury column to be somewhat *less* than it would be if no swinging motion occurred. Accordingly, it is seen that the two errors act in opposite directions, but generally they do not cancel out. However, it is possible to hold the error down to within certain limits by a suitable initial adjustment or choice of the vertical position of the axis of the gimbals with respect to the mean height of the mercury meniscus. When the swinging motion about the vertical has been going on for a time considerably longer than the lag coefficient, the net error due to these sources can become significant, especially if the chosen location of the axis of the gimbals with respect to the meniscus is not optimum. Depending upon this location, various motions of the ship often cause forced oscillations of the instrument with periods different from the natural period of vibration of the barometer, regarded as a pendulum. It is best that these periods differ, since resonance would cause serious augmentation of the pumping action. Thus, proper location of the gimbals is important.

Accurate reading of a barometer under the conditions often encountered at sea requires considerable skill and quick reading on the part of the observer, particularly in connection with the proper setting and reading of the vernier. It should be noted that the best results are obtained when the swinging motion of the mercury barometer about the true vertical is minimal, and that the average position of the barometer between the extremes of the oscillation approximates the true vertical under steady conditions. Therefore, on board ship the observer must take care not to interfere with the free motion of the barometer in the gimbal.

In view of the pumping action of the mercury column and the swinging motion of the barometer, it is necessary to base the true mean height of the column upon the average of the readings of the barometer at highest and lowest extremes over a number of successive oscillations. Accordingly, the following procedure in regard to barometer readings at sea is recommended:

(a) First read and record the temperature of the attached thermometer before touching the barometer.

(b) Then, stand with the feet well apart, keeping the arms relaxed, and at the same time following the motion of the barometer, steady the instrument to a true vertical position with the left hand as carefully as possible, while adjusting the vernier with the right hand.

(c) Follow the motion of the mercury column with the vernier. Set at a "high" position, read quickly and lower to catch the corresponding "low" position and read. Take a series of ten "high" and ten "low" successive readings of the vernier. It will take considerable skill and practice to do this with any degree of accuracy. A mean of the ten "high" and "low" readings will approximate closely the height of the mercury column if the barometer were not subject to pumping.

(d) The precision aneroid if properly set and checked against the mercurial barometer, when in a stable anchorage, should be used to obtain "station pressure," rather than the mercurial when the roll and pitch become pronounced. The aneroid will be much more accurate under these circumstances than attempts to compensate for "pumping" of the mercurial.

It has been pointed out by Giblett[15] that the motions of a ship are often conducive to the obtainment of incorrect values of the mean pressure from the readings of a marine mercury barometer.

Investigations have been conducted both theoretically and experimentally to determine the errors of a marine mercury barometer due to swinging and rolling.[15 16]

Duffield and Littlewood[16] considered the case of a marine barometer which goes through a series of small *free* oscillations about its point of support. Their theoretical derivation indicated that the barometer would tend to read too high owing to the effect of the average degree of inclination of the barometer, but that the effect of centrifugal force would act in the opposite di-

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[15] Giblett, M. A., "The Effect of the Rolling of a Ship on the Readings of a Marine Mercury Barometer," Philosophical Magazine, London, vol. 46, p. 707 (1923).

[16] W. G. Duffield and T. H. Littlewood, "The correction of a marine barometer for errors due to swinging," *Philosophical* Magazine, vol. 42, 6th ser., pp. 166–173 (1921).

rection. One of the primary objectives of Duffield and Littlewood was to determine what adjustments might be made in order to cause these two opposing effects to cancel out exactly. Their theoretical analysis revealed that the value of the ratio D/L, pertaining to the quantities D and L defined below, is the most crucial factor governing the relative error of a barometer permitted to oscillate freely about its support. In particular, let $L =$ the length of the simple pendulum equivalent dynamically to the actual barometer when it undergoes *free* oscillations about its point of support, and let $D =$ the distance of the center of pressure of the mercury column in the barometer tube below the point of support of the instrument; then Duffield and Littlewood showed that when the ratio $D/L = 1/2$, the barometer undergoing free oscillations about its point of support gave the best results, caused by the cancellation of the two effects mentioned above. In other words, when the relation between D and L is adjusted to the stage where $L = 2D$, the error due to the free swinging of the barometer tends to be nearest to zero.

Duffield and Littlewood made the following statements of interest relevant to this matter: "In practice, there are two means whereby the necessary adjustment may be arrived at: –(i.) By keeping the point of suspension fixed, when D will be unchanged, and altering L, the length of the equivalent simple pendulum, until $L = 2D$. This may be effected by loading the barometer to alter its period of oscillation. (ii.) By altering the position of the point of suspension, moving it up or down the barometer tube. Both L and D are thus varied until the required relationship is attained."[16] (Note: We have taken the liberty of employing capital letters L and D for the parameters where they originally used lower case letters for them.)

In conclusion Duffield and Littlewood also make the following comment:[16] "For accurate work the adjustment will be in error if the mercury rises or falls below the level for which the adjustment has been calculated, not only on account of the change in the position of the mercury within the tube, but also by reason of the motion of the sliding sight, which is made to follow the mercury in the operation of reading the barometer. It should be possible to arrange a second sliding weight, which should be fixed at predetermined positions on a scale for given barometric heights, and which would permit the relationship $L = 2D$ to be fulfilled on all occasions."

It will be noted that the problem treated by Duffield and Littlewood was limited to small free oscillating motions of the barometer about its support, and did not take into account the effect of the motion of the support itself due to the rolling of the ship. The latter problem was considered by Giblett.[15] He investigated theoretically the effect on the barometer reading of the forced oscillation which results from the rolling of the ship. Giblett derived an expression for the relative error of the barometer reading under the assumption that the maximum angles of inclination of the barometer and of the ship, respectively, to the vertical at any instant during the oscillation are small; and in the final analysis he also assumed that the free oscillation was absent, considering only the relative error which stems from the forced oscillation alone.

In order to summarize Giblett's results the following notation is introduced: let L = the length of the simple pendulum equivalent dynamically to the actual barometer when it undergoes *free* oscillations about its point of support; $D =$ the distance of the center of the mercury column from the point of support of the barometer; $S =$ the length of the simple pendulum equivalent dynamically to the actual barometer when it undergoes *forced* oscillations; $b =$ the maximum value of the arc displacement of the point of support from its normal central position when the ship rolls to a maximum angle of inclination; $T =$ the period of the roll; $t =$ the period of the barometer for free oscillations about its point of support; $g =$ the acceleration of gravity; $m =$ angular frequency of the free oscillations of the barometer about its support (namely $m = 2\pi/t$); $n =$ angular frequency of the roll (namely $n = 2\pi/T$); $m^2 = g/L$; $n^2 = g/S$; $A = D/L$; $r = b/L$; $R = S/L = T^2/t^2$; $h =$ the true height of mercury barometer column if there were no oscillations; h' = the mean length of the mercury column while oscillating; and E = relative error of the barometer = $(h - h')/h$.

On the basis of the assumptions mentioned above Giblett determined the following theoretical relationship which shows the relative error of the barometer due to the forced oscillations produced by the ship's roll, neglecting the effect of any free oscillations that might be present simultaneously:

$$E = (h - h')/h$$
$$= r^2(R + 2A - 2)/4R(R - 1)^2.$$

It may be seen from this equation that E will reduce to zero theoretically under the given assumptions if the following condition is satisfied:

$$(R + 2A - 2) = 0.$$

Since $A = D/L$ and $R = T^2/t^2$, one finds on substituting these expressions in the last equation that the condition to be satisfied in order to cause E to be zero is

$$(D/L) = (1 - T^2/2t^2).$$

On the basis of this equation a criterion is given for adjusting the ratio (D/L), provided the relative value $(T^2/2t^2)$ is known for which one wishes to reduce E to zero.

The reader will note that the last specified criterion based on Giblett's analysis is not necessarily the same as that recommended by Duffield and Littlewood for the case of free oscillations of the barometer about its support.[16]

2.7.7 Parallax

When the vernier of a truly vertical mercury barometer is properly set to permit correct reading of the height of the mercury column, the line of sight of the observer's eye *must be horizontal* while it passes through the lower edge of the vernier *both at front and back,* with the line of sight just tangent to the top of the meniscus. This correct line of sight is indicated by the horizontal dashed line pictured in fig. 2.7.6 (A).

However, an erroneous reading would be obtained if the line of sight just grazed the meniscus and passed through *either* the front or the back lower edge of the vernier, as shown diagrammatically in fig. 2.7.6 (B), which indicates examples of two incorrect lines of sight. It is clear from this figure that the level on the barometer scale assumed by the lower edge of the vernier does not represent the true height of the top of the meniscus when incorrect lines of sight are employed. Hence, from the examples shown in fig. 2.7.6 (B) it is easy to grasp the concept of the error due to parallax.

Another source of erroneous reading makes its appearance if the observer sets the lower edge of the vernier so that it seems to cut off the top of the meniscus, as illustrated in fig. 2.7.6(C).

Procedures regarding the proper method of setting the vernier and reading the mercury barometer are given in sec. 2.4.

2.8 INFORMATION REGARDING OPERATION AND TEMPERATURE COMPENSATION OF ANEROID BAROMETERS

2.8.0 General

The discussion presented in this section describes the method of operation of the aneroid barometer in general terms, and proceeds to an explanation of the effects of temperature upon the mechanism of the instrument, followed by an account of the principal methods used to compensate for these effects. In sec. 2.10 the reader will find a listing of the various factors which influence the readings of the aneroid barometer, with an account under each factor giving the nature of the effect and the relevant characteristics of the instrument. Thus, under the various headings of sec. 2.10 such characteristics of the aneroid as "drift" and "hysteresis" are dealt with. It is with a view to overcoming the adverse effects of these properties of the instrument that the calibration techniques outlined in sec. 6.7.2, etc., are designed.

As a matter worthy of emphasis, it may be reiterated that in order to obtain accurate results in terms of pressure on an absolute basis, the precision aneroid barometer must itself be compared with a standardized mercury barometer to determine suitable corrections which must be applied to

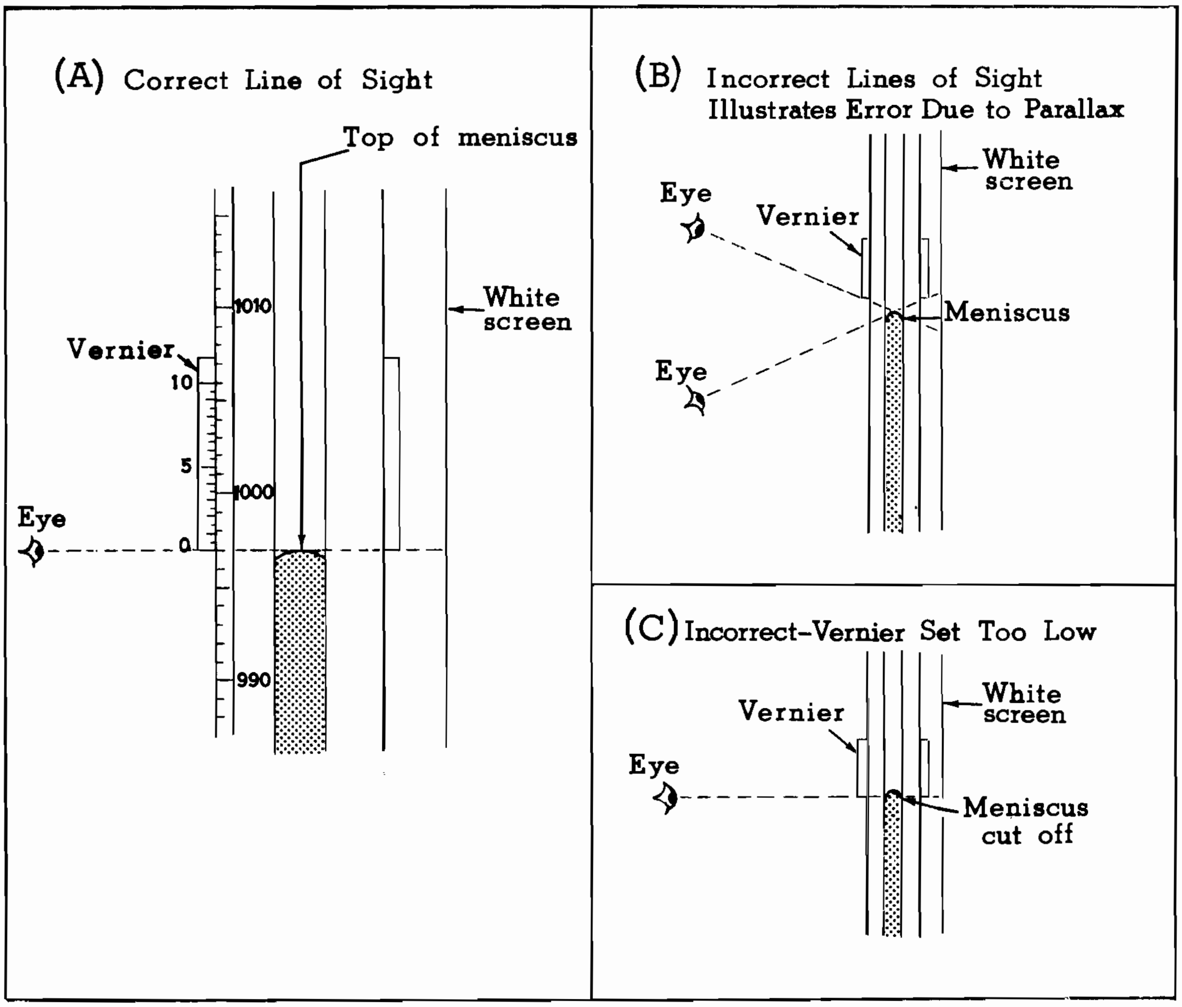

FIGURE 2.7.6. Schematic drawing of (A) correct vernier setting obtained when the line of sight passes through the following three points: front lower edge of vernier, top of meniscus, and back lower edge of vernier, which appear coincident as correct sighting is made; (B) vernier setting too high in cases where the line of sight just touches the meniscus and passes through either the front or the back lower edge of the vernier, but not both, with examples showing eye level too high and too low; (C) vernier setting too low with the upper portion of the meniscus cut off or obstructed from view.

the readings of the instrument. Knowledge of the characteristics of the aneroid barometer and of its limitations is valuable to those who wish to use the instrument for scientific purposes. Additional information relevant to this subject is given in sec. 2.9.0–2.9.3.2.

2.8.1 Method of Operation

Some basic information pertaining to the method of operation of aneroid type barometers has been given in sec. 2.3, and illustrations of different types of aneroid mechanisms are shown in figs. 2.3.0 to 2.3.4, and 2.8.0. As indicated previously, barometers of this type consist of one or more sealed metal capsules or bellows from which air and water vapor have been exhausted and a minute amount of dry, inert gas introduced. Variations in the ambient atmospheric pressure cause deflections of the bellows, or the diaphragms of the capsules. A suitable magnification device which may consist of a system of levers, a gear train, etc., is used to transmit the deflection to a pointer on a properly calibrated dial. The difference between the force exerted by the pressure of the atmosphere on the diaphragm and the feeble pressure offered by the gas within the partially evacuated chamber must be bal-

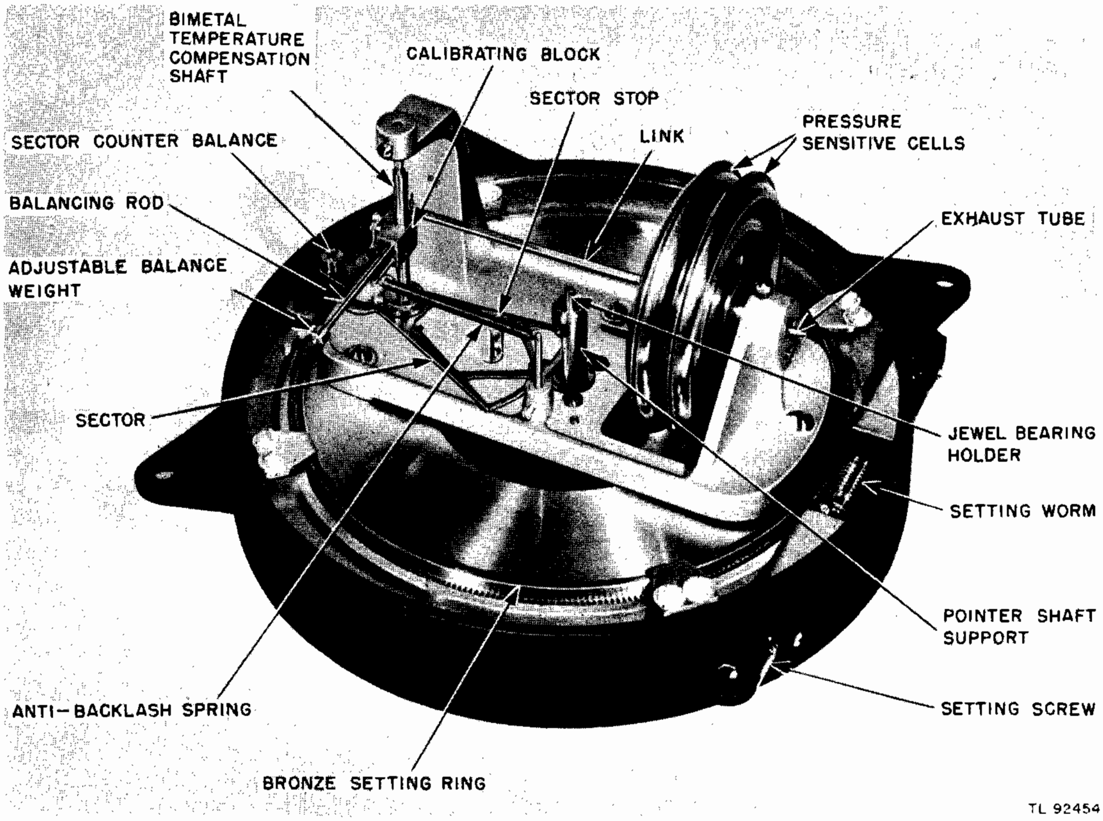

FIGURE 2.8.0. Aneroid mechanism, Barometer ML–102–E (or ML–102–F); U.S. Army Signal Corps type used by the U.S. Army and the U.S. Air Force (U.S. Army photograph).

anced by the total resisting force of the compressed chamber, and spring, if any. In effect, the instrument functions because this resisting force weighs the specified pressure difference. Hence, as the ambient pressure decreases, the capsule or bellows tends to expand and the diaphragm moves outward, and when the ambient pressure increases, the chamber is compressed and the diaphragm forced back. The reliability of instruments of this type depends much upon the strength, flexibility, and resilience of the metal used for the aneroid cell; and the repeatability of its calibration under varying conditions of pressure and temperature.

No detailed discussion need be given here regarding the Bourdon barometer which has little or no meteorological application, but is widely used for industrial type pressure gauges. This is an aneroid type instrument consisting of a curved tube closed to the atmosphere and having a flat elliptical cross section. Changes in the pressure differential between the inside and outside of the tube resulting from variations in ambient atmospheric pressure cause the radius of curvature of the tube to vary. One end of the tube is held in a fixed position, and the motion of the other end is magnified by a system of levers and transmitted to a pressure dial. See sec. A–2.13, par. (c) reference.

2.8.2 Temperature Effects and Compensation

Observation has revealed that increase of temperature weakens the force with which the metals of the aneroid capsule and the spring, if any, resist compression, while at the same time causing thermal expansion of the parts. If these effects were uncorrected, the indications of the aneroid barometer would vary with both pressure and temperature. In the better quality aneroids, two methods are usually combined to overcome most of the effect due to temperature: (a) a small amount of inert gas is left in the capsule just as it is sealed; and (b) an additional temperature compensation device is introduced somewhere in the mechanism. With regard to (a), increase of temperature acts to increase the pressure of the inert gas and this tends to compensate somewhat for the weakening of the force of the spring action. When this method is the only one employed to compensate for temperature in a given instrument, it is necessary to apply corrections for temperature on the basis of calibrations, if precise results are desired. In regard to (b), various techniques have been used; e.g. a bimetal temperature compensation shaft is built into the apparatus. See fig. 2.8.0. This shaft, whose function is often to pivot a sector gear in the magnification mechanism, may be made of a strip of invar and a strip of brass which are welded together lengthwise. Inasmuch as these metals have different coefficients of thermal expansion, an increase in temperature causes the bimetal shaft to assume a curved form. Changes of form of the shaft give rise to displacement of an adjustable lever mounted near the center of the shaft. Owing to the function of the shaft in the mechanism, this motion produces a slight shift in indication of the pointer. The bimetal shaft can be oriented in such a manner that most of the effects due to temperature change, not overcome by the inert gas, may be compensated by the device. Unfortunately, the compensation is not always perfect. Therefore, all aneroid barometers which are to be used for precise work should be calibrated at two or more temperatures under laboratory conditions in order to check the quality of the compensation, and to prepare temperature correction curves if found necessary. These curves should give the correction as a function of temperature and instrument pressure reading. A chart showing the curves which give the correction of the aneroid barometer reading for temperature variations is usually fastened to the barometer when a correction of this character is required. Application of the correction for temperature is essential when such an instrument is used under field conditions where the temperature to which the aneroid is subjected may undergo wide variations.

However, there are often circumstances where the use of the curves to correct for temperature effect is unessential. This is the case when (a) the quality of the compensation for temperature variation is good; (b) the range of the ambient temperature fluctuations at the instrument site is fairly narrow during periods of about a month in length; and (c) the system of standardizing aneroid barometers described in sec. 6.7.2 is employed. Under these circumstances, the aneroid barometer is maintained at a fixed meteorological station where a more or less constant room temperature is maintained. In addition, under the provisions of sec. 6.7.2, the instrumental correction of the device is determined by comparative readings against a standardized mercurial barometer at the prevailing temperature of the room. On this basis, even if there is some effect due to temperature, due allowance is made for the average effect as it exists under the prevailing temperature by use of the instrumental correction. (See symbol C_a as defined in secs. 6.7.1.1 and 6.7.1.2.)

It may be seen from the foregoing discussion that it is desirable to install the aneroid barometer at a location where it will not be subjected to large fluctuations of temperature. This principle is laid down in order to prevent any adverse effects due to lack of uniformity of temperature among the various components of the apparatus and to keep the contribution of error due to imperfect temperature compensation at a nearly constant value so that it can be corrected for by the procedures of sec. 6.7.2. On these grounds, aneroid instruments should not be exposed directly to convection currents and sources of heat or cold; as for example, drafts or currents from doors, windows, and heating units; or radiation from the sun or a space heater. The installation should be on or near an inside wall where heat transfer to the instrument will be at a minimum, because of homogeneous temperature environment.

If it should ever be necessary to move the aneroid barometer from one place to another or to subject it to a change in conditions whereby it will be exposed to a large variation in temperature, it is advisable to wait at least one and one-half (1-1/2) hours before making a reading. This delay is intended to secure thermal equilibrium among the parts.

2.9 SPECIAL TYPES OF ANEROID INSTRUMENTS

2.9.0 Introduction

Basically, an aneroid barometer is a pressure-responsive measuring instrument which does not involve the use of a liquid in connection with its mode of operation. In secs. 2.3 and 2.8.1 we have already presented brief accounts of the method of operation of this kind of instrument as generally employed for meteorological uses. A number of special types of pressure-responsive instruments which function in the manner of the aneroid barometer have been developed. Fairly brief descriptions of the types of such instruments considered most important for the purposes of this manual are presented in the following sections as here listed: sec. 2.9.1, Microbarographs; sec. 2.9.2, Altimeter-setting indicators; sec. 2.9.3, Altimeters; sec. 2.9.3.0, General information concerning altimeters; sec. 2.9.3.1, Aircraft altimeters; and sec. 2.9.3.2, Surveying altimeters.

All of the devices considered here may be regarded as special modifications of the precision aneroid barometer. Consequently, the quality of performance in all of these cases rests, in the final analysis, on the characteristics of the pressure-responsive element. In order to simplify the concepts, the element can be regarded as constituted of one or more elastic diaphragms clamped at the edges and subjected to a difference of pressure between the two sides. The elastic diaphragm or membrane serves both as a spring and as a barrier impervious to the medium, in the present case atmospheric *air*, whose variations of pressure are to be measured. Consequently, when the elastic membrane is exposed to the atmosphere, the deformation or deflection of the diaphragm will change as the ambient pressure varies. Thus, the operation depends upon changes in deflection with variation in the difference between the pressures on the two faces of the elastic material as magnified by the instrument mechanism. For reasons of simplicity in regard to calibration of the diaphragm, it is desirable that its change of deflection per unit change of ambient pressure be a constant; in other words that the response be linear. Elastic behavior of this character can be achieved to a fairly close degree of approximation in the case of some elastic materials, provided that the load applied to the material does not stress it to near or beyond its yield point. Thus, a relatively small pressure load will give rise to a more nearly linear response than a large one.

All of the instruments dealt with in secs. 2.8 – 2.9.3.2 are required, for meteorological purposes, to have a relatively high degree of sensitivity and to give repeatable performance within close tolerances for pressure variations over a wide range, depending upon the application of the device. In order to obtain increased sensitivity two or more diaphragms are formed to produce an elastic chamber which acts as an aneroid element yielding a greater response than can be secured from a single one. A further increase in sensitivity is obtained by arranging the capsules in series or tandem such as illustrated in fig. 2.8.0. Still an additional improvement is gained by employing corrugated diaphragms rather than flat ones, since the use of corrugations have the effect of yielding a larger deflection per unit change of pressure and of permitting the designer to have a better control over the shape of the curve which relates deflection to pressure than if flat diaphragms are used.[17]

Considerable sensitivity in response of the aneroid element is also secured by making use of the flexible metal bellows type, an example of which is illustrated in fig. A–2.21.10; while fig. 2.3.3 shows the bellows type to which the trade name "sylphon" has been applied. The bellows employed in barographs contain an internal helical spring

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[17] W. A. Wildhack, R. F. Dressler, and E. C. Lloyd, "Investigations of the Properties of Corrugated Diaphragms," Transactions of the American Society of Mechanical Engineers, vol. 79, pp. 65–82, Jan., 1957.

usually made of a special kind of steel. However, some bellows, especially the small ones constructed of strong, highly elastic alloys such as beryllium copper, employed for industrial purposes such as pressure switches, do not necessarily contain internal springs, since the metal alloy capsule in such cases is capable of providing sufficient spring effect of itself when the pressure load is not excessive. In some designs of bellows the ends of the internal helical spring which bear against the inside faces of the diaphragms are flat, thus creating a source of friction, owing to the fact that compression or expansion of the spring will cause its ends to rotate relative to one another. It is possible to overcome most of the friction from this source if suitably designed ball bearings are employed at each end, one to serve as a thrust bearing which acts normal to the diaphragm, and another to serve as a radial bearing which acts along the projection of the terminus of the helical spring, thereby providing some compensating effect for any lack of symmetry in the assembly.[18]

As a rule a small amount of dry gas such as nitrogen is contained within the aneroid capsule, both to yield some resistance against collapse under the action of the external pressure and to provide some beneficial effect in regard to temperature compensation.

Most alloys respond to temperature changes in such a manner that their elastic properties vary significantly with temperature. This has led to the search for and development of metal alloys whose elastic properties are little affected by ordinary temperature variations. As a result of advances along this line, there has been developed an alloy termed "Ni-Span C" which has elastic properties making it suitable for use in the construction of aneroid capsules and has a thermoelastic coefficient of negligible amount. For present purposes related to aneroid performance the thermoelastic coefficient is defined in terms of the variation of the slope of the pressure-deflection curve with temperature; but on an absolute basis the variation of the elastic modulus with temperature represents the thermoelastic coefficient. Hence, in cases where the latter coefficient is zero the elastic modulus is a constant, independent of temperature. By way of contrast it may be pointed out that the thermoelastic coefficient of one type of beryllium copper is about -3×10^{-5}, that of phosphor bronze is about -3.6×10^{-5}, while that of Ni-Span C is substantially zero (0) on the same scale. Ni-Span C is now widely used in the manufacture of aneroid diaphragms, owing primarily to its superior thermoelastic properties; i.e., constancy of the slope of its pressure-deflection curve despite variations in temperature.

Thus, the employment of aneroid capsules with a negligible thermoelastic coefficient tends to yield calibration curves which are relatively constant with respect to temperature changes; but this is not to be interpreted as signifying an absence of thermal expansion of the diaphragm material. One still has to allow for expansion and contraction of the aneroid element and of the connected mechanism with increase and decrease of temperature, respectively. Effects of the latter character are still to be expected; but they can be more or less compensated for by the inclusion of a suitable temperature compensation device within the mechanism (see sec. 2.8.2).

While the materials used in aneroid diaphragms for precision instruments are specially chosen for their elastic behavior, careful observations reveal that all of them are characterized by small departures from perfectly elastic performance. The term "anelasticity" is often used in referring to the non-elastic behavior of solid substances in the range where they are subjected to relatively low stresses; and therefore one can use the term "anelastic effects" when referring to such non-elastic properties or elastic defects as "hysteresis," "drift," "after-effect," "recovery," and "zero shift." Some discussion is presented later in secs. 2.10.0–2.10.10 regarding these anelastic effects which are important in regard to the behavior of aneroid instruments.

Inasmuch as the foregoing anelastic effects are referred to repeatedly in discussing the characteristics of aneroid elements and diaphragms, it is deemed worthwhile at

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[18] W. E. K. Middleton and A. F. Spilhaus, "Meteorological Instruments," Third Edition, Revised, University of Toronto Press, Toronto, Canada, 1953, pp. 45 46.

this point to present brief definitions of the relevant terms as they have been used by investigators in connection with tests made to determine the properties of diaphragms. The following definitions, which have been applied in this regard, are quoted from the work of Wildhack, Dressler, and Lloyd:[17]

"*Hysteresis* —the difference between the deflections of the diaphragm at a given load, for decreasing and for increasing loads.

"*Drift* —the increase of deflection with time under a constant load.

"*After-effect*—the deflection remaining immediately after removal of the load, that is, hysteresis at no load.

"*Recovery* —the decrease of after-effect with time under no load. (The term also may be applied to the time decrease of hysteresis at a constant load.)

"*Zero shift* —the permanent deformation, that is, the difference in no-load deflection before loading and sufficiently long after unloading for recovery to occur; or the difference between after-effect and recovery."

Illustrations pertinent to the phenomena of hysteresis, drift, and after-effect are presented in figs. 2.10.0, 2.10.1(a) and 2.10.1(b).

A finding of interest in regard to the subject is that if two hysteresis tests are made in close succession, such as on succeeding days, the second will generally show significantly less hysteresis than the first; but if a delay of, say, more than a month occurs before the next test, it will be found that the maximum amount of hysteresis manifested in the new test is substantially equal to that observed in the original, first test. The implication of this is that aneroid instruments which are subjected to frequent cyclic pressure variations are not likely to show as much hysteresis as those which are subjected to varying pressure loads only occasionally. It is also suggested that the preliminary "exercising" of aneroid elements by having them undergo several (say 5–6) cycles of pressure variation before they are put into use will cause them to give a better performance in regard to hysteresis than without such "exercise," if the operating conditions involve cyclic pressure variations.

When an aneroid capsule or diaphragm is used in an application where it will receive numerous, frequent cyclic changes in ambient or differential pressure, fatigue of the material can occur, especially in areas where the local stress is relatively high. This condition is likely to develop in a diaphragm capsule near the outer edge where the two diaphragms used to form the capsule are joined. Consequently, cracking of the diaphragm material due to fatigue is most likely to take place in these areas of most severe stress, particularly when the maximum stress which occurs in such areas is near the yield point of the material. After the inception of a crack, the continued local working of the material that results from repeated variations in the pressure load on the diaphragm can eventually lead to a failure, e.g., at the joint. When this happens, a leak develops in the capsule, rendering it useless. For this reason, it is necessary to maintain a surveillance on aneroid instruments in order to detect the onset of a failure or any mechanical defect.

2.9.1 Microbarographs

A microbarograph is a recording aneroid barometer equipped with a pen which makes a trace of ambient pressure variations on a chart having a magnified scale. They are adapted to the purpose of giving indications of the pressure characteristic and tendency. Examples of microbarographs are shown in figs. 2.9.0, 2.9.1, and A–2.21.10. In the typical barograph which was commonly used for meteorological observations before these illustrated instruments were introduced, a change of ambient pressure of 1 inch of mercury was indicated by a vertical displacement of the pen amounting to one (1) inch. However, in the case of the instruments shown in the above-mentioned figures a change of 1 inch of mercury is indicated by a vertical displacement of the pen amounting to 2.5 inches. Therefore, the instruments presented in the specified figures are termed "2.5–1 barographs"; and it is also customary to call them "open-scale barographs"; since

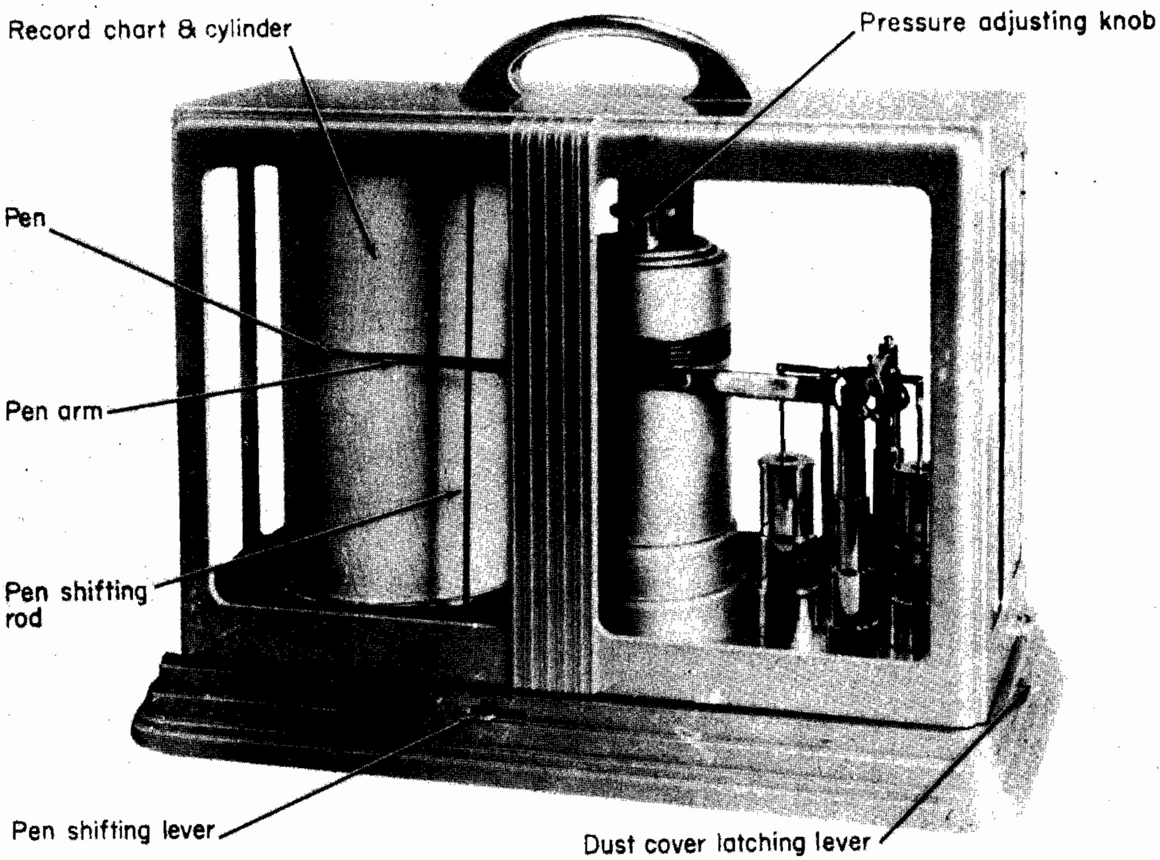


FIGURE 2.9.0. Open-scale barograph (2.5—1).

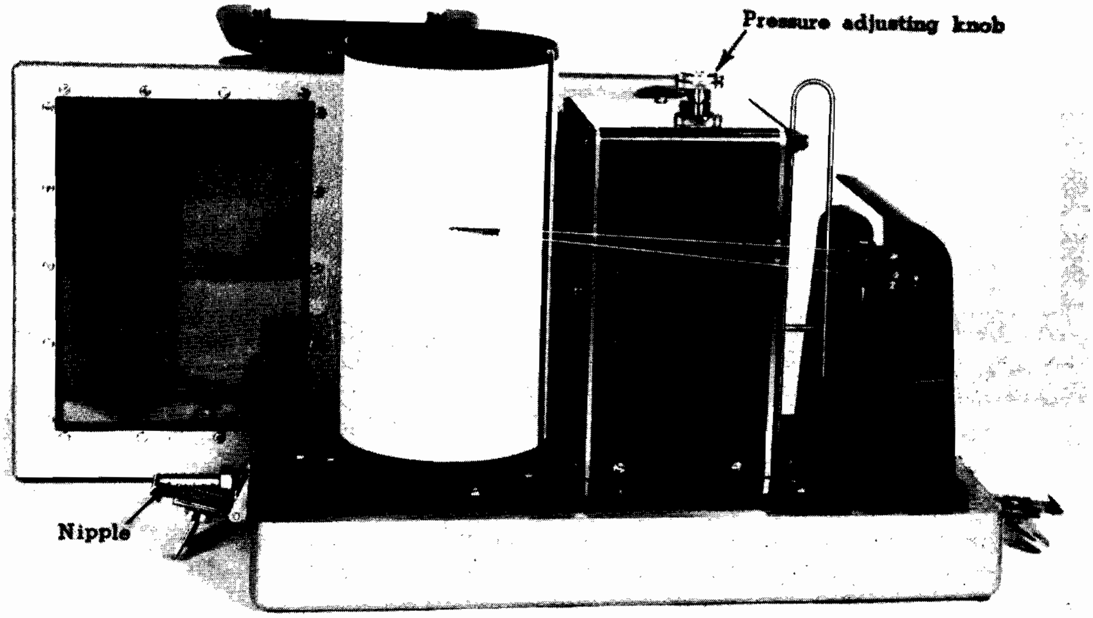


FIGURE 2.9.1. Marine barograph (equipped with sealed case and nipple connection for static pressure head).

their scale is magnified with respect to that which was employed in the case of the old-style barographs characterized by a ratio of 1:1 between pressure changes in inches of mercury and resulting vertical displacement of the pen.

The open-scale barograph usually consists of two or more bellows aneroid chambers which actuate the mechanism by virtue of the response of these elements to changes in ambient pressure (see secs. 2.3, 2.8.0–2.8.2, and 2.9.0). In order to secure an enlargement of the movement of the bellows the device includes a suitable magnifying linkage that terminates in a pen arm at the end of which is the pen for making the trace of the pressure variations. A chart is mounted on a vertical cylinder driven by clockwork so that the drum rotates at a uniform rate.

Vertical movements of the pen due to pressure variations cause the tracing of a record of these pressure changes automatically on the chart (see fig. 6.10.0 and sec. A–2.16.3.9). For normal station use 2.5–1 bargraphs are equipped with a gear system in connection with their clockwork which causes the chart cylinder to make one complete rotation in four (4) days. However, it is possible to provide special gears which will yield a complete rotation in some other time period, such as 12 or 24 hours (see sec. A–2.16.3.4).

Temperature variations may cause a given barograph to be subject to some error, depending upon the amount of the deviation from the temperature at which the barograph was calibrated and upon the effectiveness of the temperature compensation device employed in the instrument. Therefore, it is considered advisable to install barographs in a location where they will not be exposed to the direct rays of the sun and to strong sources of heat or cold (such as currents from radiators or drafts from open windows, doors, etc.). See secs. A–2.16.3 and A–2.16.4 for further information.

Barographs are equipped with either dashpots or a damper, designed to damp out the effects of vibrations and small scale pressure fluctuations. The damper may be adjusted at field stations or on shipboard where the pen of the barograph shows excessive vibration. In the case of barographs provided with dashpots, it is considered advisable to maintain the level of the dashpot fluid about 3/8 inch below the top of the dashpot (see secs. A–2.16.3.6 and A–2.16.4.10 for additional details).

It has been observed in a few cases where the barograph was not leveled and the dashpot fluid was not kept at the proper height, that the piston (dasher) rubbed against the inside wall of the dashpot, thus causing friction. Under these conditions, it is possible for the barograph trace to manifest a "staircase" configuration during periods when the ambient pressure is rising or falling. This effect stems from the fact that starting friction is greater than running friction. Owing to this difference a significant change in ambient pressure can occur before the pen moves, causing it in this manner to exhibit a small abrupt jump or step. One can overcome this fault by leveling the instrument and eliminating the cause of the excessive friction between the dashers and the inside of the dashpot cylinder walls. After adding the required high-grade instrument oil to the dashpot in order to bring it to the proper level, one must move the dashers up and down slowly until all air is removed from beneath them.

In order to prevent damage to the delicate mechanism of the barograph it should never be tampered with. One of the most important parts is the clockwork, which requires good and proper care. Of necessity the clock must be fully wound, as a rule, at the time that the chart is changed; but *it is absolutely essential that the clock never be overwound,* that is, *one must stop winding as soon as the spring resists hard.* In order to obtain reliable and accurate operation of the clockwork, and to secure a long life of service from it, a recommended practice is the cleaning and oiling of the clockwork periodically every 18 months by an expert watch repairman. Station personnel are instructed never to attempt to do this. On the other hand, regulation of the rate of the clock can be undertaken by station personnel in cases where the clock runs fast or slow. Similarly, authorized station personnel are permitted to make adjustments for the purpose of overcoming excessive backlash or friction if either of these is present in connection with the operation of the chart drum on its shaft, owing to improper meshing of the pinion mounted on the bottom of the cylinder bottom plate and the stationary gear located at the foot of the shaft (spindle). On the other hand, personnel should *never* apply any oil to either the barograph mechanism or to the clockwork; for it should be noted that pivots in the mechanism are designed to operate without oil, and that the use of oil will tend to cause gumming up, thereby increasing friction, which is undesirable in these cases. Instructions pertinent to the matters referred to above are given in secs. A–2.16.3 and A–2.16.4; see especially secs. A–2.16.3.4, A–2.16.3.5, A–2.16.4.3, and A–2.16.4.9 for details.

Owing to the fact that the barograph operates by means of an aneroid element, it is not an absolute instrument, and therefore it must be calibrated. This implies normally that the readings of the barograph must be compared with the atmospheric pressures determined simultaneously at the same place on the basis of a standard barometer, and the pertinent correction ascertained for each reading. It will be understood in this regard that "correction" signifies the local atmospheric pressure *minus* the barograph reading. On this basis it would be possible to prepare a calibration curve giving the corrections pertinent to the various readings, and one would have to apply the appropriate correction to each reading of the barograph in order to determine the corresponding atmospheric pressure. Such a procedure would necessitate referring to the curve for the purpose of obtaining the proper correction pertinent to the existing reading. However, a simpler procedure can be employed in regard to barographs for which the correction is a constant for all readings. In the latter case, the same correction is applicable to every reading of the instrument regardless of where it occurs on the scale. With a view to achieving this simplification, open-scale barographs of good quality are designed to permit adjusting them in the laboratory so that they will give a response which is linear or very nearly linear. The significance of this can be understood from the fact that when the response of a barograph is perfectly linear, a constant correction can be applied to the readings anywhere on the scale for the purpose of obtaining the corresponding ambient pressures. The 2.5–1 barographs illustrated in figs. 2.9.0, 2.9.1, and A–2.21.10 have this capability, at least to a very close degree of approximation, provided that they are properly adjusted.

In accordance with normal operating procedures in the United States the practice is to adjust the open-scale barographs in the factory or laboratory where they are tested so that the instruments will give substantially a linear response. On this account, barographs adjusted to achieve that objective require a constant correction to their readings, which depends upon the difference between the ambient pressure and the reading shown by the pen at the time that the pen position was set by means of the station-pressure adjusting screw (see figs. 2.9.1 and A–2.21.10). Accordingly, barographs must be standardized at field stations by determination of the pertinent correction at certain times as stipulated in sec. 6.10.1.2; specifically at certain standard 6-hourly intervals usually related to the times of synoptic observations, at times that the barograph chart is changed, and at times when the pen position is reset. If very large fluctuations appear in the corrections obtained at such intervals, it is deemed advisable to investigate further the behavior of the instrument in order to ascertain whether it is malfunctioning, perhaps due to the development of a physical defect.

For detailed instructions and information regarding the standardization of barographs the reader is referred to sec. 6.10. (See sec. 6.10.0 which gives general information regarding the subject; sec. 6.10.1 which indicates the procedures that apply in the case of land stations; and sec. 6.10.2 which presents the procedures applicable in the case of barographs used on shipboard.)

Whenever a new barograph is delivered to a station, it is desirable to maintain a record of the corrections determined for the instrument at various readings and at various times. By studying the list of corrections pertinent to various dates in chronological order and also in relation to the reading one can ascertain whether the corrections are independent of reading and whether they are essentially constant or vary widely. If the corrections are independent of reading and are essentially constant, it may be concluded from the sample of data that the response of the barograph was linear within the limits of the investigation. However, if the corrections depend on the magnitude of the reading or if they vary over a significant wide amplitude, it can be concluded that the response is not linear. In this case the performance of the barograph may be regarded as unsatisfactory for precise meteorological observations. Such investigations of instrument behavior for the purpose of maintaining quality control should be repeated if, over any given period of time, the corrections reveal dependence upon the reading, large or rapid systematic variations with time, or erratic fluctuations over a range which is too wide to tolerate for precise work. If such unsatisfactory performance is found to be generally characteristic of the instrument, it should be taken out of service and a new barograph secured from stock.

By virtue of the fact that a barograph involves the use of an aneroid device, such as a pressure-responsive bellows, it is subject to all of the anelastic properties characteristic of the entire class of aneroid instruments as described briefly in sec. 2.9.0, some of which are depicted in figs. 2.10.0, 2.10.1(a), and 2.10.1(b). These characteristics are likely to manifest themselves by such behavior as variability of the corrections for decreasing and increasing pressure (hysteresis), or gradual change of the correction over a period of time (drift and zero shift).

Since the effects of these inherent anelastic properties are always more or less present, they cannot be eliminated or disregarded when using instruments having aneroid elements, and yet they can be accepted provided that their magnitude always remains within tolerable limits. Therefore, some allowance for these properties like hysteresis, after-effect, and recovery must be made when judging the quality of the behavior of the instrument on the basis of the relevant information compiled over a suitable interval; for example, a list showing (a) the corrections, (b) the corresponding readings of the barograph to which they relate, (c) the dates, and (d) the times at which the corrections were determined. In order to facilitate the investigation of the performance of the barograph, it is useful to prepare a quality control chart somewhat similar to that referred to in sec. 6.7.2.9.3 in connection with precision aneroid barometers used at land stations. A deeper investigation pertaining specifically to the effects of the above-mentioned properties may be carried out more or less along the lines indicated in sec. 6.7.2.9.7 which is concerned with the similar problem of the possible variability of aneroid barometer corrections stemming from the same causes. Fortunately, the characteristics of drift and zero shift tend to become smaller and smaller on a progressive basis with aging of aneroid elements of good quality; hence they can be allowed for by application of the last determined correction to the readings.

In order to ascertain the atmospheric pressure corresponding to any given reading, it is always necessary to apply the latest pertinent correction to the reading with the proper algebraic sign. This correction must always be posted at land stations (see sec. 6.10.1.3).

The times at which a barograph chart is removed from the chart drum or is replaced must be always recorded on the chart. At land stations certain additional times must also be recorded as indicated in sec. 6.10.1 (see especially secs. 6.10.1.5, 6.10.1.8, 6.10.1.11, 6.10.1.12, and 6.10.1.14). On shipboard, not only the specified times but also the latitudes and longitudes at 1200 Greenwich Civil Time, together with the date, must be entered (see sec. 6.10.2.2).

Since the barograph chart involves a record of pressure versus time, it is important that the time indicated by the pen be correct as closely as the chart drum can be set (see secs. 6.10.1.5, 6.10.1.11, and 6.10.2.1). At land stations time-check lines are to be made on each chart at certain times (see sec. 6.10.1.8).

Barographs require a certain amount of maintenance and care in regard to their proper operation such as cleaning of the pens, inking the pens, changing of charts, etc. Information relevant to these matters is given in sec. A–2.16.3 for land stations, and in sec. A–2.16.4 for ships.

As previously indicated, the aneroid barograph is subject to the same deficiencies which characterize the aneroid barometer (such as those due to anelastic properties referred to in sec. 2.9.0); but besides, it may have other deficiencies which stem from such things as pen friction, the use of the pen-lever magnifying mechanism, clockwork, chart-drum drive, dashpots or damper device, etc. Despite the problems which arise owing to the combined effects of these factors and elements, modern open-scale barographs are capable of giving reasonably good performance and results of good accuracy if they are properly handled and calibrated. In every case it is essential for observers to determine the pertinent corrections and time checks; while the latest appropriate correction must be applied to the readings in order to obtain the corresponding pressures.

2.9.2 Altimeter-Setting Indicators

Altimeter-setting indicators constitute one of the special types of aneroid barometers. They are specifically designed to give an indication of the current altimeter setting, as illustrated in figs. 6.8.1 and 6.8.2. Definitions of "altimeter setting" are given in Chapter 8, sec. 8.0.6.0; and for the sake of convenience we shall repeat the operational definition here: "If a perfectly calibrated altimeter is set to the altimeter setting existing at any given station whose elevation is H_p, the pointer of the instrument will yield an indicated altitude equal to H_p when the instrument is subjected to the pressure which exists at a height of about 10 feet above H_p." It should be understood that in the foregoing definition the symbol H_p simply represents a numerical value corresponding to the height of the station above mean sea level, say in feet. For practical purposes we can paraphrase the definition by applying it as follows to the case of a station whose elevation is 1000 feet above mean sea level: Consider the case of an aircraft about to land and make a touchdown at a field whose height above mean sea level is 1,000 feet. If the altimeter on the aircraft were adjusted to the current altimeter setting pertinent to the field, the pointers of the altimeter would indicate a reading of exactly 1000 feet at the instant of touchdown, provided that the altimeter were a perfect instrument, accurately calibrated, and located at a height of 10 feet above the field. This hypothetical example clearly reveals the operational significance of altimeter setting for landing purposes.

Chapter 8 contains illustrations showing various designs of precision, pressure-responsive altimeters (see figs. 8.0.1–8.0.5). In figs. 8.0.1, 8.0.2, and 8.0.4 the altimeter settings to which the given instruments were adjusted when the photographs were taken may be seen in the little window on the right-hand side of the dials. From these illustrations and the definition given above, it is readily possible to grasp the application to which altimeter settings are put.

It will be noted from the information given in Chapter 8 that altimeters are calibrated on the basis of the standard atmosphere; see Table 8.1, Appendix 8.0.1, and figs. 8.0.6–8.0.11. Since the altimeter-setting indicator is the inverse of the altimeter, at least in a functional sense, it follows that the altimeter-setting indicator must also involve a calibration on the basis of the standard atmosphere. Furthermore, it may be seen from the definition of altimeter setting that pressure is correlated with altitude in this connection. By virtue of these facts one may conclude that the standardization of the altimeter-setting indicator, as outlined in sec. 6.8, requires a knowledge of the true altimeter setting at the elevation of the instrument for the purpose of permitting a comparison of the true value with the indicated value. On these grounds one may also conclude that the altimeter-setting indicator must require a fixed setting which depends upon the elevation of the station above mean sea level. In harmony with this, each altimeter-setting indicator is provided with an "Elevation Scale" as shown in the lower portion of figs. 6.8.1 and 6.8.2. It is necessary to adjust the set screw on the instrument for the purpose of setting this scale to the proper elevation of the station with respect to mean sea level. When this adjustment is performed in an appropriate manner, it controls the correction which must be applied to the indicated readings of the instrument in order to obtain the corresponding altimeter setting. Sec. 6.8.2 gives instructions pertinent to the recommended setting of the "Elevation Scale" by means of the set screw and the procedures to be employed in determining the mean correction over a running period of time.

True altimeter settings required for the purpose of standardizing the instrument must be ascertained from station pressure data determined on the basis of properly corrected readings taken from a standardized mercury barometer, and the true altimeter settings are then found by conversion from these station pressures, taking the station elevation into account. The conversion may be performed in several different ways; for example, by means of a special table pertinent to the given elevation or a circular, slide-rule computer; see sec. 8.1 and sec. 8.1.2.

It is a common practice to furnish airport stations, air bases, etc., with altimeter-setting indicators, since their use enables personnel to determine the current altimeter setting simply by observing the pointer reading of the instrument and applying to the reading any small correction which may be necessary.

Since the altimeter-setting indicator operates by means of an aneroid element, it has essentially the same characteristics as an aneroid barometer in respect to anelastic properties, such as hysteresis, drift, aftereffect, etc., which have already been outlined in sec. 2.9.0 and are further discussed in secs. 2.10.0–2.10.10. It is, therefore, not an absolute pressure measuring instrument; and consequently it must be calibrated like any other aneroid-actuated barometer by comparisons with a properly standardized mercury barometer. Sec. 6.8 gives the instructions pertinent to the standardization of altimeter-setting indicators.

According to the terms of these instructions, it is necessary to subject new altimeter-setting indicators to a procedure which involves daily checks over a certain period for the purpose of ascertaining whether the instruments are functioning properly and are giving fairly consistent or constant corrections each time that a check is made by comparison with true altimeter-setting data based on mercury barometer readings. Then, if the behavior of the instruments satisfies certain criteria, they are regarded as valid for operational use, and the proper mean correction is determined over a 5-week interval, on the basis of ten (10) comparisons. A new mean correction must be thus determined in a running manner each week.

However, in case the corrections obtained from time to time reveal significant irregular fluctuations or progressive systematic variations with time, especially if rapid, such behavior is regarded as unsatisfactory and the instrument is taken out of service.

The altimeter-setting indicator is a delicate, precision instrument, and therefore it must be handled with great care. It should be installed securely at a place where it will be safeguarded from tampering, and will not be exposed to the direct rays of the sun or to sources of heat or cold which can cause its temperature to change rapidly. Uniform room temperature conditions are best for obtaining good performance from the device.

In cases where an altimeter-setting indicator is installed within a structure which is frequently exposed to fairly strong and gusty winds, it is deemed advisable to connect the instrument to a static-pressure head; see sec. 2.11.1 and Appendix 2.11.1.

2.9.3 Altimeters

2.9.3.0 General Information Regarding Altimeters.—Two classes of altimeters are distinguished for the purposes of the present section, namely, *aircraft altimeters* and *surveying altimeters*; the former of which are discussed in sec. 2.9.3.1, and the latter in sec. 2.9.3.2. In both cases we are concerned with pressure-responsive instruments. Generally, the two specified classes of altimeters are calibrated on different bases.

As may be inferred from the term "altimeter" applied to these instruments, they are intended to indicate altitude. However, since the instruments are actuated by pressure, it is not possible to obtain from them true absolute altitude as it might be measured by means of a vertical, linearly graduated rod, tape, or yardstick. Altimeters must therefore be calibrated on the basis of some *assumed* relationship between atmospheric pressure and altitude; but the actual atmosphere does not always conform to the assumed relationship, hence one does not necessarily obtain from them the true altitude.

True absolute altitude can only be determined by some method which involves direct measurements with respect to mean sea level; e.g., as in the case of geodetic surveying based on the use of accurately graduated rods and a leveling instrument. It is a universally accepted convention that mean sea level shall serve as the datum for absolute altitude, regardless of how it is determined.

Owing to the limitations of pressure-responsive altimeters, they are only capable of giving relative indications of altitude, not absolute ones. This conclusion stems from a number of facts, including the following: (1) The relationship between pressure and altitude assumed for calibration purposes will generally differ somewhat from that which is encountered in the atmosphere; hence insofar as no correction is made to allow for the effect of the difference, corresponding errors will occur in the indicated readings. (2) If the instrument is designed with a movable pressure scale, such that the scale which is employed for the calibration may be moved with respect to the scale used to give readings of indicated altitude, then the indicated values depend upon the relative setting of the two scales, while errors may appear in the indicated readings if the setting is not representative for the locality where the instrument is actually being used. (3) Whenever the altimeter is subject to inherent instrumental errors or whenever the pressure which is applied to it is not representative of the actual, ambient static pressure, the readings yielded by it are not quite correct. (4) Since the actual free-air conditions of temperature and humidity affect the true relationship of pressure-versus-altitude in the atmosphere, as shown by the hypsometric equation developed in Appendix 7.1, these conditions have a significant influence upon the altitude indicated aloft by the altimeter for any given ambient pressure, and they have to be taken into account whenever it is necessary to determine true absolute altitude on the basis of the indicated readings.

By virtue of the fact that the pressure-responsive altimeter only enables the direct determination of altitude on a relative but not an absolute basis, it is most useful and reliable for ascertaining differences in altitude between horizontal planes fairly close together rather than for giving the absolute heights of these planes above mean sea level. Even then, the differences in indicated altitude yielded by an altimeter will generally not be strictly accurate unless they are corrected to take account of the existing conditions, especially in regard to mean virtual temperature between the planes (for further pertinent information see Appendix 7.1 on the hypsometric equation, Chapter 8 on Altimetry, and Chapter 9 on Hypsometry).

It is considered that the scope of this manual does not include those types of altimeters which are not pressure responsive, e.g., radio-altimeters.

2.9.3.1 Aircraft Altimeters.—Figs. 8.0.1–8.0.5 illustrate some samples of pressure-responsive aircraft altimeters. It is a fixed rule that the pressure-versus-altitude scale of aircraft altimeters shall be calibrated in accordance with the standard atmosphere. See Appendix 8.0.1 and fig. 8.0.6. The sensitive pressure aircraft altimeter, as shown in the above-mentioned figures, is provided with a pressure scale and a knob which permits the pilot in an aircraft to adjust the pressure-scale setting. For purposes of aircraft landing, terrain clearance, vertical separation between aircraft, and some other applications, the local, current "altimeter setting," as defined in secs. 2.9.2 and 8.0.6, is commonly used as a basis for the setting (or adjustment) of the pressure scale. When the knob is turned to change the altimeter setting, this causes the built-in pressure-versus-altitude scale to shift its position relative to that of the fixed indicated altitude scale (or dial) by means of which the pilot obtains the reading of indicated altitude (see figs. 8.0.1–8.0.5 for examples of such altitude scales). Figs. 8.0.8–8.0.11 have been designed to illustrate schematically this basic characteristic of the altimeter mechanism. Secs. 8.0.3 and 8.0.4 give information concerning the operation and performance of sensitive pressure altimeters in a fundamental sense, neglecting instrumental errors and discrepancies which arise when the pressure applied to the altimeters is not representative of the ambient, static atmospheric pressure (see sec. 2.11.1, Appendix 2.11.1 and sec. 8.2).

Sensitive pressure aircraft altimeters, like other aneroid instruments, are subject to a number of errors, some of which have already been mentioned in sec. 2.9.0, with further discussion given in secs. 2.10.0–2.10.10. The errors or factors which affect the accuracy and reliability of the pressure-altimeter system as a whole have been classified under four broad categories as follows: (a) *mechanical errors*, such as those resulting from the characteristics of the aneroid element and the instrument mechanism; (b) *operation and installation errors*, such as those appearing by virtue of the manner in which the instrument is operated, read, or installed; (c) *errors of basic principle*, such as those which stem from the calibration of the altimeter on the basis of the standard atmosphere while the actual atmosphere wherein the instrument is employed will generally have horizontal and vertical distributions of pressure and temperature different from the standard; and (d) *additional factors*, such as the size of the aircraft and the accuracy with which the desired cruising or flight level can be maintained either by a manual or automatic procedure of piloting. Since any discussion relating to these matters is highly technical and properly belongs under the heading of altimetry, we have placed the treatment of the subject in Chapter 8 (see, for example, sec. 8.2).

Thus far in this section, and in Chapter 8, the only type of instrument dealt with is the sensitive pressure altimeter, provided with a pressure scale and means to permit adjustment of the altimeter setting. In addition, there exists a type most commonly employed on light and small, low-powered aircraft, used mainly for private flying under visual flight conditions. The latter type is not equipped with a pressure scale. As a rule the altimeters most commonly installed on such aircraft, are not of the sensitive pressure type (such as the one shown in fig. 8.0.1) but are designed more simply and with less sensitivity than the kind treated in Chapter 8. Owing to the lack of a pressure scale on the simple, less sensitive type, it is not possible to adjust this type to any given altimeter setting on a scale. However, it is possible to rotate the interior mechanism of such instruments. This permits the pilot to adjust the device so that the hands of the instrument indicate zero (0) altitude or the field elevation at takeoff. When the atmospheric pressure changes at the surface or when the aircraft is flown to a different locality where the pressure and/or elevation are not the same as at the original takeoff point, the indications of the non-sensitive altimeter may be non-representative. Further discussion of this type is considered to be outside the scope of the present manual.

2.9.3.2 Surveying Altimeters

2.9.3.2.1 *Function of surveying altimeters.*—Surveying altimeters are devices actuated by atmospheric pressure and designed to give an indication of altitude, specifically for the purpose of enabling the user to determine differences of elevation between points in close proximity situated on the surface of the earth.

Almost all of such instruments function mechanically by means of a sensitive aneroid element, more or less similar to that illustrated in fig. 2.8.0; however, other methods of operation have also been developed (see fig. A–2.13.1). The surveying altimeter typically has a dial graduated in altitude units, such as feet or meters, with a mechanism so designed that the indicating hand will move over very nearly equal increments of angle for equal increases of reading of the altitude scale. Some surveying altimeters have also been provided with a concen-

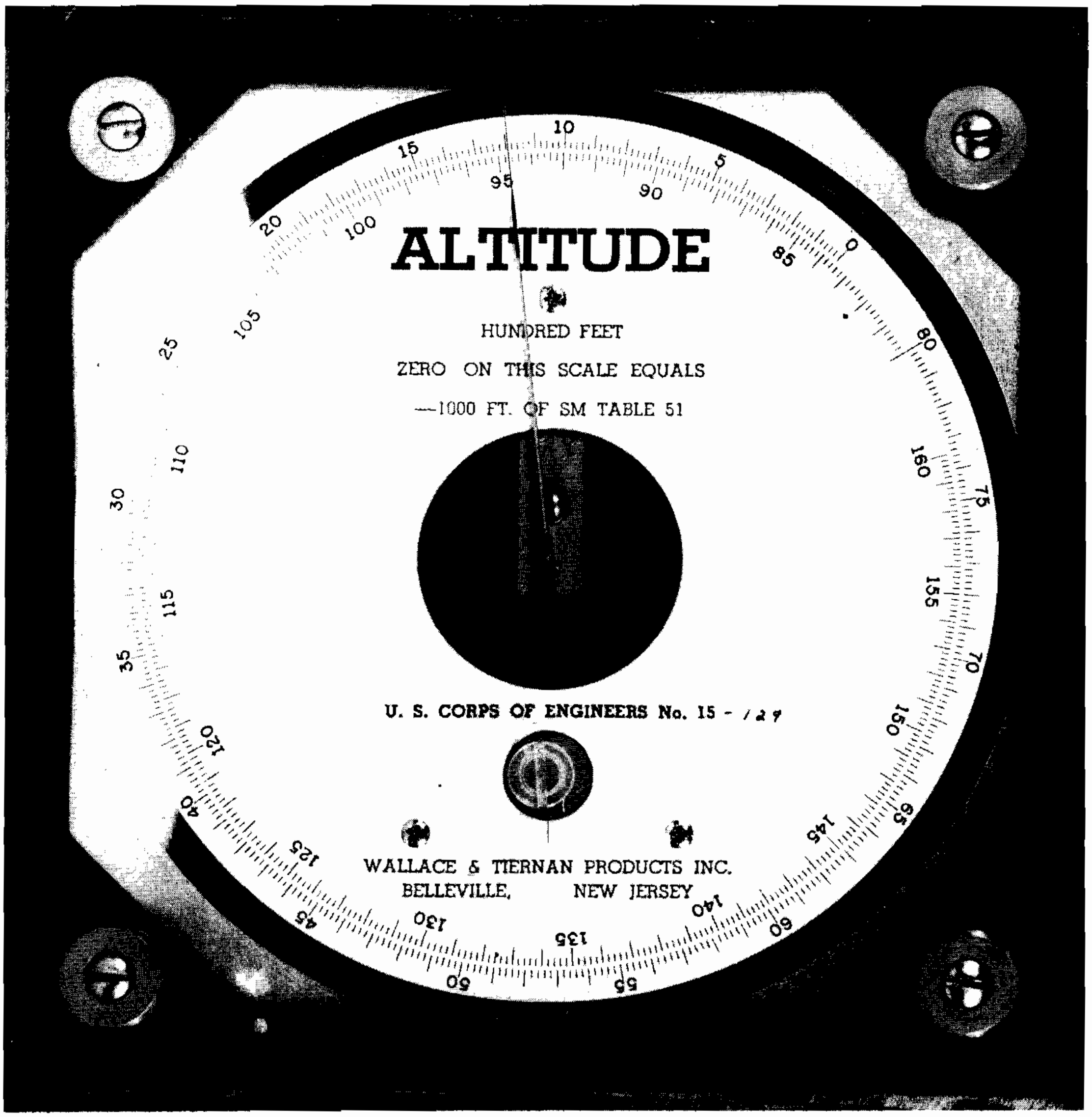
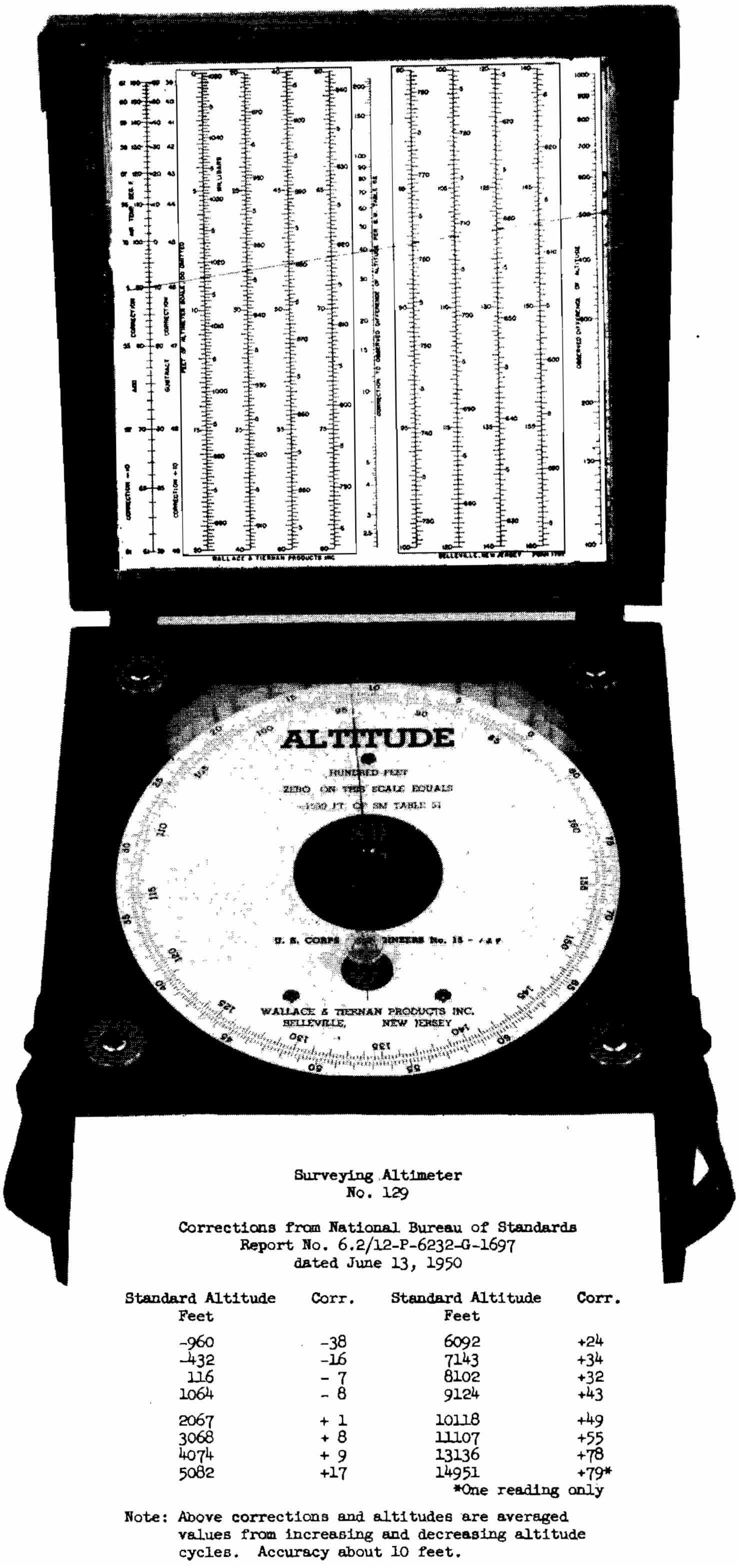


FIGURE 2.9.2. One design of surveying altimeter, graduated on basis of a fictitious dry atmosphere for which it is assumed that the temperature is uniformly 50° F., and the pressure at an altitude of 1000 feet is 29.90 in. Hg.

tric, direct reading pressure scale, which permits the same hand (needle pointer) to be employed for indicating concurrently on both the altitude scale and the pressure scale. Such instruments can serve in a dual capacity, namely as surveying altimeter and aneroid barometer.

2.9.3.2.2 *Graduation of scale.*—The scale of surveying altimeters must be graduated on the basis of some assumed relationship between pressure and altitude which refers to a fictitious atmosphere employed solely for calibration purposes. The most commonly used relationship for the calibration of the scale is derived from the assumption that the fictitious atmosphere is isothermal and devoid of moisture; that is, at uniform temperature at all altitudes and dry. It has been conventional to adopt the value of 10° C. (50° F.) for the temperature in the fictitious isothermal atmosphere. While most of the instruments were based on an as-



Surveying Altimeter
No. 129

Corrections from National Bureau of Standards
Report No. 6.2/12-P-6232-G-1697
dated June 13, 1950

Standard Altitude Feet	Corr.	Standard Altitude Feet	Corr.
-960	-38	6092	+24
-432	-16	7143	+34
116	- 7	8102	+32
1064	- 8	9124	+43
2067	+ 1	10118	+49
3068	+ 8	11107	+55
4074	+ 9	13136	+78
5082	+17	14951	+79*

*One reading only

Note: Above corrections and altitudes are averaged values from increasing and decreasing altitude cycles. Accuracy about 10 feet.

FIGURE 2.9.3. Surveying altimeter in case, showing below the instrumental corrections determined by calibration, and above by a nomographic chart used to calculate effects of deviation of temperature *in* the actual atmosphere from the assumed standard. (See figs. 2.9.2. and 2.9.4.)

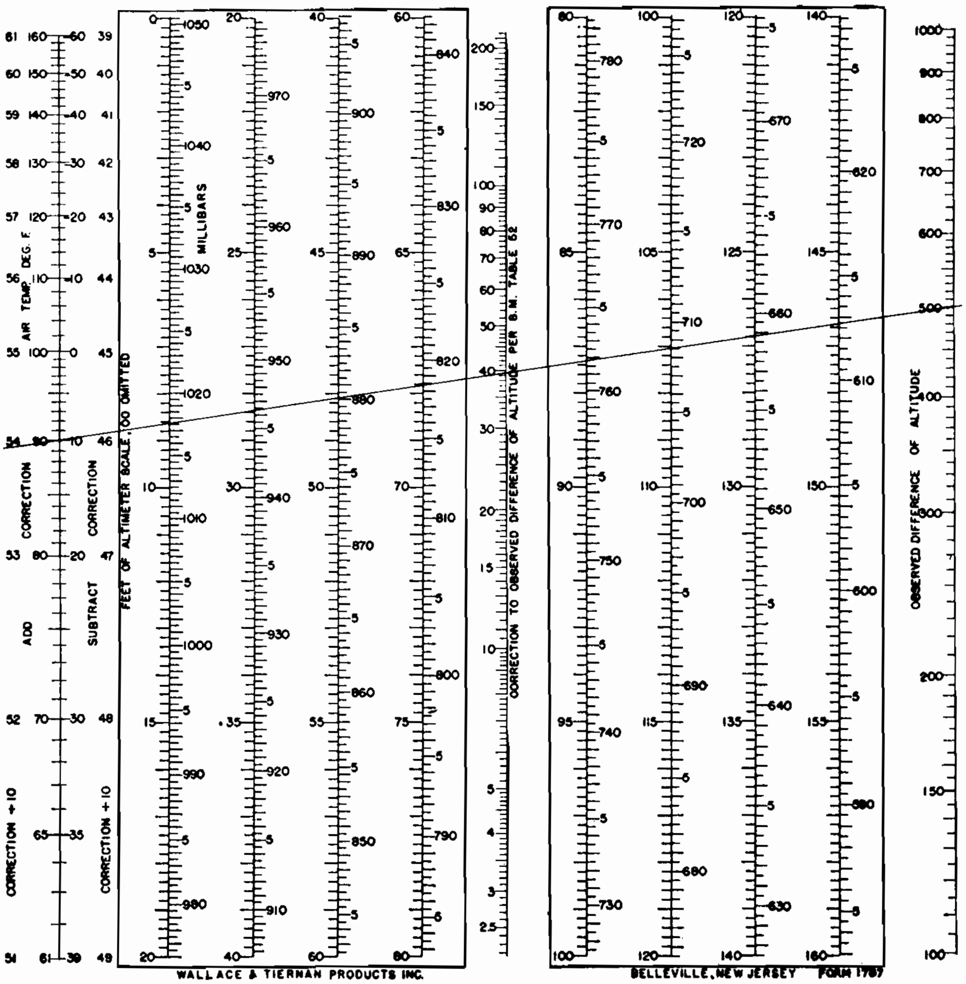


FIGURE 2.9.4. Nomographic chart for calculation of temperature correction of surveying altimeter. (See figs. 2.9.2 and 2.9.3.)

sumed dry atmosphere, some have been calibrated under the assumption of an average degree of humidity.

Another assumption is necessary in regard to the pressure which is to correspond to the zero (0) of the altitude scale in the fictitious atmosphere employed for the calibration. Some surveying altimeters used in the United States are graduated on the basis of a fictitious isothermal atmosphere having an assumed temperature of 50° Fahrenheit and an assumed pressure of 29.90 inches of mercury corresponding to the zero (0) of the altitude scale.

Thus, on the basis of these assumptions the altitude scale is calibrated in accordance with the following equation:

$$Z = 62583.6 \log (29.90/P) \qquad (1)$$

where Z is the indicated altitude in feet, P is the atmospheric pressure in inches of mercury, and log denotes the common logarithm (base 10); and where it is assumed that the fictitious, dry atmosphere is uniformly at temperature 50° F.

Tables giving Z for various values of P, by increments of 0.01 inch of mercury, over the range from 12.00 to 30.89 inches of mercury, and computed on the basis of the foregoing equation, have been published.[19]

Fig. 2.9.6 illustrates a surveying altimeter graduated in conformity with equation (1), from which it may be observed that in the case of values of P in excess of 29.90

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[19] Smithsonian Meteorological Tables, Fifth Revised Edition, First Reprint, 1939, Smithsonian Institution, Washington, D. C. (See the Introduction, pp. xliv–xlix; and Table 51, pp. 133–136. Note: The earlier issue, dated 1931, contained some *errors relevant* to the subject.)

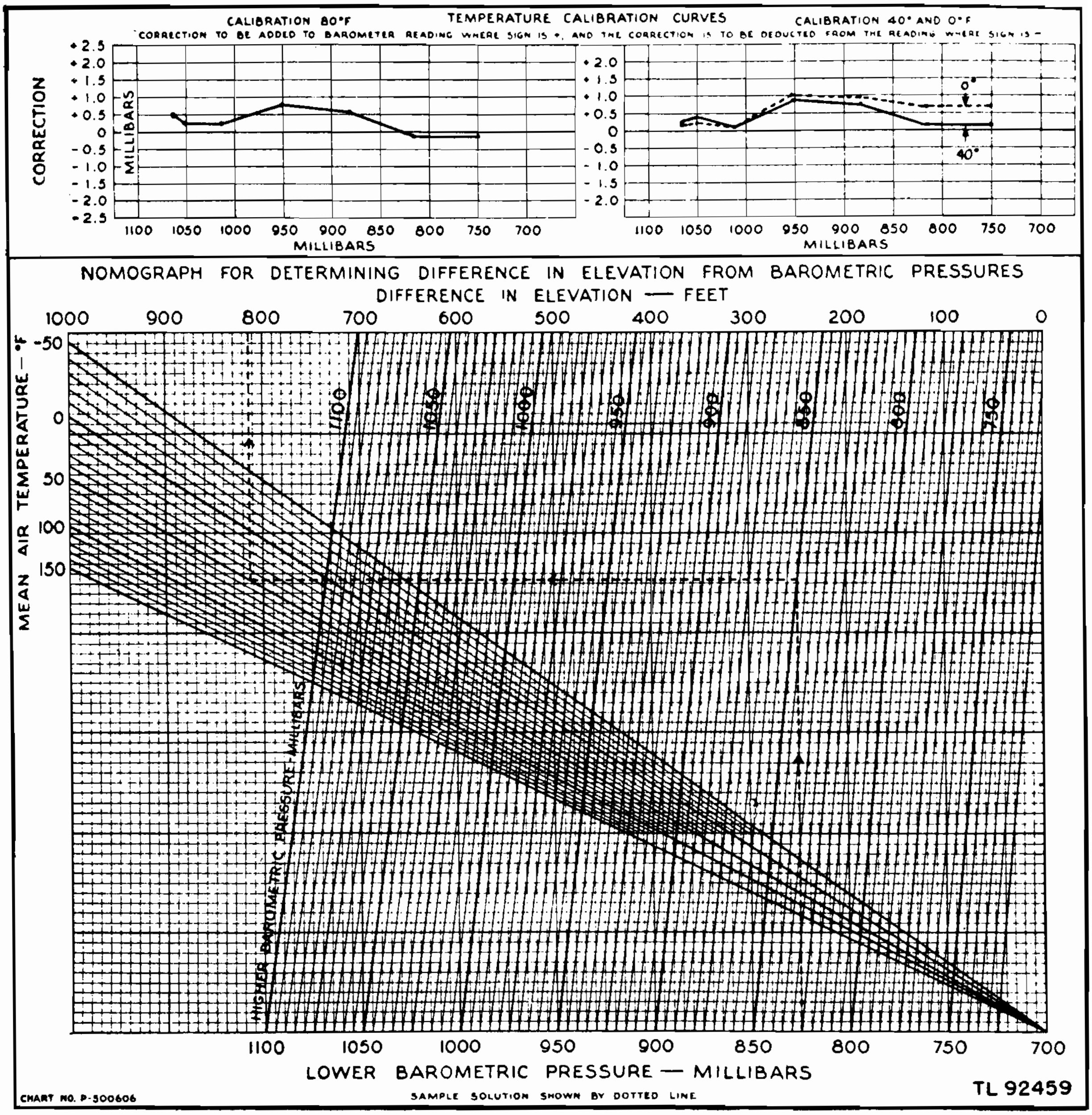

FIGURE 2.9.5. *Upper portion:* Sample temperature calibration charts prepared for a particular aneroid barometer of type ML–102–E showing the corrections to be applied to the instrument readings at temperatures 0, 40, and 80 degrees F., depending upon the observed scale reading in millibars. *Lower portion:* Nomograph which may be used to compute the difference in elevation between two neighboring points, depending upon the pressures observed at the two levels and the mean air temperature. (The dotted line marked with arrows indicates the procedure for obtaining a solution in a typical case.)

inches of mercury, the indicated altitude (Z) will be negative (—).[20]

Fig. 2.9.7 shows a lightweight portable surveying microbarograph, designed to present a continuous record of indicated altitude on a chart mounted on a clock-driven cylinder and calibrated in accordance with equation (1); therefore yielding results consistent with those given by the instrument depicted in fig. 2.9.6, which is manufactured by the same company.[20]

Other surveying altimeters used in the

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[20] Photographs for figs. 2.9.6 and 2.9.7 supplied through the courtesy of the manufacturer, American Paulin System, Los Angeles, California; figures published by permission.

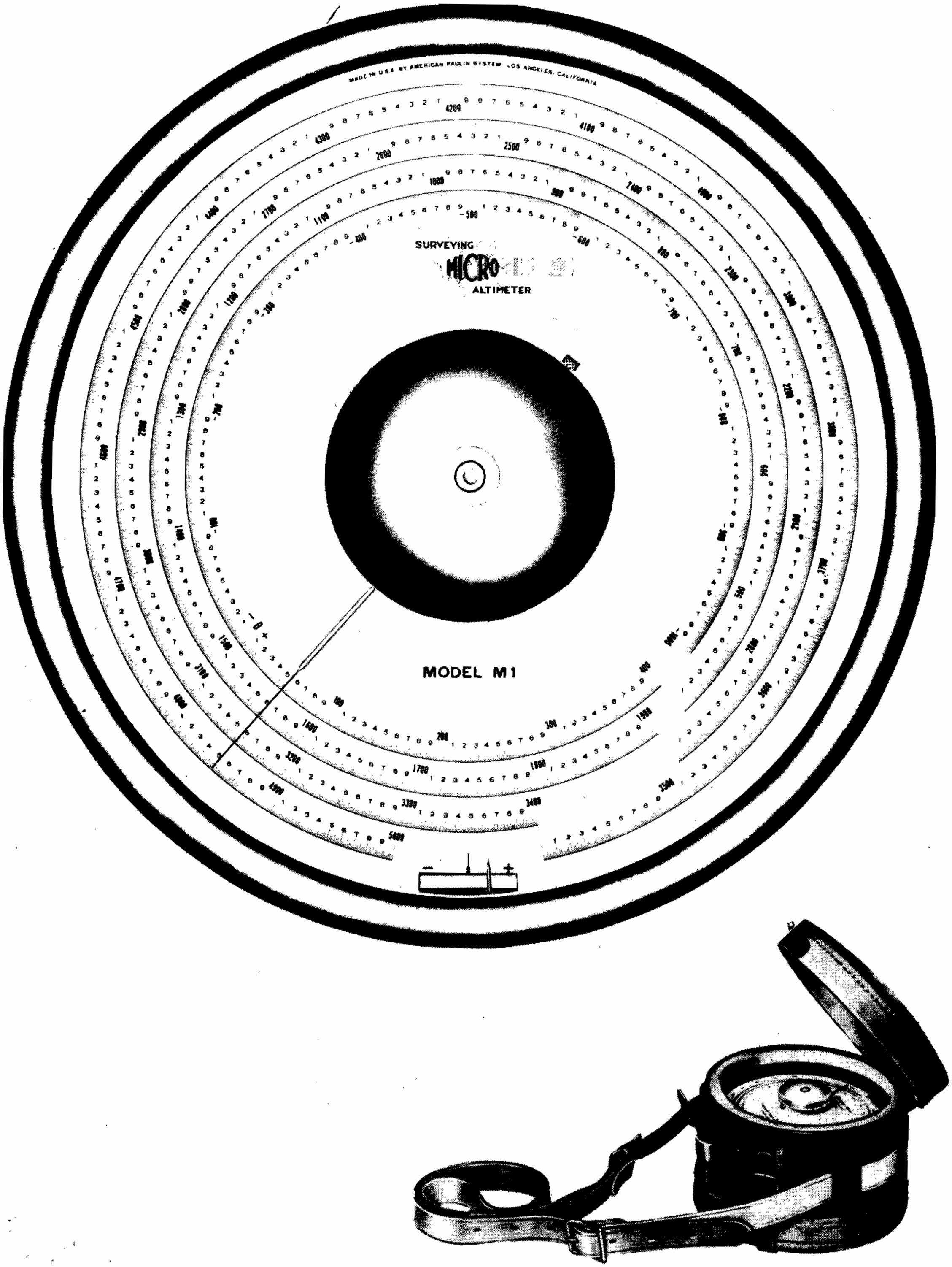

FIGURE 2.9.6. A design of precision surveying altimeter manufactured by American Paulin System. (Graduated to intervals of 1 foot; range −1000 feet to +5000 feet.)

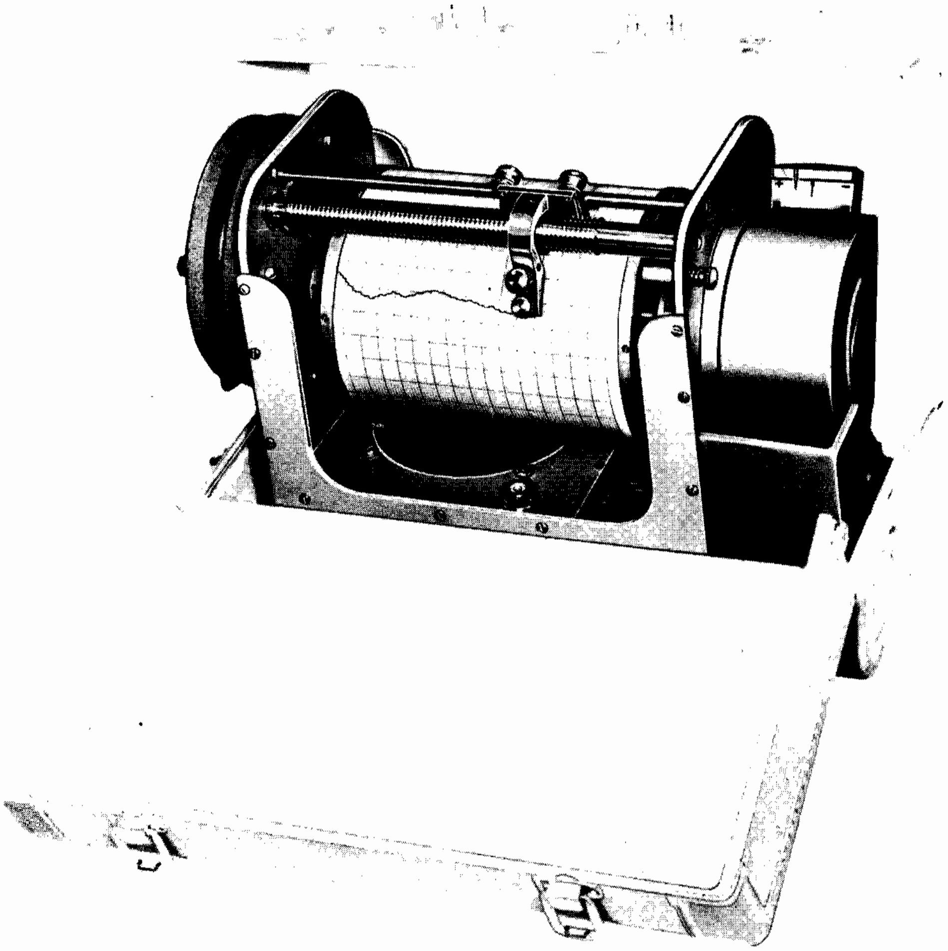

FIGURE 2.9.7. Surveying microbarograph manufactured by American Paulin System, Los Angeles, Calif.

United States are graduated on the same basis as explained in connection with equation (1), except that the altitude scale is engraved in an orientation which is shifted by the amount plus (+) 1,000 feet relative to that employed for those instruments strictly graduated in conformity with equation (1). Figs. 2.9.2 and 2.9.3 illustrate surveying altimeters the scales of which are shifted by this amount; hence the equation on whose basis they are calibrated is

$$Z = 62583.6 \log (29.90/P) + 1000 \text{ feet}; \quad (2)$$

where Z is the indicated altitude, in feet, for such instruments. The effect of employing equation (2) is to cause the indicated altitude (Z) to be positive for values of pressure (P) less than 31.026 inches of mercury.

A comparison of equations (1) and (2) reveals that if a pair of surveying altimeters graduated on the basis of these relationships, respectively, is exposed to pressures P_a and P_b in turn, the *differences* between the indicated values of Z observed under these two pressures should be concordant as determined from each of the instruments.

2.9.3.2.3 *Corrections for air temperature and humidity.*—When surveying altimeters are used in the field with a view to determining the true difference in elevation between two points (such as one at a base point within a valley and the other on a hilltop nearby), it is necessary to take account of the average (mean) temperature of the air column between the two levels in order to ascertain the temperature correction of the indicated difference in altitude. The indicated difference in altitude is found by subtracting the indicated altitude of the lower point from the indicated altitude of the higher point. The correction of the indicated difference in altitude for temperature depends upon the product of the indicated difference and the departure of the mean temperature of the air column from the temperature assumed in the fictitious isothermal atmosphere.

Various methods have been developed to enable one to compute the correction of the indicated altitude difference for mean temperature of the air column. A graphical method involves the use of a nomographic chart such as that depicted inside the cover of the instrument shown in fig. 2.9.3, and presented in more enlarged form in fig. 2.9.4. The lower portion of fig. 2.9.5 presents a different design of nomograph which may be used for the computation of the difference in elevation between two points not too far apart horizontally, and which may be applied when air temperature and barometric pressure readings are made simultaneously at both points. Another method is based on the employment of computation tables designed to facilitate the arithmetic work entailed.[21] The latter method is of such general validity that it may be used on the basis of surveying altimeter data or of barometer data.

The theory relating to the calculation of true differences in altitude as determined on the basis of pressure, temperature, and humidity observations made at a succession of levels at progressively higher altitudes is given in Appendix 7.1.

A correction for humidity at a point in the air column for which the dew point, pressure, and temperature are known can be estimated with the aid of Tables 7.6.1 and 7.6.2 of this manual, taking account of the information given in sec. 7.3.2.0.4 (see also pages 295–301 of the Smithsonian Meteorological Tables, Sixth Edition, First Reprint, 1958).

The information presented in sec. 7.3 of this manual is relevant to the problem of determining the mean virtual temperature of the air column for the purpose of computing the true difference in altitude between two points, one above the other in the free air or at neighboring places on the surface of the earth; see also sec. 7.0.3 and Appendix 7.1.

2.9.3.2.4 *Geopotential used for scale graduation.*—All altimeters are graduated in units of geopotential, not geometric altitude; see sec. 1.3, and Appendixes 1.3.1, 7.1, and 8.0.1. Conversion from meteorological units of geopotential to geometric units, and vice versa, may be performed with the aid of tables given on pages 217–223 of the Smithsonian Meteorological Tables, Sixth Edition, First Reprint, 1958. It should be noted that in the meteorological system of units one (1) geopotential meter is equal to 9.8 $m.^2$ $sec.^{-2}$; whereas in the aeronautical system of units one (1) standard geopotential meter is equal to 9.80665 $m.^2$ $sec.^{-2}$ See Appendix 8.0.1.

Both aircraft and surveying altimeters have their scales graduated on the basis of the standard geopotential unit; that is, one (1) so-called "meter" or "foot" of indicated reading on the scale of the instrument is in reality one standard geopotential meter or foot, respectively, where one standard geopotential foot = 0.3048 standard geopotential meter = (0.3048 x 9.80665 $m.^2$ $sec.^{-2}$).

2.9.3.2.5 *Calibration.*—Precision surveying altimeters are generally sensitive to a change of one foot in elevation; and they can usually be read to about the nearest foot. However, these instruments operate on a relative basis, and do not yield direct readings of absolute, true elevation as previously indicated, since certain corrections are essential. In order to obtain the maximum capabil-

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[21] "Smithsonian Meteorological Tables," published by the Smithsonian Institution, Washington, D.C. See Fifth Revised Edition, First Reprint, Corrected 1939, pp. 133–138, and 143–151; and Sixth Revised Edition, First Reprint, Corrected 1958, pp. 203–210, 224–262, and 295–301.

ity in regard to accuracy from such devices, it is necessary to calibrate them carefully at close intervals on the scale both immediately before and after each field surveying project.

Corrections to the indicated readings to overcome mechanical instrumental errors are determined on the basis of calibrations; and such corrections are usually tabulated and/or plotted, as illustrated in figs. 2.9.3 and 2.9.5. The appropriate corrections must be applied to the readings of the instruments in order to obtain the proper, corrected indicated altitudes, conforming more or less with equations (1) or (2), whichever is pertinent. See sec. 2.9.3.2.6 regarding the correction for instrument temperature.

While it is theoretically possible to calibrate precision surveying altimeters in a chamber under carefully controlled temperature and pressure to within an accuracy of about one or two feet by means of a large bore standard barometer connected to the chamber (see Chapter 6), such an operation would require unusual precautions and much more time for its successful completion.

With a view to obviating the need for a calibration procedure which entails such a great consumption of time, Dr. Daniel Johnson of the Mechanical Instruments Section of the National Bureau of Standards has developed a barostat, designed to yield conveniently a series of constant pressure steps within the test chamber. Fig. 2.9.8 shows a schematic diagram of the Johnson barostat as modified and constructed at the instrument shop of the Geological Survey, U.S. Department of the Interior.[22] That agency supplied the following description concerning the principle of operation of the barostat depicted in fig. 2.9.8:

"Inasmuch as the stops limit the deflection of the bellows to a small range, hysteresis is virtually eliminated. To simplify the diagram, the weights are shown inside the bellows; in the actual instruments, however, they are placed in a pan situated outside and below the bellows unit. With the system in

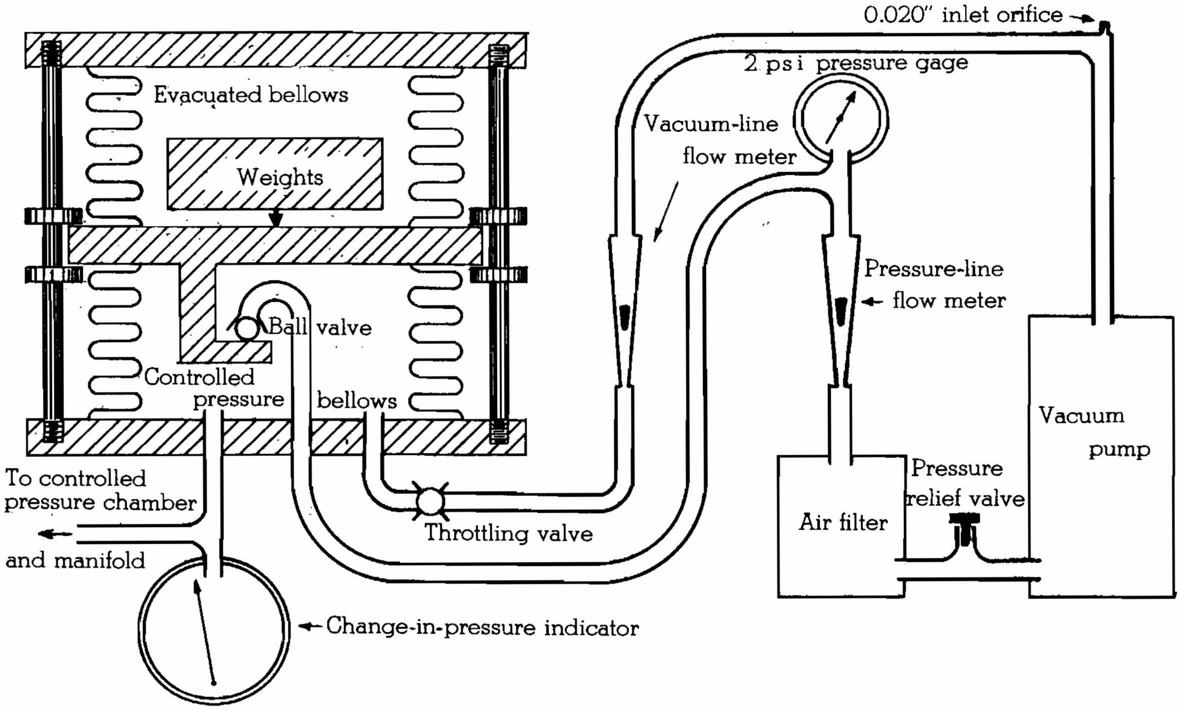

FIGURE 2.9.8. Schematic diagram of barostat used by the U.S. Geological Survey to test surveying altimeters at constant pressures corresponding to 100-foot altitude intervals. (Device is modified version of the barostat designed by Dr. D. P. Johnson of the National Bureau of Standards.)

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[22] Figure and related material obtained from the monograph by James L. Buckmaster and Atherton H. Mears, entitled "Instrumental Improvements in Altimetry," Geological Survey Circular 405, U.S. Department of the Interior, Geological Survey, Washington, D.C., 1958. Figure published by permission of the Director.

equilibrium, air flows continuously through both the vacuum and pressure lines; the rate of flow is limited to 1 or 2 liters a minute by the throttle valve of the vacuum line. Because of the evacuation of the upper bellows, the floating member and controlled pressure are not affected by external air pressure or barometric changes.

"As an example of the operation of the barostat, assume that the test-chamber pressure is to be changed from an equivalent elevation of 1,200 feet to 1,300 feet. Weight 12 is removed from the weight pan. As the air pressure within the control bellows is now greater than the force exerted by the weights, the floating member rises, closing the ball valve and cutting off the flow of air from the pressure line into the chamber. Air continues to be exhausted from the chamber through the vacuum line, reducing the controlled pressure until the air pressure acting on the floating member again equals the opposing force of the weights."

During calibrations the test-chamber pressure is governed by removing from the pan or applying to it in regular succession a set of precisely machined weights, calculated to produce in the test chamber constant pressure at intervals which correspond to 100-foot steps of altitude on the instrument scale. It is essential to calibrate independently by means of a standard barometer at least one of the constant pressure intervals yielded by the barostat, in order to establish a pressure datum. Investigations conducted at the Geological Survey have shown that with proper care and experience the barostat permits the rapid calibration of surveying altimeters by a relatively simple operational procedure. It provides accurately repeatable constant pressure steps, to a degree of precision and consistency which would be impracticable to achieve by means of a small bore mercury barometer or an aneroid barometer. The results derived from the calibrations with the aid of the barostat for decreasing and increasing pressure steps are combined to give mean corrections to the indicated readings of the surveying altimeters at 100-foot intervals. An advantage of this technique is that it reduces the effects of error due to hysteresis (see secs. 2.9.0 and 2.10.0–2.10.10).

When a group of surveying altimeters is employed in the field, for example as a set of six, to determine elevations at a number of points on the surface, as for the purpose of topographic mapping, it is of the utmost importance that the corrected data yielded by the various instruments of the group be in harmony. The obvious method of achieving such agreement and consistence would be, of course, to calibrate the altimeters within a test chamber whose pressure can be precisely controlled and measured independently by accurate means at one or more steps if necessary, as previously explained.

However, when a surveying party is in the field and it is not practicable to undertake such an extensive laboratory calibration, the following instructions may be pursued with the objective of securing a certain degree of consistency between the corrected readings obtained from the group of surveying altimeters: (a) Install the altimeters in a vehicle. (b) Drive the vehicle from a low to a high elevation, or vice versa, and return. (c) Stop the vehicle about every hundred foot increase or decrease of elevation as indicated by the average readings of the instruments in the group; and the vehicle should be held at each such stopping place for at least several minutes before making any readings. (d) Read each of the altimeters, record the data on a suitable form, and check the readings to be sure that no errors in either interpretation or entry of data have occurred. (e) Compute the average of the readings of all of the altimeters in the group at each respective stopping point. (f) For every stopping point determine the departure of the average (mean) of the readings of all of the altimeters at the given point from the individual reading of the given altimeter. (g) Prepare for each instrument a chart showing a plot of the departure just defined against the individual reading, and consider that the departure represents a correction. (h) Construct a curve on the chart for each instrument based on the plotted data; doing this by connecting each adjacent pair of plotted points by straight line segments and projecting the segments to the nearest 100-foot lines of the scale of indicated altitude reading, thereby obtaining a calibration curve. (i) Afterward, when using the instruments as a group for surveying at various points in the field, obtain the correction corresponding to each individual reading from the chart pertinent to the given instrument, and apply it with the proper algebraic sign to the reading. Thus, if the departure is positive (that is, if the mean reading based on all of the instruments *minus* the individual reading of the given instrument is a plus value), the correction should be added to the readings during subsequent surveys; but if the difference yields a negative value, its arithmetic magnitude must be subtracted from the reading, in order to obtain results consistent with the mean derived from all the instruments.

The foregoing procedure is designed to obtain consistent, corrected results from the various instruments in the group, but it does not assure that the results are absolutely accurate. An improvement in the final results can be secured if the foregoing process is repeated several times and the curves developed from the averages of the several determinations relating to the points for each 100-foot level pertinent to the individual instrument. As a rule, the above-mentioned departures based on the ascent and descent, by 100-foot steps, should be combined to obtain means representing the corrections which are plotted as points, rather than single values, since this procedure will tend to average out effects of hysteresis and yield more stable results.

By performing calibrations at intervals closer than 100 feet on the scale readings, it has been found that some individual altimeters will reveal anomalous points on the calibration curve; that is, points which deviate significantly from a smooth curve constructed on the basis of observations at 100-foot intervals. For example, a deviation of six (6) feet was determined in one case, when the altimeter was calibrated at 10-foot intervals.[22]

Fig. 2.9.9 illustrates calibration curves of a service surveying altimeter determined by two different methods: (a) by means of the barostat; and (b) by means of comparisons with 9 other service altimeters of the same make, where all of the instruments were observed simultaneously within a chamber at constant, controlled pressure. A systematic difference between the curves which varies with indicated altitude is apparent. This difference is attributed largely to anelastic phenomena, e.g., hysteresis in the aneroid instruments, since the barostat is not similarly affected.

2.9.3.2.6 *Temperature effect on instrument.*—Surveying altimeters of good quality should be compensated insofar as practicable for the effects of temperature variations of the aneroid element and its associated mechanism. However, perfect compensation is not obtainable. For this reason in precision work with surveying altimeters it is desirable to calibrate the instruments for the effects of temperature, to prepare a temperature correction curve for each altimeter, and to apply an appropriate correction for temperature to each field reading of the instrument.

In order to permit ascertainment of the temperature of the instrument a thermometer should be in direct contact with the de-

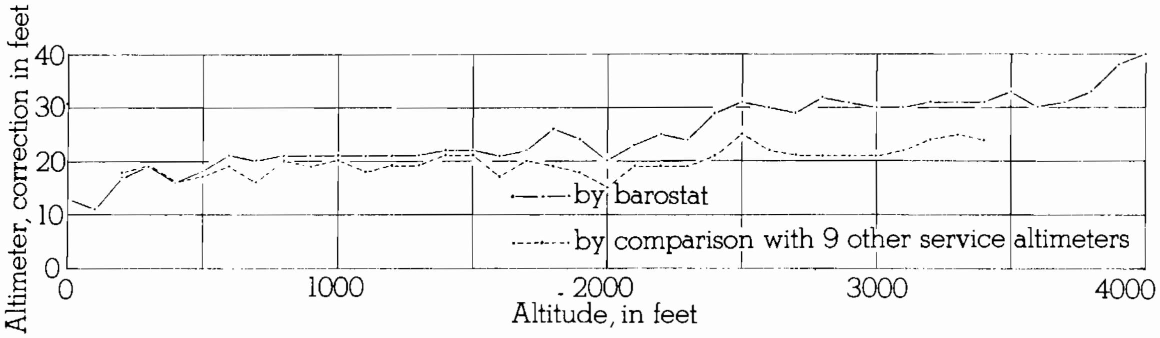

FIGURE 2.9.9. Calibration curves for service altimeter T-25270 obtained at the U.S. Geological Survey by two methods.

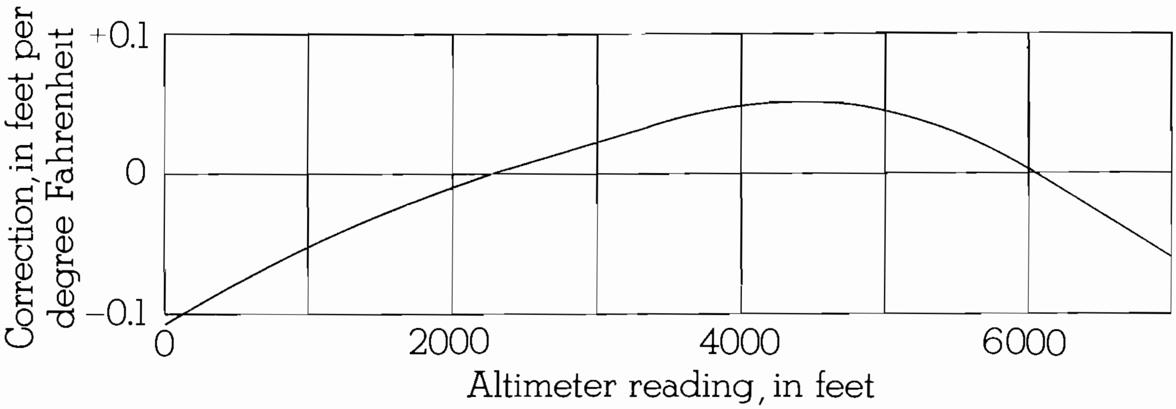

FIGURE 2.9.10. Temperature correction factor curve for a U.S. Geological Survey service altimeter. The ordinate is a factor which when multiplied by (t° F. — 75° F.) yields the correction of the indicated altimeter reading for temperature; where t° F. = temperature of the surveying altimeter, in °F.

vice. Care must be taken *never* to allow the altimeter to be exposed to direct rays from the sun; instead it should be used in the shade, as a rule face up in a horizontal position. If placed on a rigid surface, it is desirable to employ an intervening thermal insulator.

Fig. 2.9.10 shows a temperature correction curve for a surveying altimeter used by the U.S. Geological Survey.[22] This instrument was calibrated within the test chamber of the barostat at a temperature of 75° F.; hence the effects of temperature given by the curve vary with departure of the altimeter temperature (*t*° F.) from 75° F. The ordinate of the curve represents a factor, in feet per °F., which if multiplied by (*t* — 75° F.) yields the correction, in feet, considered algebraically.

If a surveying altimeter is used in the field for precision work under conditions of rapidly varying temperature it is desirable to maintain the instrument in the shade for a suitable time at each point being surveyed before readings are made. This lapse period is intended to permit the instrument to come closely to thermal equilibrium with the environment.

The effect of temperature variations of the instrument should, of course, not be confused with the effect of temperature variations of the atmosphere, the latter having a role in the calculation of true difference of elevation (see Appendix 7.1).

2.9.3.2.7 *Conditions of field operations.*—The following outline of instructions suggests the main points to be considered in the operational use of surveying altimeters in the field:

(a) Handle the instrument with care; do not jolt it; employ a good carrying case with a sturdy carrying strap for its transportation; do not drop the instrument.

(b) Keep the altimeter out of the rays of the sun.

(c) Place the instrument face up in the reading position when it is not being carried. Employ some thermal insulator between the instrument and the supporting surface if their temperatures differ significantly.

(d) Wait until thermal equilibrium is reached, if the project requires work of high precision.

(e) Tap the instrument case lightly with the eraser of a pencil before making a reading.

(f) Compare and check the corrected readings of all the instruments daily at a single point where they are collected before beginning the daily field work and at its conclusion. All watches should be likewise synchronized.

(g) Avoid parallax error (see fig. 2.10.2). If the dial is equipped with a reflecting ring, the reading should be made with the pointer and its image appearing to be coincident.

(h) Simultaneous readings of all surveying altimeters in the group engaged in the survey are desirable. A good plan is to have five or six readings taken simultaneously at two minute intervals at each field point. Double check each reading. Errors in readings may thus be readily detected and the corrected data averaged on the basis of five or six values to yield more reliable results. Continuous recordings at base stations are desirable.

(i) Observe the air temperature and the instrument temperature at each field point.

(j) Make accurate and careful records of all pertinent data in a suitable notebook.

(k) Best and most accurate results can be secured by means of surveying altimeters when the field operations are conducted in suitable stable weather conditions. These involve relatively light winds, with fairly steady pressure and temperature over the survey area. Periods with strong winds, stormy weather, and rapidly varying pressure and temperature are found to be unsatisfactory for precise surveying field work. (See Chapter 9, vol. II, of this manual for more details.)

2.9.3.2.8 *Recording surveying altimeters.* —It is advantageous to employ recording altimeters at the fixed-base stations when precise surveying work is to be carried out over a large area and at many field points simultaneously. These recording instruments yield a record of indicated altitude or pressure, either in a continuous or an intermittent manner (periodically).

The number of fixed base stations involved in the surveying operation usually will range from one to four, depending upon the technique of altimetry surveying chosen to be employed. Experience shows that within reasonable limits the greater the number used the greater the theoretical accuracy of the results.

Fig. 2.9.7 illustrates the Paulin system portable recording microbarograph involving the use of a chart on a clock-driven cylinder. This type is employed in some surveying operations where readability to the nearest five feet is acceptable. The surveying altimeters used for the roving field stations are capable of yielding results of higher precision than this (see figs. 2.9.2, 2.9.3, and 2.9.6).

An entirely different type of recording surveying instrument has been developed in the form termed "the Wallace and Tiernan Alticorder (Recording Altimeter)," which is capable of giving indications readable to the nearest foot. In this device use is made of a regular surveying altimeter of the company's manufacture (see fig. 2.9.2). A photographic record of the dial of such an instrument is taken by means of a camera which is combined with a driving mechanism that permits an exposure to be made on standard 35 mm. film on either five (5) minute or ten (10) minute exposure intervals. A single magazine loading for the camera includes 100 feet of such film, which enables 1600 frames to be obtained. Thus, such a magazine loading of the film will be expended in approximately 5 1/2 days when 5-minute exposure intervals are employed. When an 8-day clock is used with 10-minute exposure intervals, 72 feet of film will be expended in the limited running time of the clock. The instrument can thus be operated unattended.

The driving mechanism of the "Alticorder" embodies a constant speed, 6-volt D.C. motor which advances the film at either 5 or 10 minute intervals and operates an exhaust fan in the instrument case to provide ventilation. Illumination for the recording camera is activated by a program cam on the driving mechanism for the proper time interval of exposure. The camera, which has an adjustable iris set at the factory, provides a record on the photographic film of the following three elements: (1) air temperature shown by an attached, ventilated dial thermometer with a stem bulb; (2) time shown by a contained 8-day clock; and (3) indicated altitude shown by a standard surveying altimeter of the same make as that illustrated in fig. 2.9.2. The face of the altimeter is in focus directly under the camera lens to avoid parallax.

Batteries are employed in the field to furnish power enabling the electric motor to operate the driving mechanism of the photographic recording altimeter and the lamps to provide illumination for the intermittent film exposures. It is possible for a man to transport the case containing the equipment, excluding the altimeter, batteries, and accessories.

A third type of recording altimeter (or barograph) which makes use of electronic methods has also been developed.[23] This type is designed to show indicated altitude data on a chart intermittently at frequent intervals. Two sample records yielded by this type are illustrated in fig. 2.9.11.[22] A brief explanation of the significance of this figure has been provided by Buckmaster and Mears[22] as follows:

"Figure shows sections of altigrams taken in the same room at the same time on two United Geophysical electronic altigraphs. The upper record was made by altigraph 14, and the lower record (superimposed on the same time scale as the upper graph) was made by altigraph 15. Each vertical division represents 1 foot of altitude, and each horizontal division represents 1 minute of time. The altigraphs recorded an altitude reading every 2 seconds.

"Atmospheric conditions were ideal, with the pressure remaining constant within about 2 feet of the average for a period of 1-3/4 hours. However, local disturbances caused variations in altitude readings as great as 3 feet in 30 seconds. Such disturbances obviously can cause errors in comparing instruments or in taking field readings."

By means of the electronic method of indication it is possible to obtain results readable to the nearest 0.1 foot. The technique employed in the operation of the third type of recording instrument has been described by Flauraud, Mears, Crowley, and Crary[23] in the following terms:[24]

"*Pressure indicator.* The pressure indicator *B* is a barometer that operates on the 'Paulin' barometer principle which is a null method of measurement with two outstanding features. These are:

1. No pivots are employed in the pressure-sensitive system and hence external frictional errors are avoided.

2. The elastic errors (internal frictional errors) in the pressure-sensitive system are reduced by the restriction of the magnitude of the displacements of the aneroid chambers. The deformations of the aneroid chambers are, therefore, held to a small fraction of the possible displacement within the proportional range by keeping the central parts of the aneroid chambers near a predeter-

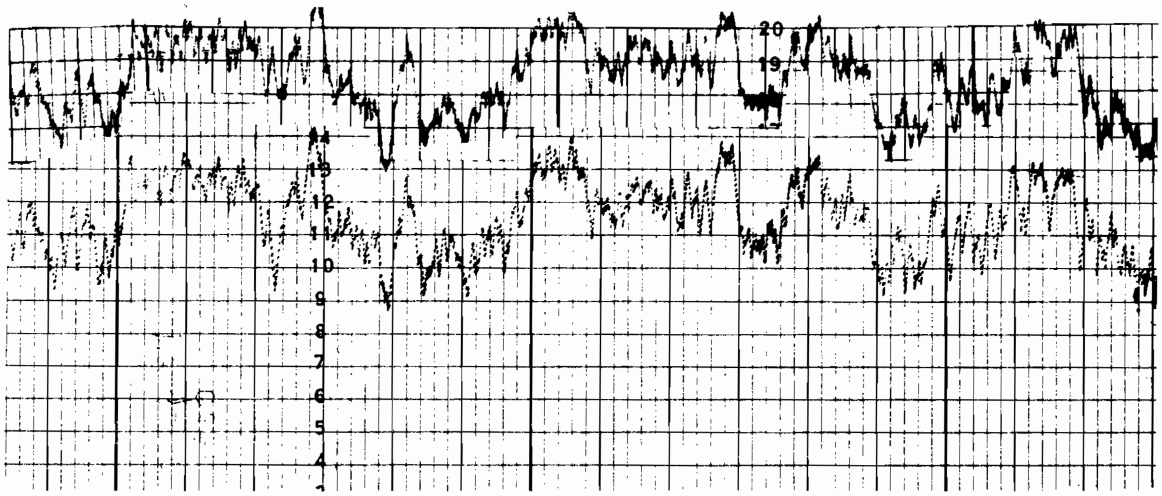

FIGURE 2.9.11. Examples of two simultaneous records obtained in the same room by means of two micro-altigraphs constructed by the United Geophysical Co. (See fig. 2.9.12.) One unit division on vertical scale denotes 1 foot altitude, and on horizontal scale 1 minute of time. An indicated altitude is recorded by a dot every two seconds.

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[23] E. A. Flauraud, A. H. Mears, F. A. Crowley, Jr. and A. P. Crary, "Investigation of Microbarometric Oscillations in Eastern Massachusetts," Geophysical Research Papers No. 27, Geophysics Research Directorate, Air Force Cambridge Research Center, Air Research and Development Command, Cambridge, Mass., (May 1954).

[24] Published by permission of the Director, Geophysics Research Directorate, Air Force Cambridge Research Center, Hanscom Field, Bedford, Mass.

mined standard extension which is usually limited by mechanical stops.

"In general, 'Paulin' type barometers employ a mechanical or optical null indicator; the barometer manufactured by the United Geophysical Co. uses a null indicator which is an electronic micrometer. The principle upon which the null indicator is based is expressed in the variation of spacing between the condenser plates, shown in Fig. 2 [see our fig. 2.9.12] immediately above the aneroid chambers. The mechanical assembly of this portion of the pressure-sensitive element is shown in Figs. 3(*a*) [see our fig. 2.9.13] and (*b*) [omitted here].

"The measuring element of the electronic micrometer is provided by the connections of three condenser plates into a capacitance

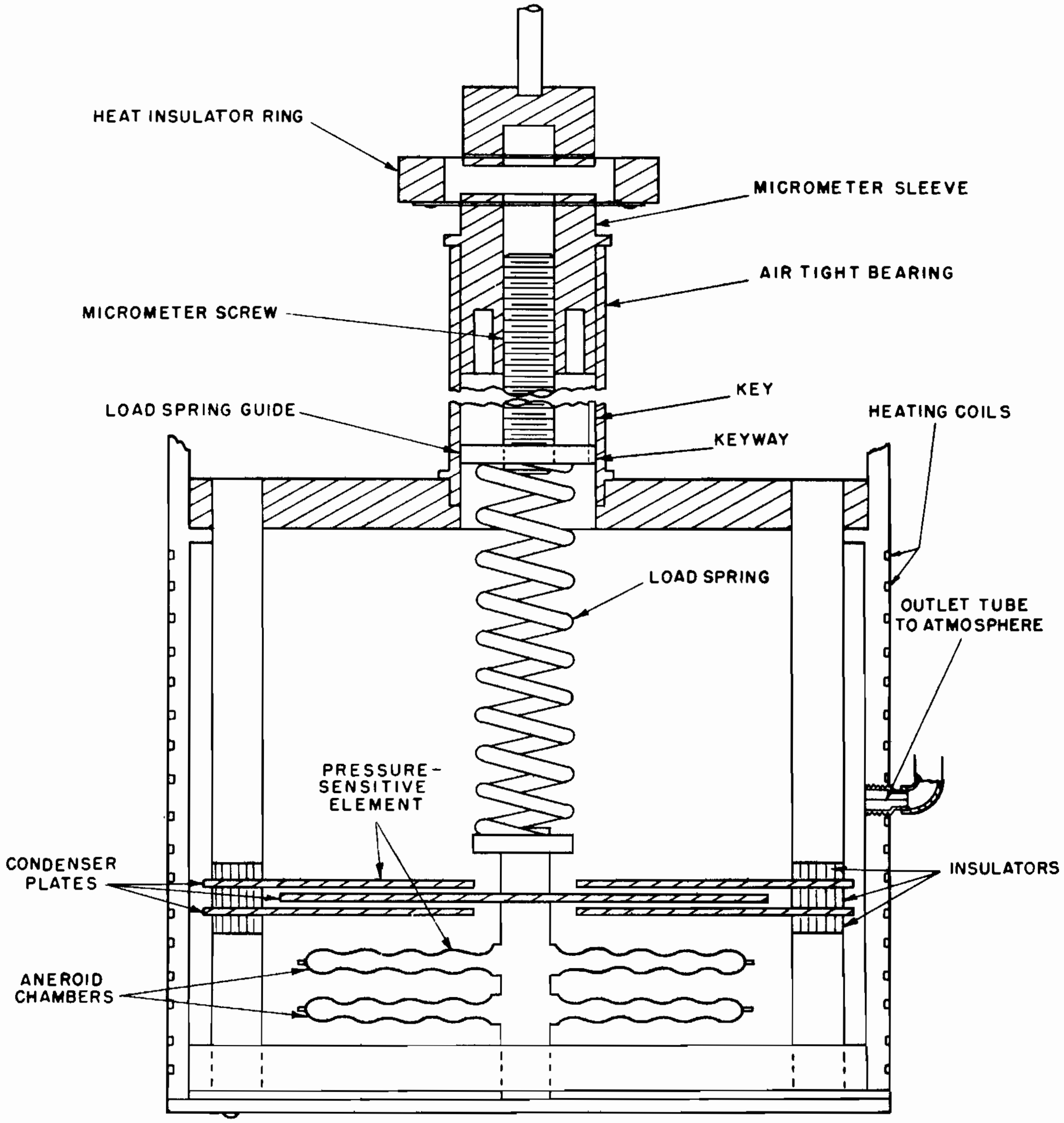

FIGURE 2.9.12. Schematic diagram of the major parts of the pressure-sensitive system of the microbarograph manufactured by the United Geophysical Co. which uses a null indicator constituted in the form of an electronic micrometer, where the variations in spacing between the condenser plates control the current in the signal circuit.

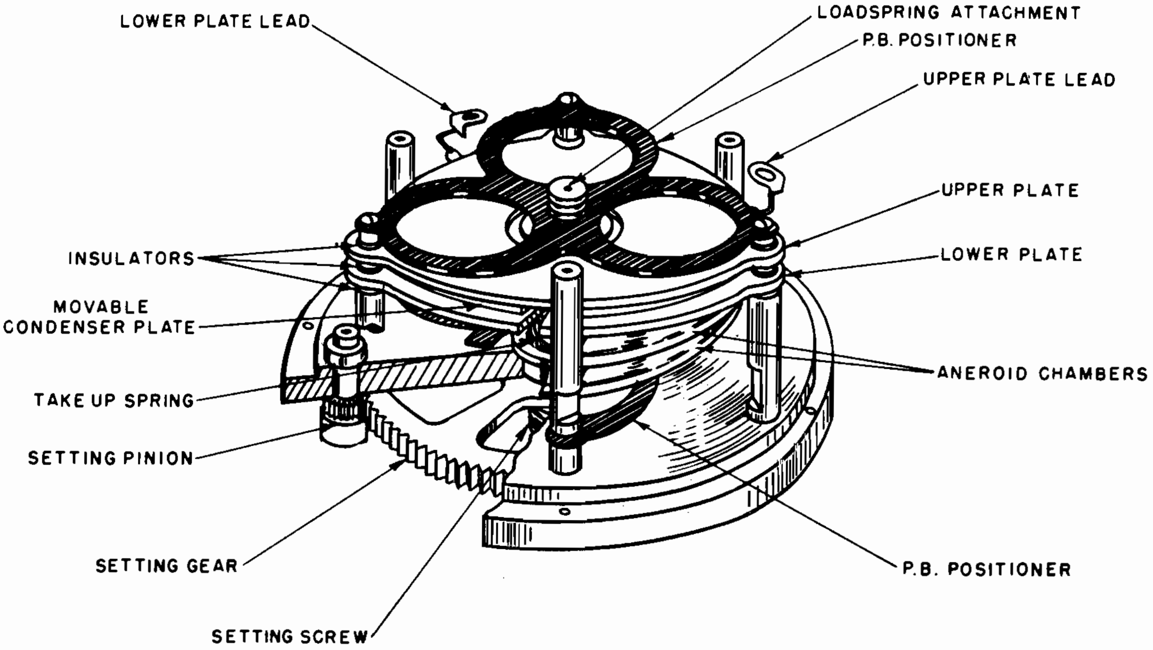

FIGURE 2.9.13. Schematic diagram of the pressure-sensitive element of the microbarograph shown in fig. 2.9.12.

bridge-discriminator circuit. The positioning of the middle, movable condenser plate relative to the predetermined null positions affords the means of measurement.

"The current in the signal circuit is so adjusted that it is zero when the movable condenser plate is in the null position. The signal current is measured by a center-zero microammeter. The DC in the signal circuit reverses its direction when there is a displacement of the movable condenser plate with reference to the null position. The condenser plates also provide limits or constraints to the possible displacements of the pressure-sensitive element.

"*Pressure-sensitive system.* The essential parts of the pressure-sensitive system are shown in Fig. 2 [see our fig. 2.9.12] where the pressure-sensitive element has been somewhat simplified for the sake of clarity. The mechanical details of the element are shown in Figs. 3 (*a*) [see our fig. 2.9.13] and (*b*) [omitted here].

"The operating principle of the pressure sensitive system can be understood by an inspection of Figs. 2 and 3 (*a*) [figs. 2.9.12 and 2.9.13] and (*b*) [omitted here]. The aneroid chambers are evacuated so that due to the external air pressure, the upper and lower corrugated walls of each chamber contact each other unless held apart by some force acting along the central axis of the aneroid chambers. This force is supplied mainly by the tension in the load spring. For a given barometric pressure range (about 35 mb.), the opposing collinear forces can be brought into equilibrium. These forces are due to strains set up in the load spring and aneroid chambers and act in opposition to the barometric pressure exerted upon the walls of the aneroid chambers. The equalization of these forces is accomplished by varying the length, and consequently, the tension (strains) in the load spring. The amount the load spring length is increased or decreased depends on the number of revolutions of the micrometer sleeve shown in the upper part of Fig. 2 [see our fig. 2.9.12]. The micrometer sleeve raises or lowers the micrometer screw attached to the end of the load spring. In the operation of the indicator, the rotation of the micrometer sleeve is brought about by turning a knurled null knob. Rotations or twists of the pressure-sensitive system must be avoided. The key and keyway milled in the load spring guide (Fig. 2) [see our fig.

2.9.12] prevent any twists due to rotation of the micrometer sleeve.

"The pressure indicator is adjusted to any 35 mb. range by means of a reset or setting mechanism. Details of the setting mechanism are shown in Fig. 3(*a*) [see our fig. 2.9.13]. Any rotation and consequent twists in the pressure-sensitive system due to an adjustment of the pressure range is prevented by the two phosphor bronze positioners (flexure plates) which allow for the small longitudinal displacements of the aneroid chambers (Fig. 3) [see our fig. 2.9.13].

"*Recorder.*—The modified Esterline-Angus Recorder C is shown in Fig. 1 [omitted here]. A barogram that has been recorded on the chart roll may be seen through the recorder-case window. Fig. 4 [see our fig. 2.9.11] shows sample barograms.

"The barogram is recorded by means of a printing mechanism similar to that employed by inkless recorders and differs only slightly from the system used in the Friez radiosonde recorder. The mechanism consists of a drum upon the surface of which is a raised helix. The pitch of the helix affords one complete 360 deg. for a distance equal to the chart width. The helix, however, extends for about 370 deg. The drum is mounted above the chart roll, as can be seen in Fig. 1 [omitted here], through the top portion of the recorder-case window. A two-color typewriter ribbon (not shown in figures) is held by means of a cradle against the raised helix. This ribbon is, therefore, between the raised helix and the chart roll. The typewriter ribbon cradle can be rotated slightly about the drum axis. This provides for a recording in either color. Below the chart roll and in a position to strike the raised helix at any point along a straight line parallel to the axis of the drum, is a tapper bar.

"The tapper bar is actuated by a solenoid. When a momentary current is sent through the solenoid the tapper bar makes a single rapid stroke towards the helix and produces a mark or dot on the chart roll corresponding to the point where the typewriter ribbon is supported by the helix. Thus, the position of this point on the chart roll depends on the angular position of the helix. The helix extends about 370 deg. Whenever the printing position occurs at either end of the helix, a record is printed on both sides of the chart (see Fig. 4) [our fig. 2.9.11].

"The recording drum is geared to the balancing mechanism of the indicator by means of a flexible shaft. Any movement of the balancing mechanism results in a corresponding rotation of the raised helix. Thus, every pressure indication may be recorded.

"A reversible motor (servomotor) is also connected into this gear system to provide automatic balance of the indicator. The DC signal current of the indicator is made to bias the grids of a twin triode (7F8). The plate currents of this tube are fed into two sensitive relays. The double contacts of these relays control the direction of the current from a 6-v. battery to the reversible motor. When the indicator is in the null position (signal current below relay closing value), both relays are in the open-circuit position and no current is fed to the reversible motor circuit.

"The chart roll is propelled by means of a strong spring motor. The chart speed is controlled by either an escapement, or sixty times faster, by an air fan governor. Different pairs of chart speeds—fast and slow —may be obtained by the use of several pairs of gears which can be assembled readily into the spring motor gear train. At the slow chart speed, the spring motor will run for eight days when fully wound. From April 1951 onward, the chart speed used was 6 in./hr.

"The current through the tapper-bar solenoid is controlled by either the clock escapement or a thermal timer. Manual tapper bar operation may also be made by a push button. The escapement chart-speed control carries a cam which momentarily closes a contact every 15 sec. The thermal timer causes a contact every 2 sec.

"CALIBRATION. The pressure-scale constant represents the amount of pressure change required to cause a change of indication of a scale division (about 1/4 in. on the recorder chart). The manufacturer determined the average chart scale factor for each set of equipment at operating temperatures of 114° to 115° F and the variation of the chart scale factor with pressure.

"In general, the stiffness of the pressure-sensitive system increased with an increase in the pressure. The first five columns of Table 2 show the variations of the pressure-scale constant at 970 and 1050 mb. for an operating temperature of 114° to 115° F.

Table 2.—Calibration of United Geophysical Recorders

Instrument No.	Operating temperature	Mb. per scale division at 970 mb.	Mb. per scale division at 1050 mb.	Increase in constant for pressure range	Average mb. per scale division
	° *F.*				
12	114	0.0388	0.0402	0.0014	0.0390
13	115	.0374	.0383	.0009	.0380
14	115	.0356	.0364	.0008	.0332
15	114	.0387	.0393	.0006	.0327

The average pressure-scale constants are tabulated in the last column of Table 2.

"A determination was made of the average value of the pressure-scale constant. The method used for this evaluation consisted in the comparison of the pressure changes recorded by the equipment with the corresponding pressure changes indicated by an aneroid barometer (ML–102–D#1596). These comparisons were made for the existing atmospheric pressures. The pressure range was from 990 to 1045 mb. The equipment operated at regulated instrument temperature from 80° to 130° F.

"The operation of the equipment was continuously monitored. Frequently, two or more recorders were operated within a few feet of each other, at the same elevation. Barograms obtained under such conditions were found to be practically identical (Fig. 4) [see our fig. 2.9.11]."

It may be remarked parenthetically that Dr. H. F. Stimson[25] of the National Bureau of Standards has made use of an electrostatic capacitance scheme for determining accurately the height of a mercury surface in a large bore manometer, similar in principle to the method employed in connection with the instrument described by Flauraud, Mears, Crowley, and Crary.[23]

A fourth type of recording instrument capable of yielding pressure readings on a magnified basis is one that permits obtainment of a sensitivity of between 25 and 6 mm. of scale displacement per mm. of mercury change in pressure. This microbarograph, manufactured by a German company (Askania), involves the use of a suspended helical Bourdon tube of considerable length for the pressure actuated element. As the pressure varies, there occurs a corresponding rotating movement of the tube (a tubular spring). This motion is converted to electrical values by means of a photoelectric transducer, and these values are transmitted to a suitable recording device. The device provides a record on a chart which moves under the indicating pen at a controllable rate (usually 20, 40, 60, 80, 100, or 120 mm./hour). Since a photoelectric method of magnification of the pressure element movement is employed, effects of friction are eliminated, thereby permitting results of considerable sensitivity to be obtained, and reducing some apparent effects of hysteresis found with mechanical means of magnification. For further information regarding this instrument see sec. A–2.13, particularly the reference to the article by Heiland in paragraph (c).

2.9.3.2.9 *Errors relating to surveying altimeters.*—One may classify errors pertaining to surveying altimeters under the categories of (a) instrumental; (b) meteorological; and (c) gravitational.

With respect to the first category (a), the list of items pertaining to the conventional, typical aneroid mechanism is likely to include the following: diaphragm error, zero shift, after-effect, drift error, hysteresis error, friction error, temperature error, backlash error, instability error, *scale-calibra-*

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[25] "Temperature, Its Measurement and Control in Science and Industry," vol. 2, edited by Hugh C. Wolfe, Reinhold Publishing Corp., New York, 1955. Chapter 9, pp. 141–168 by H. F. Stimson, on "Precision Resistance Thermometry and Fixed Points."

tion error, and readability error. Definitions of most of these terms are presented in sec. 8.2.2 (see also the discussions relating to anelastic characteristics, drift, hysteresis, zero shift, etc., in secs. 2.9.0 and 2.10.0–2.10.10).

It is possible to overcome the effects of most of these errors by means of carefully performed calibrations both immediately before and after each period of field use of the surveying altimeter, provided that the instrument is of first class quality, designed for precision work, and has its scale accurately calibrated in the manufacturer's laboratory. Those effects which stem from diaphragm error, drift error, and to some degree also zero shift and hysteresis, can be more or less corrected on the basis of such calibrations, in cases where the diaphragms have been given a proper heat treatment both before and after being formed; and the aneroid element also baked at an optimum temperature after assembly.[26]

A reduction of hysteresis and drift is often achieved in the manufacturer's plant by subjecting the assembled aneroid element to a number of cycles of pressure pulsations at an optimum mean pressure and baking it at a suitable temperature for a certain length of time found to yield best results.[26]

The temperature error of the surveying altimeter can be largely overcome by calibrating the apparatus for effects of variation of instrument temperature from the temperature at which the scale was calibrated (usually 75° F.) and making use of a temperature correction table or chart in order to correct the readings for temperature (see fig. 2.9.10).

Generally, an effort is made to eliminate the friction error by tapping the altimeter lightly with a pencil eraser just before making a reading. When pin bearings are used in connection with a magnification lever system, these always exert a frictional influence. Therefore, modern developments directed toward seeking improvements have led to application of magnification systems which either make no use of components that contribute friction or employ techniques of magnification that involve a minimum of friction (see fig. 2.9.12).[26] Examples of this trend are cited in sec. 2.9.3.2.11, where development models of surveying altimeters which embody optical methods of magnification are illustrated. Greatly increased sensitivity concomitant with elimination of friction can be obtained by application of a recording optical lever.[27]

When an aneroid instrument includes bearings, there is bound to be some friction and often some play or looseness in the bearings. Under these conditions the hysteresis curve for the complete instrument can be quite different from that for a single diaphragm. The combined effect of diaphragm hysteresis, friction, bearing play, and other instrumental factors can cause the resultant hysteresis loop obtained from the equipment to have more nearly a rectangular shape than a lenticular one (see figs. 2.10.1(a) and 2.10.1 (b)).[26] Experience has revealed that in the case of mechanical magnification systems which usually involve levers that flex, together with bearings, there is some loss of energy in the transfer from the deflections of the diaphragm to the movement of the indicating pen or needle. In such cases the combined effect of hysteresis, friction, play in the bearings, flexure of the levers, and other mechanical phenomena entailed in the operation of the magnification system can produce significant amounts of deviation from a smooth curve of pressure-versus-scale reading together with objectionable apparent hysteresis which is detrimental to the obtainment of results of the highest precision desired in accurate surveying work. When such characteristics are present, it is difficult to overcome them by means of calibrations performed at large scale intervals, such as 100 feet; hence it is often desired to obtain calibrations at much closer intervals; but this is very time consuming.

Effects of backlash errors are present at times in those designs of aneroid-actuated instruments which have mechanical means of magnification; hence it would be possible to eliminate such effects by the employment

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[26] F. B. Newell, "Diaphragm Characteristics, Design and Terminology," The American Society of Mechanical Engineers, New York, N.Y., 1958.

[27] R. V. Jones and J. C. S. Richards, "Recording Optical Lever," Jour. of Scientific Instruments, vol. 36, pp. 90–94, February, 1959.

of other suitable means of magnification (see sec. 2.9.3.2.11 and fig. 2.9.12).

Readability errors can be reduced by the application of good observing practice to minimize parallax errors (see fig. 2.10.2).

Scale-calibration error is generally compounded of errors due to a number of causes, including the absolute error or errors in the calibrating standard (reference) barometer, the readability errors in the latter barometer, the personal equation of the observer, the factors which give rise to instability in either the calibrating standard or the aneroid instrument being calibrated (see secs. 2.7.1 and 2.9.3.2.5); etc. When points on the true calibration curve of the aneroid instrument deviate significantly from linearity between fixed calibration points on the scale at large intervals (e.g., 100 feet), there is contributed a troublesome source of error difficult to overcome without considerable expense. For this reason it is often useful to make check calibrations at some intermediate points and to eliminate from service those instruments which show intolerable deviations.

It is possible to some extent to keep the effects of hysteresis error to within relatively small limits by exposing the instrument to a suitable number of cycles of pressure pulsations as mentioned above and by basing the calibration scale corrections on the mean of the results obtained from the calibrations for decreasing and increasing pressure (see sec. 2.9.3.2.5).

By employing surveying altimeters intended to operate over a limited range of pressure change, it is possible to secure diaphragms so designed that they are subjected to an applied stress which is a fairly small fraction of the yield-point stress (e.g., 0.3 or less); and this fact makes it possible to develop surveying altimeters having relatively small elastic errors and yielding very nearly a linear response.[22] [26]

At the beginning of this section it was noted that there exist errors in categories (b) and (c), which relate to meteorological, gravitational, and topographical factors capable of contributing discrepancies to the results of barometric surveying (hypsometry). Although these factors lie outside the realm of instrumental considerations with which this chapter is mainly concerned, it is deemed worthwhile to present a brief discussion at this point relating to the subject keeping in mind the plan to treat this matter in greater detail in Chapter 9.

Fundamentally, the errors in categories (b) and (c) depend upon the horizontal and vertical distributions, over the area being surveyed, of certain meteorological and geophysical elements or parameters, which include: (1) air temperature; (2) atmospheric water vapor content; (3) barometric pressure; (4) atmospheric eddies, turbulence, and wind; (5) accelerations, pulsations, and variability of the atmosphere; and (6) local anomalies of the acceleration of gravity over the earth.

To a considerable extent, the effects of air temperature and water vapor content, items (1) and (2), can be taken into account by means of suitable corrections (see sec. 2.9.3.2.5). However, it is difficult for surveyors to ascertain the proper allowance for the effects of horizontal and vertical distributions of these meteorological elements, which may have local peculiarities correlated with the local topographical features, together with the wind flow, and other factors often dependent upon the synoptic meteorological situation and its changes over considerable intervals of space and time. Both the air temperature and its vertical gradient vary diurnally near the surface, as is well known. If the survey project involves determination of differences in elevation between points which are widely separated either horizontally or vertically, then the three dimensional distributions of pressure, air temperature, and water vapor content should be taken into account. An effort is made to do this in the so-called "multiple base altimetry" or "multi-base method of barometric leveling" which requires simultaneous observations by means of barometers or altimeters at three or more stations (see Chapter 9).[28] [29]

In "multiple base altimetry" the effect of the slope and orientation of isobaric sur-

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[28] W. F. Haring and A. H. Mears, "Multiple Base Altimetry," Photogrammetric Engineering, pp. 814–822, December, 1954.

[29] R. A. Hodgson, "Precision Altimeter Survey Procedures," published by American Paulin System, Los Angeles 15, Calif., 1957.

faces (surfaces of constant atmospheric pressure) over the area being surveyed is determined within certain limits, and some allowance is made for these factors in the calculations of difference in elevations between points whose height above some datum plane is desired. Such refinements as may be achieved by means of the "multiple base altimetry" are not attainable as a rule by means of the other, less extensive altimeter survey procedures customarily employed.

The various altimeter survey procedures in vogue are classified under the following terms by Hodgson[29] and others in ascending degree of complexity or reliability: (1) single altimeter method; (2) single base method; (3) moving base method; (4) skip-stop or leapfrog method; (5) two-base or Hi-Lo method; and (6) multi-base method or "multiple base altimetry." Details are omitted here (see Chapter 9).

It would be possible to take into account to some degree the effects of vertical variations of air temperature and humidity by making use of the data obtained with radiosonde observations, considering the observed diurnal variations of temperature and dew point at various surface stations over the area and tying these in with the vertical gradients at certain times as observed by means of radiosonde. When the virtual temperature of the air varies linearly with height, it is possible to calculate difference of altitude by means of a specially adapted formula (see equations (26) and (27) of Appendix 7.1).

On the other hand, if it is desired to determine the difference in elevation between two points in close proximity, the average temperatures and dew points, respectively, could be ascertained over a sufficiently long period of time at the two places with a view to determining the mean virtual temperature (T_{mv}) of the air column between the two levels. (See Appendix 7.1.) If concurrent pressure or altimeter readings are made at the two places over the same period of time and averaged it is possible to employ such mean data in conjunction with equation (19) of Appendix 7.1 to compute the required difference in elevation to within a fairly close degree of approximation, provided that unusual circumstances which can cause significant discrepancies do not exist (such as effects of strong winds and eddies on mountains).

In order to overcome the effects of changes of barometric pressure with time it is necessary to have all surveying altimeter observations made simultaneously; although this would not be practicable in the case of the single altimeter method.

With a view to reducing the effects of winds, eddies, turbulence, and other atmospheric variabilities which directly influence the pressure field, it is desirable to conduct barometric leveling operations during periods with relatively favorable weather conditions, such as light winds, and fairly steady barometer readings, without storm and frontal passages; etc.

Gravity anomalies generally have little effect on the results of barometric leveling; but they have some degree of significance when a large difference in elevation is to be determined by such means in regions where the earth's gravity field is greatly disturbed and large anomalies exist (for example, near volcanoes). See Appendix 1.3.1, and Appendix 7.1.

2.9.3.2.10 *Use of capillary tube in surveying altimeters.*—Some surveying altimeters are designed with an airtight case having a capillary tube which connects the interior of the case to the ambient atmosphere. The capillary tube may serve three purposes: (1) when sealed, it enables the altimeter to be transported by aircraft or by other means at high altitudes outside of the normal operating range of the instrument; (2) when open to the atmosphere, it controls the flow of air between the exterior and the interior of the airtight case which attends changes in the ambient barometric pressure, and therefore it acts to damp out the effects of small, rapid fluctuations in this pressure, such as those which result from passage of eddies, wind gusts, atmospheric oscillations, and local disturbances (e.g., owing to movement of a vehicle on a nearby highway); (3) when the nipple outlet of the capillary tube is connected into a pipe line which transmits air pressure to the system employed for calibration of the instrument, such as a barostat or the cistern of a standard testing mercury barometer, the use of the tube permits surveying altimeters to be calibrated in groups under controlled pressure and at room temperature, without requiring them to be installed in a closed vacuum test chamber which would hamper precise reading of the instruments. These functions of the capillary tube yield advantages of considerable practicable importance.

2.9.3.2.11 *Developments to improve surveying altimeters.*—In order to overcome the deficiencies which stem from mechanical methods of magnification, the Geological Survey of the U.S. Department of the Interior has developed models of surveying altimeters which employ optical methods of magnification.[22] Figs. 2.9.14 and 2.9.15 based on the work of Buckmaster and Mears[22] show schematic views of two instruments of this character. In both of these an effort was made to reduce to a minimum the inclusion of elements which produce friction. In the case of the instrument depicted in fig. 2.9.14, a scale attached directly to the free end of the aneroid capsule is viewed through a microscope. A very slight lateral restraint is necessary to maintain or adjust in focus the glass slide which contains the graduated altitude or pressure scale. Although this could introduce a very small amount of friction, such a design of the instrument, having a minimum of mechanical parts, affords the possibility of yielding better performance than the conventional surveying altimeters.

In fig. 2.9.15 there is indicated a surveying altimeter which involves the use of a tilting mirror for the purpose of obtaining optical magnification. The small tilting mirror, linked to the moving end of the aneroid element (vacuum boxes), reflects the image of a finely divided glass scale into a 50X reading microscope. This microscope is mounted with its axis vertically above the optical center of the tilting mirror. The eyepiece, index reticle, and objective lens of the microscope are shown diagrammatically in fig. 2.9.15 directly over the mirror. In order to overcome detrimental effects upon the aneroid element of the heat produced by the lamp used in the illuminator for the glass scale, it is necessary to keep the pencil of light passing through the glass outside of the instrument case which contains the vacuum boxes. Further details concerning the specific optical and mechanical features of the two experimental models of the surveying altimeters illustrated schematically in figs. 2.9.14 and 2.9.15 are omitted here; and for them the reader is referred to the original source.[22]

Calibrations performed with a model of a kind nearly like that depicted in fig. 2.9.15 showed that the calibration curve was relatively smooth, but was parabolic in shape. This matter is not serious, especially since it is possible to cause the calibration curve to approximate a straight line by raising the effective pivot point between the connecting element and the lower arm. The connecting element is that vertical member (push rod) which links the vacuum box to a

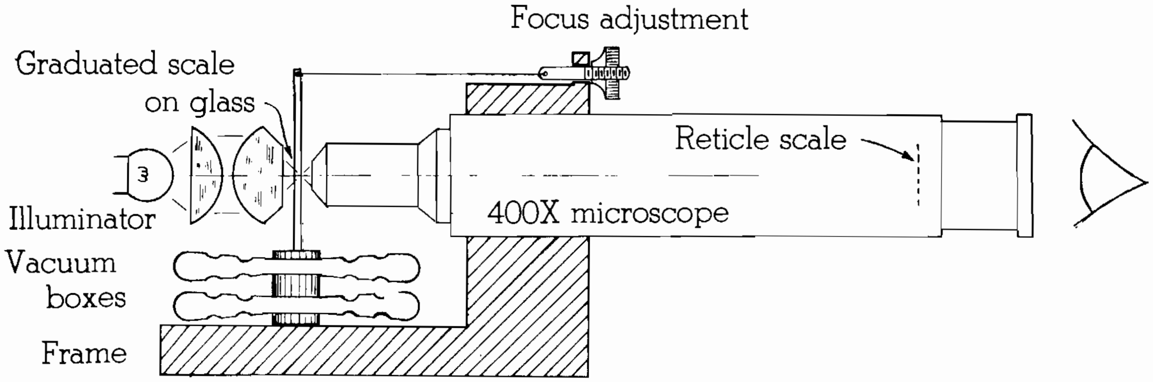


FIGURE 2.9.14. Schematic diagram of experimental model of surveying altimeter developed by Buckmaster and Mears of the U.S. Geological Survey, which involves a direct-reading optical system of magnification.

lever arm on the mirror support. It is found necessary to provide temperature compensation for all of the members which connect with and support the tilting mirror. Precision to within one (1) foot is very likely obtainable with such a design, assuming that normal technological developments will permit elimination of the major deficiencies of the apparatus.

2.10 FACTORS INFLUENCING THE ABSOLUTE ACCURACY OF ANEROID BAROMETERS

2.10.0 General

Aneroid barometers and barographs are subject to a number of effects that determine their absolute accuracy. The remainder of this section is devoted to general discussions on these topics, including material on the subject of temperature effects, scale error, drift, hysteresis and after-effect, leaks, friction, backlash, imperfect balance or position, and parallax. It is advisable for the user of the instruments to have some knowledge of the facts concerning these subjects, in order to understand the limitations of the equipment and to know how to get the best performance out of it. Some references to the literature on the subject of diaphragms and aneroid barometers are given in sec. A–2.10.

2.10.1 Effect of Imperfect Temperature Compensation

As explained in some detail in sec. 2.8.2, an increase of temperature of the aneroid capsule and the spring, if any, has the effect of weakening the spring action of the device; hence even under constant pressure conditions a temperature rise of the instrument could cause an increase of its reading, unless the mechanism is equipped with some means yielding perfect temperature compensation. While every precision aneroid barometer is provided with temperature compensation of a kind, the means used has limits regarding its possible accuracy. As a rule, the temperature compensation system yields fairly accurate results only under a restricted range of pressure and temperature. Therefore it is to be expected that outside of this range significant errors may appear; while even within a narrow range of suitable conditions slight errors could possibly occur where the degree of compensation is good but not perfect.

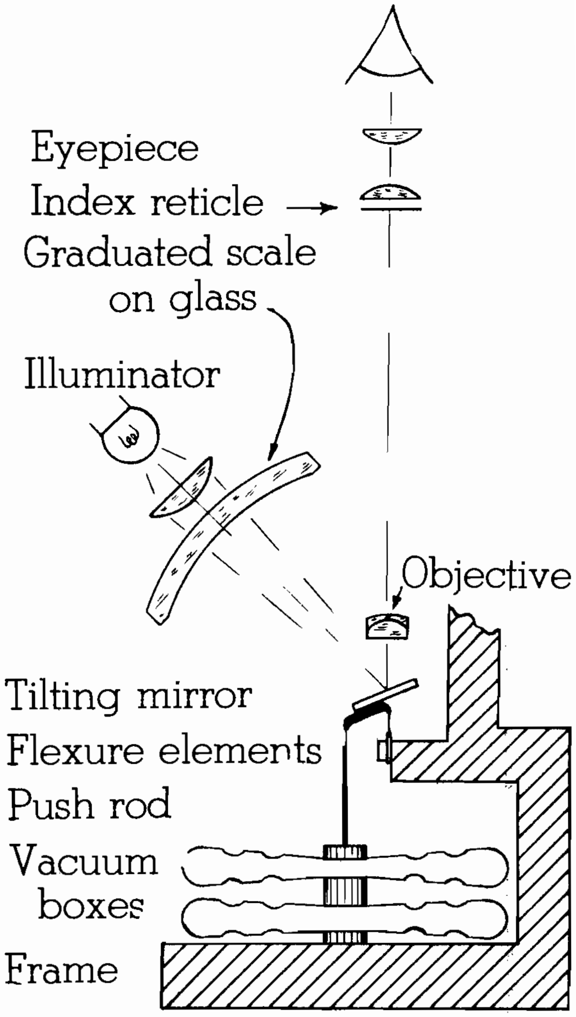


FIGURE 2.9.15. Schematic diagram of experimental model of surveying altimeter developed by Buckmaster and Mears of the U.S. Geological Survey, based on use of a tilting-mirror optical device for magnification. (Note: The flexural elements are shown below their proper position for clarity.)

When the calibration method described in sec. 6.7.2 is performed within a narrow range of room temperature, it is to be presumed that the effect of imperfect temperature compensation will have little consequence, provided the corrections to the aneroid barometer readings are properly determined and applied. In the case of field use of the instrument under a wide range of conditions as regards temperature *and* pressure, it is probable that corrections for the temperature effect will be necessary if results of great absolute accuracy are sought.

2.10.2 Scale Error (Effect of Variations in Scale)

Although some, perhaps most, aneroid barometers are equipped with a uniform scale, it is difficult to achieve a design of the mechanism such that it will yield equal displacements of the instrument needle per unit pressure change over the entire range of the scale. As a rule the scale factor (i.e., change of reading per unit change of pressure) varies slightly over different parts of the scale, and the factor may shift slightly as adjustments are made in the setting of the instrument. For these reasons, with a given setting, the correction may be a function of the reading itself (see secs. 6.7.1.0–6.7.1.3; and fig. 2.9.5). If the instrument is re-set, the correction will change.

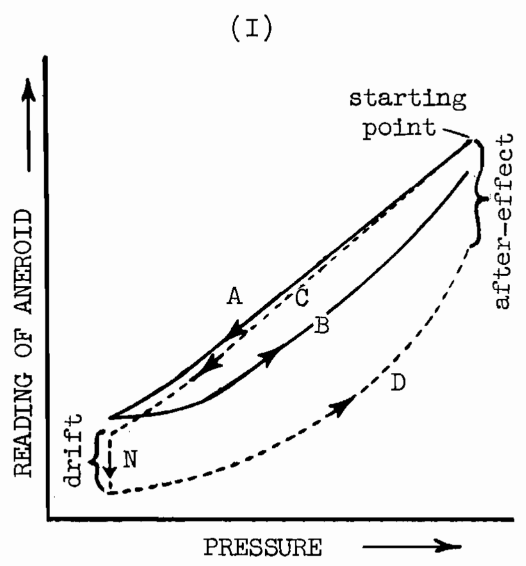
With regard to altimeters, the International Civil Aviation Organization has employed the term "diaphragm error," defined in the following words: "Due to physical properties and the construction of the aneroid and linkage, the diaphragm deflection will not be linear but will differ for the same given change of atmospheric pressure at different heights. This error should be known as the *diaphragm error.*" (Reference: ICAO Doc 7672–AN/860; Montreal, 14–22 February 1956.)

2.10.3 Drift (Creep) Owing to Deformation of Metal

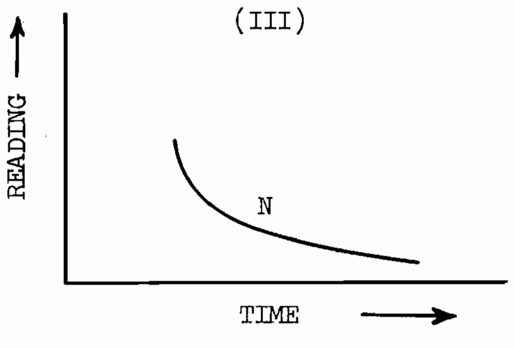
When an aneroid barometer is exposed to a variation in pressure, the metallic diaphragm on either face of the evacuated aneroid capsule suffers a change in strain. If it has a rod that connects the diaphragm to a supporting spring, this change in deformation is a maximum immediately around the rod, for the atmospheric pressure applies over the entire area of the diaphragm, whereas the load is taken up principally by bending of the metal, which surrounds the point of contact of the rod. The deformation does not remain constant for a given variation of pressure, but rather it undergoes additional alteration with time in the same direction as the initial changes. Accordingly, the indication of the aneroid barometer tends to "drift" *in the same sense* as the variation from the initial pressure, rapidly at first, and then more and more slowly. See fig. 2.10.0 (III). The phenomenon of drift (sometimes called "creep") stems from the changes in flexure of the metal as it accommodates itself to the difference in stress imposed by the variation in pressure. Experiments show that the amount of the drift will depend upon such factors as the initial and final pressures to which the instrument is subjected, the rate of change of pressure, the lengths of time involved, the temperature, and previous life-history of the aneroid in respect to pressure variations. It is found that the rate of drift increases with the time rate of pressure variation, in the case of pressure change in a given sense (plus or minus). This is not extremely serious for slow rates of pressure variation at the ground, but it is very significant for aneroid instruments carried in rapidly ascending or descending aircraft. If the aneroid capsule has no external supporting spring and the entire surface of the diaphragm moves uniformly with change in pressure (for example, as in the case of evacuated bellows made of beryllium copper), the changes in strain accompanying the variations in pressure occur in other parts of the capsule (such as in the folds of the bellows). Under these circumstances, the atmospheric pressure continually acting on the diaphragm keeps tending to crush the capsule, and therefore the tendency to drift with age is in the direction of increased reading (apparently towards higher pressure).

2.10.4 Hysteresis and "After-Effect"

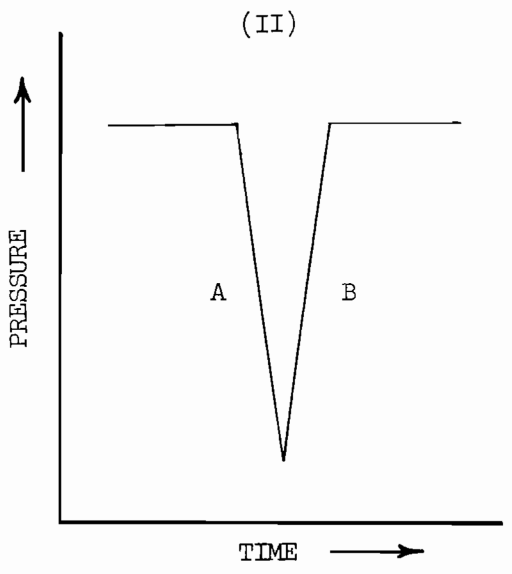
When the aneroid barometer is subjected to a cycle of pressure change, consisting of a decrease of pressure followed immediately by a rapid increase, the calibrations in the two cases are found to differ in the following respect: the readings observed on the dial at a given pressure are greater when the pressure is being decreased than when the pressure is being increased in the cycle. This is the phenomenon called "hysteresis" (see figs. 2.10.0, 2.10.1(a) and 2.10.1(b)). When the pressure is brought back to its



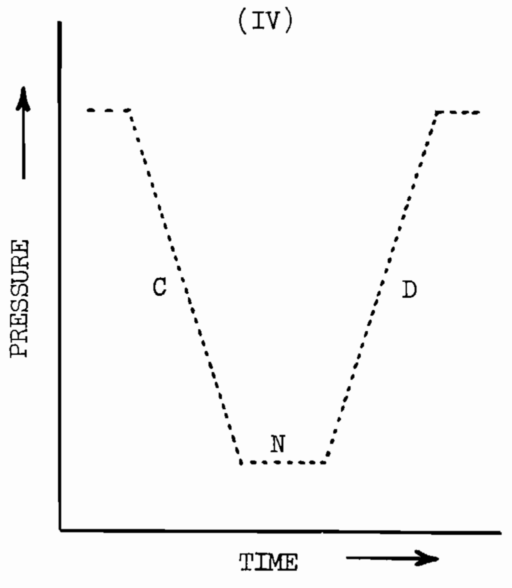
Schematic diagram illustrating effects of hysteresis and drift in greatly exaggerated amounts, (scale is non-linear). Cycle A-B illustrates hysteresis pure and simple; cycle C-N-D illustrates hysteresis and drift combined. See (II) and (IV) for pressure cycle patterns corresponding to curves A-B and C-N-D, respectively.



Reading of aneroid plotted against time to show drift as the pressure is kept constant at a low value, indicated by line N in (I) and (IV).



Barograph record relating to curves A and B in (I).



Barograph record relating to C, N, and D in (I).

FIGURE 2.10.0. Effects of hysteresis and drift in an aneroid barometer.

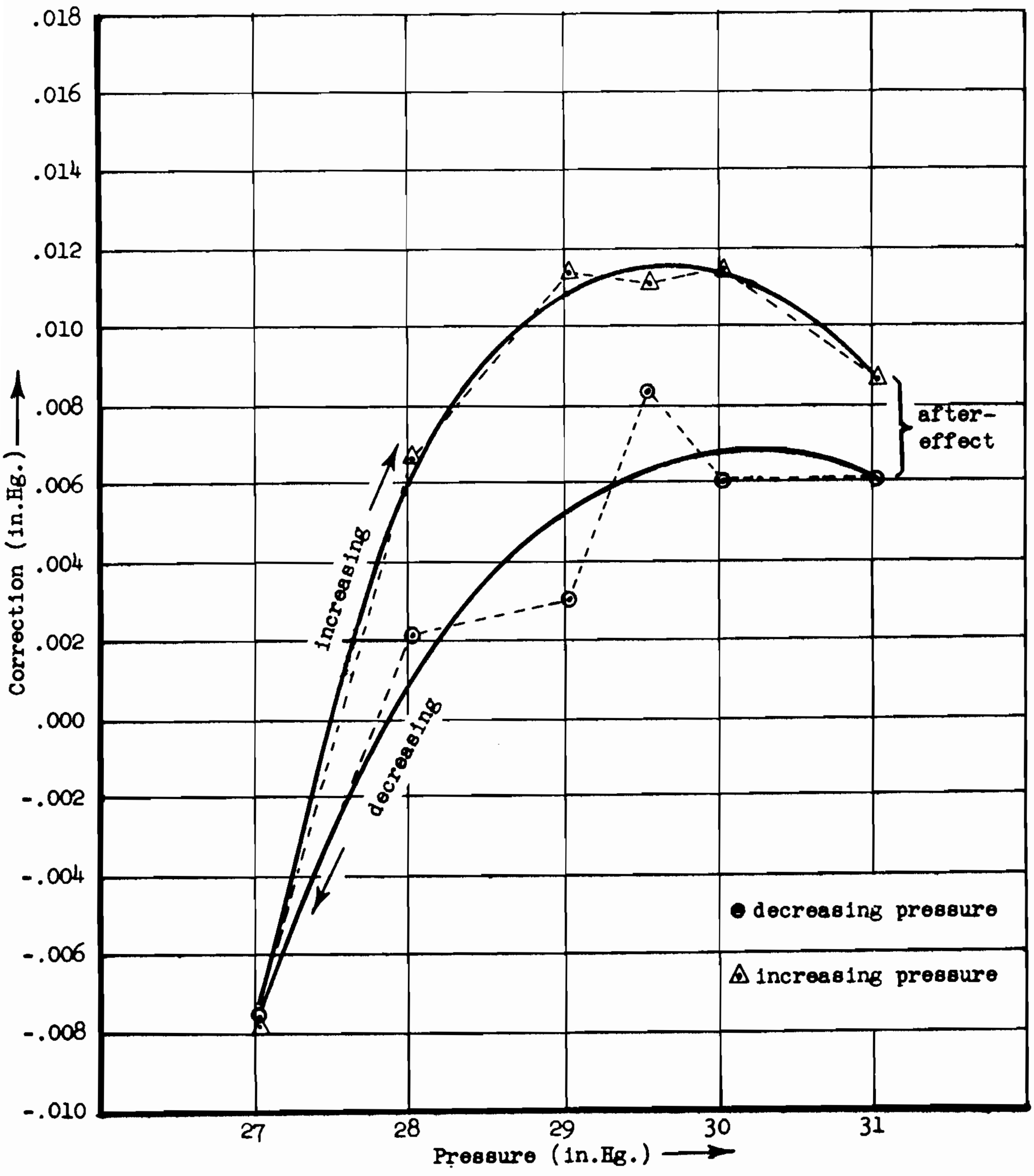


FIGURE 2.10.1(a). Illustration of corrections applicable to an aneroid barometer to compensate for errors due to hysteresis and after-effect as the barometer is subjected to a cycle of falling and rising pressure. Additional cycles would bring the curves closer together. Plotted points are based on average of data from eleven similar aneroid barometers.

initial value for the cycle, the final reading is lower than the initial reading at the beginning of the cycle; this difference being called "after-effect" see fig. 2.10.0 (I). However, if the aneroid barometer is caused to undergo about five repeated cycles of decreasing and increasing pressure, a progressive diminution occurs in the difference between the readings at a given pressure pertaining to the decreasing and increasing pressure phases of the cycle, until a limiting difference is attained. Under these cir-

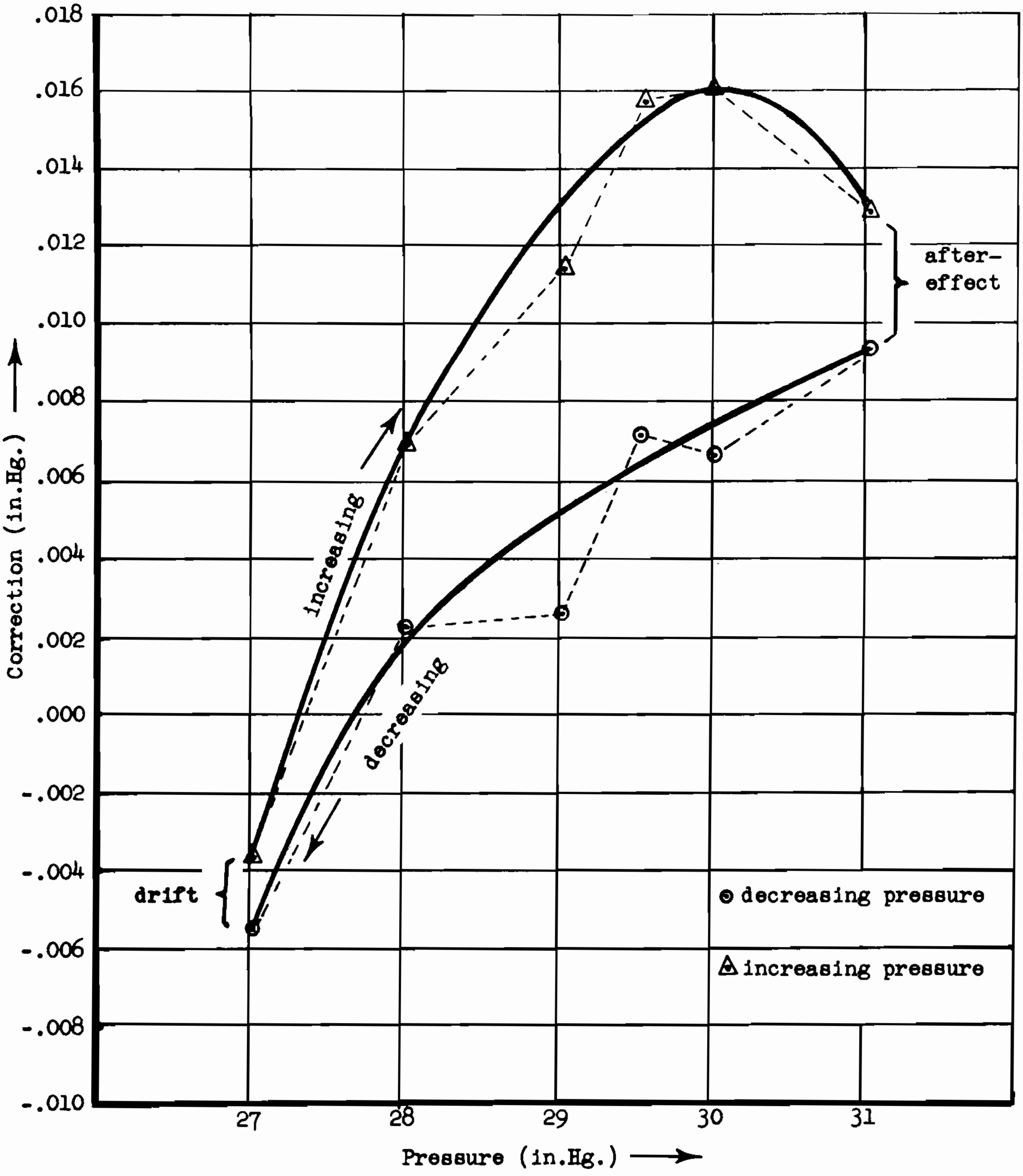


FIGURE 2.10.1 (b). Illustration of corrections applicable to an aneroid barometer to compensate for errors due to hysteresis, drift, and after-effect as the barometer is subjected to a cycle of falling and rising pressure. Additional cycles would bring the curves closer together. Plotted points are based on average of data from eleven similar aneroid barometers.

cumstances, the amount of the "after-effect" diminishes somewhat on a relative basis with successive cycles until the limit is reached. The repetitive cycling process described above may be considered an artificial aging of the aneroid element, which tends to stabilize its performance. Some "after-effect" is to be expected as a consequence of a sharp drop in pressure followed by a rapid rise as when the eye of a hurricane passes over the station. However, if the aneroid barometer is left subjected to the low pressure for some time, it exhibits drift; that is, its needle drifts towards lower readings, rapidly in the first few hours and then more slowly, approaching a steady value over a period which may last several days.[30] See fig. 2.10.0 (I) and (III).

2.10.5 Examples of Hysteresis and Drift

To give the reader some idea of the magnitude of the effects described above, the following data and additional information may be considered as fairly representative:

(1) **Hysteresis (*AB*), fig. 2.10.0 (I).**—The maximum hysteresis effect shown by the extreme difference between the lines labeled *A* and *B* in fig. 2.10.0 (I) is of the order of 0.1 to 0.2 percent of the range of pressure change in the case of the best commercial instruments (an example is shown in fig. 2.10.1 (a)); but it may be as large as 0.5 percent or more in the case of inferior grades.

(2) **Drift (*N*), figs. 2.10.0 (I) and (III).**—The vertical extent of the line marked *N* represents the drift in the given time interval as depicted in figs. 2.10.0 (III) and (IV). When this time interval is one hour, the "drift" is of the order of the amount cited above under "Hysteresis." Fig. 2.10.1(b) shows an example of drift which occurred at pressure 27 in. Hg during a period of one-half hour, yielding a value of drift rate equal to 0.1% of the range of pressure change per hour. After this, the drift rate slows down fairly rapidly as indicated in fig. 2.10.0 (III).

(3) **Correction for hysteresis in one cycle, fig. 2.10.1(a).**—Fig. 2.10.1(a) presents an example of hysteresis when an aneroid barometer of good quality is subjected to one cycle of decreasing and increasing pressure. Performance depends on quality. Thus, the maximum spread between the curves might approach a value about double that shown in the figure if the cycle were applied in the case of instruments of the quality of commonly available microbarographs. Hysteresis may be regarded as the characteristic leading to the fact that the correction which must be applied to the instrumental readings to obtain absolute pressure is different for the phase of decreasing pressure than for the phase of increasing pressure. In the figure, the maximum hysteresis shown by the extreme difference between the curves is about 0.14% of the range of pressure change (4 in. Hg for this example); while the extreme difference between the plotted points is 0.21%. Considering the hysteresis tests whose results are given in fig. 2.10.1(a) it may be noted that the test lasted 3 hours, 20 minutes; and the pressure was held constant at 27 in. Hg for only 5 minutes, hence drift was negligible. The maximum hysteresis is observed to decrease when the instrument is subjected to a number of pressure cycles in rapid succession. The "after-effect" indicated to the right of fig. 2.10.1(a) represents the difference between the corrections which remains when the pressure is brought back to its original value after undergoing a cycle of decreasing and increasing values. The amount of the "after-effect" depends upon the duration of the cycle, and of the following lapse of time; for it decreases with time after the cycle is completed. (Note: In connection with the figure, readers may raise questions concerning the lack of smoothness in the differences between the plotted points at certain pressures. These may be attributed to such factors as: (a) irregularities in some element of the magnification system of the instrument, e.g. the teeth of the pointer-shaft pinion gear or of the sector which mesh with the former; (b) irregularities in or non-linear characteristics of the diaphragm of the aneroid cell at certain positions of strain; (c) use of a non-uniform hand-drawn pressure scale for the instrument with respect to which a change in setting of the mechanism may have been made owing to drift; (d) irregularities at certain points of the scales of the standard barometer against which the instruments were calibrated; (e) random errors in reading of instruments; (f) backlash errors of different sign, owing to overshooting of pressure and reverse during calibration at certain points.

(4) **Correction for hysteresis and drift combined, fig. 2.10.1 (b).**—In fig. 2.10.1(b) there is given an example involving both hysteresis and drift for the same instruments

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[30] Sir R. Glazebrook, "Dictionary of Applied Physics," vol. III, Article on "Barometers and Manometers" by F. A. Gould (Macmillan and Co., Ltd., London, 1923).

referred to in fig. 2.10.1(a) (see paragraph 3 above). The test pertaining to fig. 2.10.1(b) lasted about 6 hours; and the pressure was held constant at 27 in. Hg for one-half hour, which produced a drift of about 0.002 in. Hg (see paragraph 2 above). It may be noted that the "after-effect" shown in fig. 2.10.1(b) exceeds the "after-effect" indicated in fig. 2.10.1(a) by an amount which depends upon the drift.

(5) **Apparent abnormal hysteresis.**—Occasionally, when laboratory tests of hysteresis are made, the apparent hysteresis is observed to have the opposite sign from that expected. One explanation for this anomalous behavior is that the calibrating device has greater effective hysteresis than the aneroid barometer. Examples of this may be encountered under abnormal conditions, particularly when the calibration mercury barometer suffers from certain deficiencies: thus (a) in case the mercury is rather badly fouled and the menisci assume different heights, angles of contact, and shapes for rising and falling pressure and there is a lack of establishment of proper equilibrium for every adjustment; or (b) in case the vacuum above the meniscus in the barometer tube undergoes some impairment due to release of a bubble of air into the vacuum space between the two phases of the hysteresis cycle. (See secs. 2.7.1 and 2.7.3.)

(6) **Abnormal drift.**—On rare occasions the drift may be of the opposite sign from that usually observed. Various explanations for this peculiar behavior have been offered; but a clear example of it may be found when the capsule of the aneroid element is expanded so that the diaphragm is forced against the mechanical stop as during air transport, or when the instrument is exposed to a relatively low pressure beyond its normal operating range.

2.10.6 Effect of Leaks in Evacuated Aneroid Cell

Occasionally minute leaks will develop in the cell which has a partial vacuum. Air will leak into the cell, causing it to be more expanded than it would be at the same pressure and temperature if it had been perfectly sealed. When the leaks are so small that the process is gradual, the effect of the leakage is an apparent drift towards lower readings, requiring corrections which increase algebraically with time. When the rate of increase of the corrections is greater than can be expected due to normal drift (or creep) of an aneroid element, this may be taken as a possible indication of a vital defect in the instrument. After the first six months of use at a fixed station with customary care, the normal drift due to ordinary mechanical causes should rarely exceed about 0.1 or 0.2 mb. per year, decreasing with passage of time in an instrument of good quality. Apparent drift due to leakage is usually much more rapid than this. Development of leaks in an aneroid barometer is a serious matter since it leads to progressively greater and greater errors, and eventually complete impairment of the instrument. Evidence of a rapidly developing leakage will generally become noticeable as a marked rate of rise in the corrections necessary for the instrument, or by a marked *actual* decrease in reading of the instrument not substantiated by other criteria such as a corresponding fall in pressure shown by the mercurial barometer or microbarograph. When the aneroid instrument gives clear indications of malfunctioning, it should be immediately taken out of service.

2.10.7 Effects of Friction, and Backlash

Friction anywhere in the mechanism of the barometer tends to make it stick and to fail to respond immediately to small changes in ambient pressure. For this reason, the aneroid instrument must be tapped lightly before each reading to overcome friction, and to see that the pointer is free, although in a state of equilibrium under the existing pressure on the element.

Backlash error arises owing to lost motion in the gear transmission or other gearing and linkage connections of the instrument mechanism. Thus, if the calibration of the aneroid barometer or altimeter is performed during a process of progressively decreasing pressure, a shift to increasing pressure may bring forth a slight error if lost motion exists in the mechanism, and this can be attributed to backlash.

2.10.8 Effect of Imperfect Balance or Position

Each type of sensitive barometer is designed to be mounted in a certain position, namely the position in which it was calibrated and at which there will be a static balance of the component parts of the mechanism. If the instrument is used in some other position, and the balance is imperfect, the calibration does not exactly apply. Lack of perfect balance in any instrument has a tendency to cause a deviation from the state in which it was originally calibrated. Therefore, it is necessary to install aneroid barometers in the position at which they were calibrated, and to determine corrections for the instruments when placed in the same position.

In the case of an aneroid barometer, altimeter, or microbarograph mounted in a vehicle which is accelerating or decelerating, forces which result from these changes in velocity act upon the different components. It follows that if a state of balance does not exist among them under these conditions, a torque is produced on certain components. This tends to cause a deviation from the reading that would be observed, if the instrument were stationary, as was the case when the calibration was performed. We conclude that an instrument which is not dynamically balanced will be subject to errors under conditions where accelerations and decelerations occur, as for example on a ship. Consequently, the specifications for marine barometers and altimeters require mechanisms which are dynamically balanced or nearly so. From these considerations, it may be seen that any installation of an aneroid instrument in a site where severe shocks or vibrations will be experienced is objectionable, particularly when the instrument is not especially designed to be balanced dynamically.

2.10.9 Effect of Parallax

Consider two lines passing through the tip of the pointer of the aneroid barometer, one perpendicular to the dial of the instrument and the other slightly off of perpendicular but still intersecting the scale. If the eye of the observer is in the perpendicular line of sight, he sees the proper relationship of the pointer to the scale and he can make a correct reading; but if his eye is in the line of sight which is not perpendicular to the dial, he fails to see the proper relationship of pointer to scale, and he will make an error in reading. This latter is termed the "error due to parallax." See figure 2.10.2. It is essential to avoid the error due to parallax at all times. The observer should do this in a manner depending on how the instrument is mounted. When the dial is vertical, the line of sight should be perpendicular to the scale portion; and must be on a level with the pointer, passing through it. When the dial is level, the line of sight should also be perpendicular to the scale portion, but this time the eye must be directly above the pointer. In case the dial is equipped with a mirror ring, the observer should make the reading along such a line of sight that the image of the pointer in the mirror ring is obscured by the pointer itself. This test assures that the line is perpendicular to the plane of the mirror. Failure to observe these precautions contributes to the total error, and adds another source of random variations.

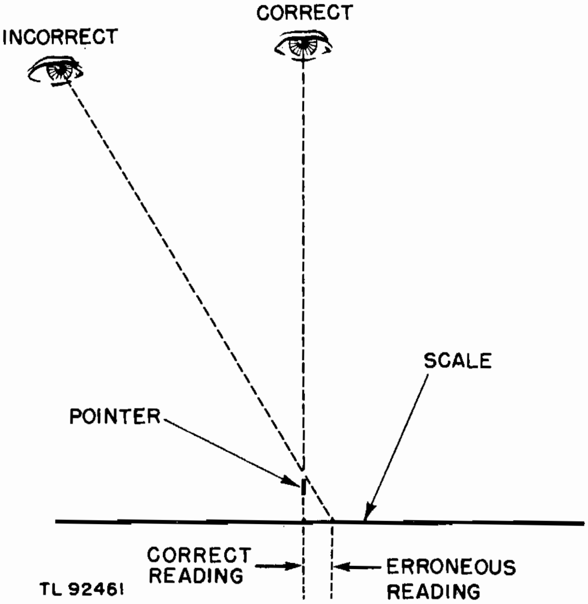

FIGURE 2.10.2. Correct and incorrect method of reading an aneroid barometer, where the incorrect line of sight leads to an error due to parallax. Correct line of sight is perpendicular to plane of the instrument scale (U.S. Army photograph).

2.10.10 Summary: Long-Period Drift and Superimposed Random Variations

The correction pertinent to a given aneroid barometer will usually display two characteristics: (a) drift of the correction over a period of time; and (b) random variations superimposed on the general trend. Usually when a barometer is shipped, it may travel up and down (as on mountains, and hills; or by aircraft) giving rise to hysteresis effects. Also, enroute, it may experience various pressure systems (LOWS and HIGHS), which possibly subject it to slower rates of change of pressure and which produce analogous effects. Owing to these reasons there is generally a rapid drift for several days after the instrument is delivered to the station; then the drift slows down, but it continues over a period of time as the instrument accommodates gradually to the new conditions to which it is exposed. After the instrument is installed, it will further experience pressure variations owing to passage of cyclones and anticyclones. These deviations from the normal will also give rise to slight drifts as they maintain the pressure low or high for a period; but the rates of change will, as a rule, be different, and extend over various time intervals.

In the long run, the various factors that operate will contribute to a general tendency for slow drift in one direction, owing to the progressive deformation of the diaphragm. Because of wind gustiness, thunderstorms, etc., more frequent fluctuations in pressure of smaller scale influence the aneroid barometer, each fluctuation having some effect on the amount and direction of the drift. These short-period alternations of pressure tend to produce random variations in the corrections. However, some contributions to the apparent random variations come from other sources, such as variable errors in the determination of the station pressure by means of the mercurial barometer. The procedures for standardizing aneroid barometers at stations, as described in sec. 6.7.2, are designed to correct for more or less constant instrumental errors as well as for the long period drift, and to cancel out, if possible, some of the effects of hysteresis.

2.11 FACTORS INFLUENCING THE ABSOLUTE ACCURACY OF ALL ATMOSPHERIC PRESSURE MEASUREMENTS

2.11.0 General

This section is devoted to a discussion of certain sources of error which may affect all measurements of atmospheric pressure, regardless of the type of instrument employed. Among these sources of error may be listed the influence of wind on the pressure within buildings or other structures, and the effects dependent upon heating and air conditioning. To a certain extent one may classify them under the heading of "installation error." This broad term is intended to apply in cases where the pressure acting upon the measuring instrument at its given site and with its given communication to the outside is not the same as the ambient pressure in the free atmosphere. One of the most outstanding examples of installation error occurs with regard to the static pressure connection of aircraft in motion, where this pressure is essential for the correct reading of altimeters and air-speed indicators. In such cases, serious errors may occur when the airspeed attains a certain range of values, especially just below the speed of sound. While this problem is extremely important for aviation (see Chapter 8 on "Altimetry"), it is less important at fixed stations. However, even here the matter is not negligible, as may be seen from the following discussion, particularly with reference to winds of hurricane force; while the problem of orographic effects, which is related, involves other significant consequences, dealt with later in this manual (see Chapter 11).

2.11.1 Wind Effects

When the wind blows against a building, it produces an impact pressure on the windward side and a suction on the leeward side. It thereby affects the actual pressure within the building, owing to leakage of air through open windows and doors, or cracks, crevices, chimneys, etc. The influence of the wind depends greatly on the location and size of the openings. The impact pressure and suction, referred to above, are to be regarded as positive and negative deviations, respectively, with reference to the static pressure. Static pressure at any definite level is that pressure which exists in the undisturbed air well away from obstacles at the level. This is the pressure which is desired for normal meteorological use.

It is possible to establish the static pressure by means of a special static pressure head mounted on a tube well above the building. The tube may be conducted into the building; and, in the case of fixed-cistern barometers it is possible to connect the static pressure tube to the cistern. When this connection is made, the effect of wind on the pressure in the building does not influence the pressure indicated by the barometer.

However, in the case of barometers installed without advantage of a static pressure connection, the effect of the wind on the pressure in the building is to cause the barometers to yield a value different from static pressure. At some points on the exposed windward face of the structure the impact pressure may reach a maximum value denoted by the letter q, in excess of the static pressure.[31] Also, at some points on the leeward face of the structure the deviation of the actual observed pressure from static pressure may attain an extreme value of $-q$ (that is, a suction equal in magnitude to the maximum impact pressure on the windward face).

There will be other points on the outside of the building where the deviation will lie between the extremes of $+q$ and $-q$, with the preponderance of positive deviation on the windward side and of negative deviation on the leeward.

If the building has wide open doors and windows facing the wind, the deviation will be generally positive within the building, and may attain to a value, in extreme cases, of $+q$. But, if the doors and windows on the windward side of the building are closed, a suction will develop within the building. This is a negative deviation of pressure from the static pressure, and may, at most, attain to a value of $-q$. As a rule, however, the suction will not be so great, and the negative deviation is represented by $-Cq$, where C is a factor lying between 0 and 1. In ordinary buildings of rectangular cross section, where the doors and windows are closed but allow a normal amount of air leakage through cracks, a typical value assumed by C is 0.3. Under the circumstances just stated, there is generally a suction in the building.[32]

The formula for the absolute value of the pressure deviation inside the structure is given by the expression: *pressure deviation* $= Cq = C(1/2)bdv^2$, in millibars, where $d =$ air density; $v =$ speed of the wind undisturbed by the structure; and b is a constant depending upon the units used for d and v. Thus, if d is air density in pounds mass per cubic foot, and v is wind speed in knots, $b = 0.0424$. As stated previously, C may vary between plus and minus 1. Variations in C owing to change in wind direction may be quite considerable, especially if a chimney is present on the building.[33]

The following table shows the value of the pressure deviation for various wind speeds based on the value $C = 0.3$, and the normal value of air density at sea level, $d = 0.07648$ lb.(mass)/cu.ft. This illustrative table is not intended for correction purposes, since the proper value of C for any given building should be determined for various wind directions by calibration, if necessary, using a static pressure tube to provide a basis for the standard.

It should be noted that if we had taken $C = 1$ (the extreme possible case), the

Table

Average pressure deviation—a typical building at sea level, with doors and windows closed, but normal amount of air leakage

Wind speed knots	Pressure deviation (suction) mb.
25	0.3
50	1.2
75	2.7
100	4.9
125	7.6
150	10.9

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[31] The maximum possible impact pressure, q, is determined by one-half of the product of the air density and the square of the wind speed undisturbed by the structure.

[32] Proceedings of the American Society of Civil Engineers, vol. 62 pp. 1111-1119 (1936).

[33] Meteorologische Zeitschrift, vol. 44, pp. 337-339 (1927).

values in the table would have been 3.3 times greater in amount.

The data indicate that comparative readings made between barometers in two buildings are likely to be subject to discrepancies because the factors *C* and *v* applying to the two cases may be unequal.

When the wind is gusty and turbulence is strongly developed, variations of the square of the wind speed produce relatively significant fluctuations of pressure inside a building or ship. These fluctuations are shown by vertical oscillations of the column of mercury in a mercurial barometer, or by variations of the needle of the aneroid barometer. As noted in sec. 2.7.6, such behavior of the pressure-measuring instruments is termed "pumping." It increases the difficulty of reading the instruments, and may lead to errors.

In the case of a barometer installed in a ship, the heading of the ship into a wind increases the relative wind acting on the vessel so that under these conditions the effect is usually stronger than if the wind had been astern or abeam.[34] The actual effect depends considerably upon the direction of the relative wind with respect to open doors, windows, portholes, chimneys, exhaust stacks, ventilators, etc. Studies have indicated that when the barometer was mounted in the chart room of a ship with the lee-side door open, a suction was produced in the room.[35] Closing of the door reduced the degree of the suction, and hence diminished the amount of the pumping observed in a gusty wind.

Experience with a barometer installed within the chartroom of a modern liner which can travel at a speed of 20 or more knots has revealed serious deficiencies and fluctuations in the pressure reported from the vessel. When the vessel was traveling against a strong headwind, a very marked suction effect was observed; whereas, when it was followed by a wind from the stern at about the ship's speed, the effect was practically negligible. Under headwind conditions encountered in a storm, the periodic gusts of great force which buffeted the vessel produced erratic fluctuations of the barometer, thus rendering the pressure reports of little value for synoptic purposes. It is easy to deduce from the foregoing, with regard to effects of winds from ahead as contrasted with those from astern, that ships traveling in nearby parallel courses in opposite directions during a severe storm will yield pressure data which appear inconsistent on the weather chart, unless static pressure heads are used in both cases. With a view to minimizing the errors which attend "pumping," it is customary to take the mean of the lowest and highest readings observed when oscillations occur. However, it should be noted that this practice may not yield perfectly accurate results, considering the fact that gusts generally involve a greater deviation of wind speed from the mean than the lulls. One can readily appreciate the effect of this with the aid of the table given above. To this end we may calculate results for a case where the *mean* relative wind speed is 45 knots, with relative wind peak gusts attaining a velocity of 80 knots from the bow of the ship, and the lulls causing the relative velocity to drop down to 35 knots.

Thus, on the basis of the table it would appear that in an average case the peak gust would produce a *negative* deviation of 2.1 mb. from the mean at 45 knots and the lull a *positive* deviation of 0.4 mb. from the mean. Since the average of the algebraic sum of the deviations $(-2.1+0.4)$ mb. is not zero, these figures disclose the likelihood that the mean of the readings may be too low under gusty conditions.

Superimposed upon the direct effects of wind outlined above are the effects due to the rolling, pitching, and yawing movements of the ship which involve accelerations that contribute to the errors and pumping of the barometer as explained in sec. 2.7.6.

All of the information given above lends emphasis to this conclusion: To improve pressure observations aboard vessels it is necessary to overcome the effects of relative winds. This may be accomplished by installing a static pressure head on a pipe or mast in a well-exposed location above deck where lee-wind effects will be minimized, and connecting the head by means of

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[34] Report of the Eighty-Seventh Meeting of the British Association for the Advancement of Science, 1919, pp. 89–92.

[35] Quarterly Jour. Roy. Met. Soc., vol. 34, p. 100 (1908).

a tube to the nipple of the barometer. The tube should have an inside diameter sufficiently large to give a sufficiently small, acceptable value of the time-lag constant determined in accordance with equation (7) of Appendix 2.11.1. Criteria are given in the latter appendix to enable one to choose an acceptable value of the time-lag constant. A plenum chamber must be provided at the lowest point of the line to enable the observer to drain moisture from the system. The chamber should be transparent so that moisture which condenses or is entrained may become visible as it collects. In regard to aneroid barometers, the case of the instrument should be airtight so that the nipple connection to the tube permits outside static pressure to apply at the measuring apparatus; and a similar remark is pertinent to the cistern of fixed-cistern mercurial barometers. For similar reasons modern marine barographs such as the one illustrated in fig. 2.9.1 have an airtight case and a nipple at either end of the base to permit connecting the interior of the instrument to a static pressure head (see fig. 2.11.0). If, on the other hand, an older type of barograph without an airtight case were employed, it would be necessary to install the entire instrument inside of a transparent, airtight glass container which is itself connected to a static pressure head. In the latter situation the glass container must be designed not only for readability of the chart but also for ease of opening and sealing the chamber with a view to permitting rapid changes of the chart, inking of the pen, etc.

Whenever action is taken to provide a static-pressure head for any pressure-measuring or pressure-responsive instrument, it is essential to select for the connecting tube a bore sufficiently large to prevent undue lag from developing in the system. In order to visualize the importance of this it can be understood that if the tube were a capillary, the lag might become so great under conditions of rapidly falling or rising ambient pressure as to cause serious errors to occur in the indications of the instruments. The proper choice of bore for the tube will depend upon the length of tube required to make the necessary connections, the volume of air capacity to which the tube connects, and some other factors explained in Appendix 2.11.1. The information given in that source will permit one to compute the minimum, tolerable inside diameter of the connecting tube according to certain criteria. The calculations involve the use of the so-called "time-lag constant" (or "lag coefficient") pertaining to the tube and the connected equipment. It is shown that if the tube is chosen so that its inside diameter exceeds the minimum, tolerable value, one may have assurance that the error due to lag can be kept within acceptable limits, even though the static-pressure head is exposed to an extreme probable rate of variation of ambient pressure. Certain recommended practices in regard to the subject are stated in Appendix 2.11.1.

2.11.2 Pressure Effects Dependent on Heating and Air-Conditioning

A forced draft produced by motor-driven fan is generally used in the ducts of heating and air-conditioning systems to move the air to the various floors and rooms of the structure. Within the ducts, the fan produces an excess pressure above the static pressure which exists in the rooms. For example, at the fan location the excess pressure between the duct and the neighboring interior of the building may be of the following orders of magnitude: (a) domestic installation, 0.25 inch of water; (b) typical industrial or office building installation, 3 inches of water; and (c) high velocity, forced ventilation system for special industrial installations, 6 inches of water, as measured by a U-tube manometer. This excess pressure is necessary to overcome losses due to friction and to dynamic effects, such as owing to changes in the direction or in the velocity of the air flow. Most of the latter effects result from changes in size and shape of the cross section of the duct, from bends or elbows, and from obstructions to flow imposed by dampers, etc. As a rule, the dynamic losses of excess pressure in the sytem are greater when the air flow decelerates on going from a smaller to a larger duct or space, than when the air flow accelerates on

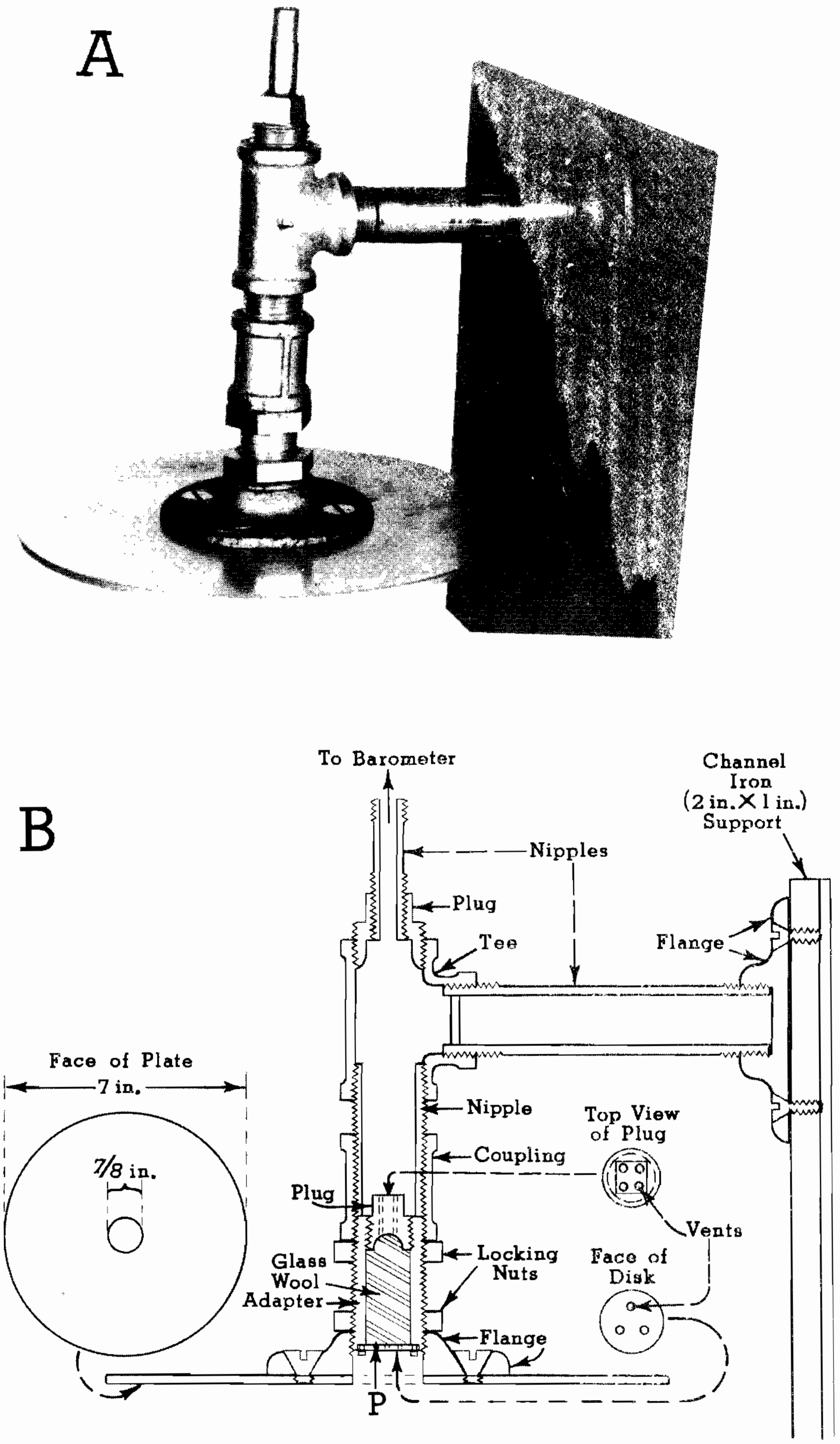

FIGURE 2.11.0. (A) External view of Static Pressure Head, (B) cross section of the same instrument.

going from a larger to a smaller duct. This fact is fortunate for meteorological barometric observations within rooms, since it prevents the attainment of very large pressure differentials in rooms with respect to the outdoors, when the air emerges from the ducts into the larger room spaces. However, leakage of air from imperfect joints in duct fittings will permit a fraction of the extreme pressure difference between duct and outdoors to apply in the rooms, depending somewhat upon the wind, tightness of the building, temperature difference between indoors and out-of-doors, height of the building, character of the joints, distance along the duct system from the fan, sizes of the ducts, etc.

When the air in air-conditioned structures is re-circulated, the difference in pressure between rooms and outside may be significant, so long as doors and windows are closed. If the building has many openings to the exterior (e.g. cracks around doors and windows), leakage will tend to reduce the excess of the pressure in the rooms over that out-of-doors, but wind effects may be greater under these circumstances than otherwise.

Estimates and measurements of the pressure difference between the interior of air-conditioned buildings and the out-of-doors vary with the conditions, excluding wind and temperature effects. But, some idea of its order of magnitude may be obtained from crude experiments which indicate that differences of about 0.3 mb. to 0.6 mb. in extreme cases, can exist. The effect can be circumvented by use of a static pressure head connected to the barometer. Another way, sometimes practicable, of overcoming the effect is to open a window or door to the outside during the time of the observation, excluding occasions when strong winds are blowing on the structure.

There is an additional influence of considerable import depending upon temperature difference between the inside and outside. This governs the pressure differential of heated or air-conditioned buildings that have completely sealed walls and windows, with at most one or two revolving doors on the ground floor. One may visualize the situation in terms of two hypothetical cases; (A) winter; and (B) summer. For simplicity consider the building to contain a vertical column of air always maintained at a mean virtual temperature of 68° F. (20° C.), in all seasons of the year, and assume that the barometric pressure at ground level is 1013.25 mb. in each instance, both inside and outside the building. The stair well and the elevator shafts serve to provide the connections for the supposed vertical column of air within the structure. We shall suppose the top floor of the building to be 100 meters (328 feet) above ground. The following table illustrates the comparison between the columns of air of this height inside and outside the building, based on theoretical calculations involving the use of the hypsometric equation.

Table

Character of data	Case (A) Winter: heated interior	Case (B) Summer: cooled interior
Pressure at ground level	1013.25 mb.	1013.25 mb.
Mean virtual temperature of air column inside building	68° F. = 20° C.	68° F. = 20° C.
Mean virtual temperature of air column outside building	5° F. = −15° C.	95° F. = 35° C.
Pressure inside the building at the 100 m. level, P_i	1001.52 mb.	1001.52 mb.
Pressure outside the building at the 100 m. level, P_o	999.94 mb.	1002.09 mb.
Difference, $(P_i - P_o)$	1.58 mb.	−0.57 mb.

It is apparent from the data that in winter the air column within the building is less dense than the air column outside, hence the situation is stable and the warm air tends to remain in the building. The data thus imply that if no leakage whatsoever occurred there would be a tendency at the 100 m. level for the pressure to be about 1.58 mb. higher within the building than outside. Actually some leakage is likely to occur, and this will act to reduce the difference. However, the pressure discrepancy produced by the effect resulting from temperature difference is still very significant, and it could be more serious in taller buildings and under colder outdoor conditions.

In the summer case the air column within the building is denser than that outside and leakage of air tends to occur from outside to inside near the upper floors. The latter fact raises the pressure slightly within the structure, hence the situation has some degree of instability. All of these considerations lead to the result that the cool, denser air tends to flow out at the ground level and the warm air to flow back into the structure in bubbles. But, the use of revolving doors generally hampers this exchange, while the continuance of cooling by the air-conditioning system tends to maintain the difference between inside and outside. Thus, even in summer, the effect may be significant, although of opposite sign to that of winter.

The action of wind on the building will act sometimes to enhance the pressure difference cited in the table and sometimes to reduce it, depending upon the wind direction and speed.

Only by using a static pressure head properly installed on the outside in a favorable location and connected to the barometer may one expect to overcome the effects described in this section, should it be necessary to use the instrument well above ground level. Clearly, it is preferable to install it in a structure of low height, if practicable.

ANNEX TO CHAPTER 2

MISCELLANEOUS INFORMATION; TYPES OF BAROMETERS; HANDLING OF MERCURY AND BAROMETERS; TRANSPORTATION OF INSTRUMENTS

A–2.0 INTRODUCTION

This Annex is intended to contain miscellaneous information of the character germane to the subject and of interest to scientists, but not necessary to the everyday operation of meteorological stations. First of all, there is presented a classification of various types of instruments used for the determination of atmospheric pressure. Then, some brief descriptive material is given concerning the various types. Information is rendered in regard to the cleaning of mercury and the filling of mercurial barometers. Finally, instructions are given pertaining to the transportation and handling of mercury barometers.

A–2.1 TYPES OF BAROMETERS

Barometers may be classified according to the following categories:

I **Cistern Types, Mercurial**
  - A. Fortin-type (fixed scale; level of mercury in cistern adjustable to zero of scale)
  - B. Movable Scale (movable scale whose zero is brought to level of mercury in cistern, as in Newman design)
  - C. Fixed-Cistern Type (cistern not adjustable; fixed scale)

II **Siphon Barometers, Mercurial**
  (Cross-section areas equal for lower and upper mercury surfaces)*
  - A. Non-adjustable regarding level of mercury with reference to zero of scale
  - B. Adjustable regarding level of mercury with reference to zero of scale
  - C. Wheel mechanism, float controlled

III **Two-Liquid, Expanded-Scale Barometers**

IV **Weight Barometers**

V **Aneroid Barometers**

VI **Sympiesometer**

VII **Hypsometer**

VIII **Recording Barometers; Barographs**

Further information regarding these types is given briefly in the following sections.

A–2.2 FORTIN-TYPE MERCURIAL BAROMETER

This type, illustrated in figures 2.4.0 and 2.5.0, is the kind most widely used in the United States, and is always recommended for land stations. Such a barometer shall have the inner bore of the glass tube not less than 0.25 inch in diameter. Since the Fortin-type is not a primary instrument, it must be compared with a standard barometer to determine its instrumental error. This error arises owing to the following effects: capillarity; imperfect vacuum; incorrect location of zero of scale; imperfect graduation of scale; improper adjustment of the sighting edge to the zero line of the vernier; etc. *The correction for instrumental error* is a net correction depending upon the algebraic aggregate of these errors from various sources. Functioning of the ideal barometer depends upon the fact that atmospheric pressure exerted upon the surface of the mercury in the cistern must balance, theoretically, against the weight of the vertical column of mercury of unit cross-sectional area in the barometer tube above the level of the specified surface. However, in practice there are also some smaller factors which must be taken into account, including

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*Barometers have been constructed using a siphon tube having unequal areas for the upper and lower mercury surfaces. Such instruments do not have the same characteristics as the siphon barometers defined above. Under the present classification system, we regard those with unequal areas as examples of the fixed-cistern type.

the back pressure of any residual gases or vapors existing in the *"vacuum space"* at the top of the barometer tube *plus* the surface tension which produces different capillarity effects in the cistern and the tube, as revealed by the different height of the meniscus at the two surfaces.

As indicated with more detail in sec. 2.5, the zero point (usually composed of ivory) of the barometer scale is fixed. A thumb screw is provided beneath the barometer to permit the level of the mercury in the cistern to be raised or lowered. In order to bring the meniscuses to conditions of contact angle and shape similar to those which prevailed during the calibration of the instrument, a certain standardized procedure for tapping the barometer is recommended (see secs. 2.4.2, 2.7.1, and 6.5.5). Just prior to any barometer observation, an adjustment must be made by means of the thumb screw until the ivory point just perceptibly touches the surface of the mercury in the cistern, as shown by a small dimple. A scale is fastened to the metal tube which surrounds the glass tube, and a sliding vernier with connected sighting edges is provided for it. In order to make the barometer reading, the sighting edges are aligned precisely to the top of the meniscus in the tube, being careful that the line of sight is horizontal in order to avoid errors due to parallax. From the data of the scale and vernier, the observed height of the mercury column is determined, this being termed the "barometer reading." A thermometer is always attached to give the temperature of the instrument. It should be read at the beginning of the observation, as it provides the basis for the temperature correction. For accurate results the temperature at which the scale gives true linear units in accord with the standard should be known, so that the proper tables for the temperature correction will be referred to. The reader will find additional information regarding procedures for reading Fortin-type barometers in sec. 2.4.2.

A–2.3 MOVABLE SCALE BAROMETER

This type, shown in fig. A–2.3.0, is capable of yielding highly accurate results when the scale is calibrated; and it serves as a primary barometer when the vacuum is controlled by means of a vacuum pump. However it is rarely used, partly owing to its weight. In making an observation, the entire scale must be moved by means of an adjusting screw until the zero point of the scale is coincident with the surface of the mercury in the glass cistern. Consequently, there is no possibility of constant zero error of the scale as in the case of fixed-scale instruments, and no adjustment of the volume of the cistern is necessary. However, a vernier setting is required to make a reading of the height of the mercury column. An early type of movable-scale barometer was designed by Newman. In this instrument, the cistern was divided into upper and lower compartments connected by a port which could be opened or closed as desired. This barometer was designed to be prepared for moving by carefully inverting it so that the tube and upper compartment were filled with mercury, after which the port would be closed.

A–2.4 FIXED-CISTERN BAROMETER

The fixed-cistern barometer of the Kew (English) pattern is illustrated in fig. 2.6.0, while designs of American manufacture are pictured in figs. 2.4.0(A), 2.6.1, and 2.6.2. Barometers of somewhat similar construction are also manufactured in other countries (for example, Germany). In barometers of the fixed-cistern type, no adjustment of the scale position or of the cistern is necessary; however, the setting of the vernier is required, of course, for scale readings, as in the case of other mercury barometers. As explained in sec. 2.6, when the mercury rises in the barometer tube owing to an increase of atmospheric pressure, the level of the mercury in the fixed cistern falls by a different amount, since the effective cross-sectional areas of the tube and of the cistern are unequal. (Compare the situation in a U-tube barometer having equal areas, as illustrated in Appendix 1.4.2: the change in the level would be equal in both limbs of the instrument.) Therefore, as pointed out in sec. 2.6, it is necessary to graduate the fixed-cistern barometer on the basis of a reduced or contracted scale. It will be clear

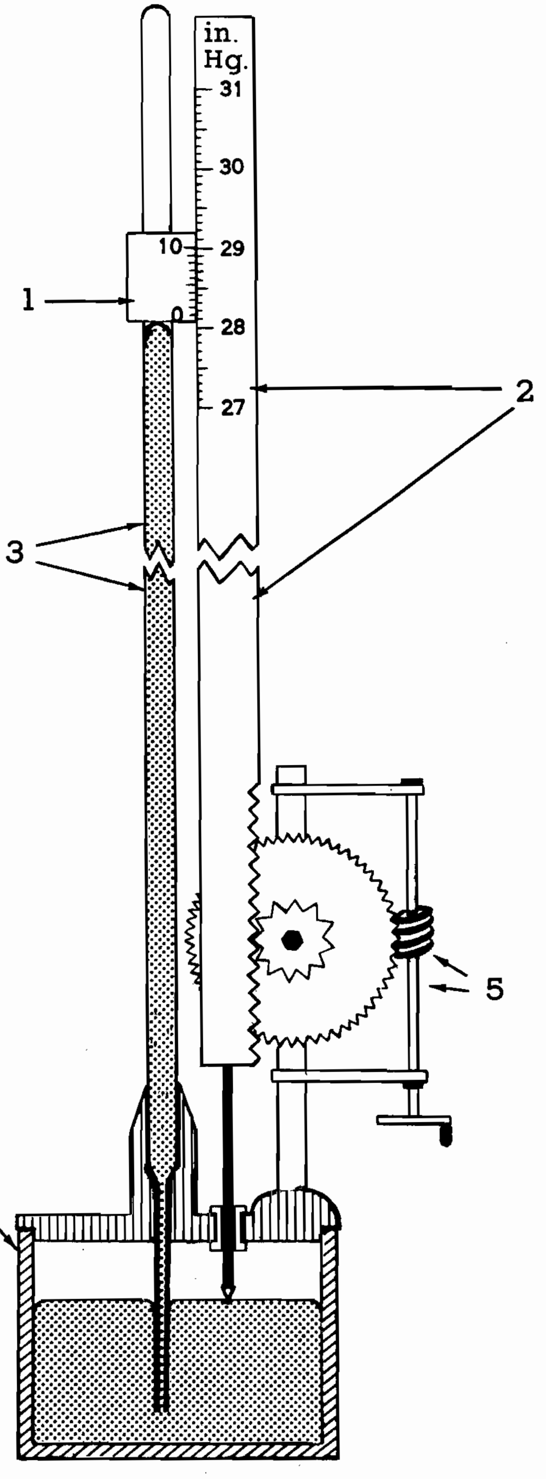

FIGURE A–2.3.0. Schematic principle of a movable-scale barometer. Indicated parts: 1. Vernier shown adjusted to top of meniscus. 2. Movable scale with its zero at tip of ivory point shown as lower extremity. 3. Mercury tube. 4. Mercury cistern. 5. Gear system for moving scale to set ivory point tip at surface of mercury.

that in order for a fixed-cistern barometer to maintain its calibration, the volume of mercury contained in the instrument must be kept constant; hence it is of especial importance that the instrument be calibrated or checked against a standard barometer after the mercury and the cistern are cleaned, since there is a likelihood that some mercury will be lost during the cleaning process.

With regard to the matter of the correction of the fixed-cistern barometer for temperature, the reader is referred to sec. 5.3. At this point it may be briefly explained that the correction of the fixed-cistern barometer for temperature has been generally regarded as the algebraic sum of two terms, the first being the same as the correction of the Fortin-type barometer for temperature and the second being a special function which pertains to the particular fixed-cistern barometer involved. It is important to note that the principal parameter which enters into this special function is the ratio of the total volume of mercury in the barometer (V) to the effective cross-sectional area of the cistern (A); that is, the ratio V/A. Another factor involved in the function is the composite mean coefficient of linear thermal expansion of the materials of which the (iron) cistern and the glass barometer tube are composed. This coefficient depends upon such factors as the ratio of the volume of mercury in the tube above the meniscus level of the cistern to the total volume of the mercury, V; and the ratio of the volume of the tailpiece immersed in the mercury to the volume V. Most of these quantities vary slightly with pressure and temperature in a rather complex manner.

By calibrating a number of fixed-cistern barometers of given design it is possible to determine a representative value of the composite mean coefficient specified above; and by actual measurements it is possible to ascertain a representative value of the effective cross-sectional area, A. In addition, the volume of mercury, V, at the standard temperature would have to be measured for the particular instrument. Finally, the correction for instrumental error for the individual instruments would have to be found by comparing their readings against those of a standard barometer.

Another technique which may be used to determine all of the parameters necessary for the correction of the individual fixed-cistern barometer both for instrumental error and temperature is to perform the calibrations at two or more different temperatures which are widely spaced and cover the operating range. In this technique, which is explained in sec. 5.3, the comparative readings between the given fixed-cistern barometer and the standard barometer are made at a series of pre-selected, constant barometer readings of the fixed-cistern instrument, covering the range expected under operating conditions, while the temperature of the instrument is kept constant. When this process is completed for at least two temperatures such as 0° C., and 30 or 40° C., it is possible to ascertain the parameters involved, so that by a suitable transformation of the formulas one may obtain the appropriate correction of the fixed-cistern barometer for temperature making use of the published temperature-correction tables for Fortin-type barometers.

It may be seen from the foregoing discussion that the principal advantage of the fixed-cistern barometer is that only one adjustment need be made for the purpose of making a reading (that is, the vernier setting at the top of the mercury column). However, there are some disadvantages, including the uncertainty regarding the repeatability of the capillary depression in the cistern, especially when the mercury becomes dirty, the necessity for a re-calibration when there is a change of volume of mercury in the barometer, and the complications pertaining to the accurate determination of the correction of the fixed-cistern barometer for temperature.

The fixed-cistern instruments are not used to any great extent at meteorological stations in the United States, but they have been employed widely in other countries for station barometers; and in a form especially designed for marine purposes they are still used to some extent on board ships. In order to aid in the damping out of violent oscillations of the mercury in the barometer tube which would occur in a storm on board ship if a regular land-station barometer were used, the marine version is provided with a constriction in the tube. This tends to limit the amplitude of the "pumping" action (see sec. 2.7.6). The constriction has the effect of introducing a lag in the readings of the barometer, so that the instrument requires time to reach equilibrium with the ambient pressure when the latter is changing. It follows that the tendency of the marine barometer is to read too low when the pressure is rising and too high when the pressure is falling (see sec. 2.7.1). In order to overcome, more or less, the effects of friction and lag in the marine barometer, it is necessary to tap it nearly continuously for several minutes. Such tapping aids in establishing approximate equilibrium conditions for the meniscus in the cistern and the meniscus in the tube. The same considerations apply, but to a less acute degree, in the case of a land-station fixed-cistern barometer.

Without appropriate tapping, variations occur in the shape of both menisci (see secs. 2.4.2, 2.7.1, and 6.5.5); so that when the shapes are different from what they were during the calibration, the assumed capillary correction is not representative and errors are introduced. For example, when a marine barometer is subjected to a rise and then a fall of pressure at an ordinary rate, the readings for the same pressure in the two instances may differ by about 0.2 or 0.3 mb., depending upon the rate at which the pressure changes, the cleanness of the mercury in the instrument and of the cistern, the diameters of the barometer tube and the capillary constriction, etc.

It will be evident from the foregoing considerations that the advantages of properly designed aneroid instruments for marine use will tend to cause them to supersede the marine fixed-cistern barometer for routine observations.

Comparisons made over a period of years between a number of fixed-cistern and Fortin-type barometers at a given station indicate that generally the latter show a greater degree of consistency in their readings than the former, especially where trained, experienced observers make the readings and where the mercury in the cisterns of the barometers become dirty, owing to the influence of atmospheric pollution and moisture. From this it is inferred that the effect of fouling of the mercury in the cisterns is somewhat more serious in the case of the fixed-cistern barometer than in the case of the Fortin instrument, since the fouling tends to cause the meniscus to become more or less flattened. It will be noted that one cannot correct for such an effect when the fixed-cistern barometer is used without checking the instrument against another; whereas in the case of the Fortin-type barometer one can set the surface of the mercury in the cistern to the ivory point, depending on how well the actual surface can be observed.

Another problem pertaining to the fixed-cistern barometer relates to the contraction of the scale outlined in sec. 2.6. The degree of the contraction of the scale depends on the ratio $(A + a)/A$, where $A =$ the effective cross-sectional area of the cistern, and $a =$ the cross-sectional area of the inside working portion of the barometer tube where the upper meniscus is read. The value of A is given by the actual cross-sectional area of the cylindrical portion of the cistern *minus* the actual cross-sectional area of the glass material in the tailpiece of the barometer tube which projects down into the mercury. It will be clear from these facts that the ratio $(A + a)/A$ must be accurately known in order to graduate the contracted scale properly; and that if the barometer tube is changed, it is important to choose for replacement purposes another tube which is the same as the original one in respect to the areas involved. It is also essential that all working sections over which the mercury meniscus moves under operating conditions should be accurate cylinders. Obviously, if the areas in a replacement tube no longer satisfy the ratio according to which the original barometer scale was graduated, it is necessary to replace the original scale with one properly graduated in accord with the relevant areas pertaining to the tube and cistern as finally assembled.

The fixed-cistern barometer is provided with an air trap as indicated in fig. 2.6.0, whereas the Fortin-type barometer is generally not so equipped. This device is intended to catch bubbles of air that may be rising along the inside wall of the barometer tube in order to prevent them from reaching the vacuum space above the meniscus in the tube. For this purpose the air trap is fairly successful, although occasionally some small bubbles of air manage to reach the vacuum space by rising through the column of mercury, especially after the barometer is inverted. Often the air contains moisture (see sec. 2.7.3). With regard to the gaseous matter which collects in the air trap, one should note that it has the effect of displacing mercury, hence an increase in the amount acts in the same manner as an increase in the total volume of the mercury. On the other hand, if the gaseous matter had reached the vacuum space, it would have caused an increase in the back pressure pushing down on the column of mercury, thereby producing a decrease in the reading for a given ambient atmospheric pressure. From these facts it is clear that the addition of gaseous matter to the air trap and its addition to the vacuum space yield errors acting in opposite directions.

One useful advantage of the fixed-cistern barometer lies in the fact that it may be procured with an arrangement on the cistern permitting it to be connected by means of a tube to a static-pressure head, which is a necessary adjunct when the barometer is installed under conditions where strong winds are encountered. (Fig. 2.4.0(A) illustrates a barometer equipped with a nipple and tube on the cistern for a static-pressure head connection; while secs. 2.11.0, 2.11.1, and 2.11.2 explain how the strong winds and some other conditions make the use of such a connection desirable.)

Large-bore fixed-cistern barometers are widely used by the military establishments as working standards for the calibration of any instruments which operate by means of pressure-responsive devices (for example, altimeters). An excellent illustration of such a fixed-cistern barometer is shown in fig. A–2.4.0, while fig. A–2.4.1 presents a close-up view of its upper portion. *In order*

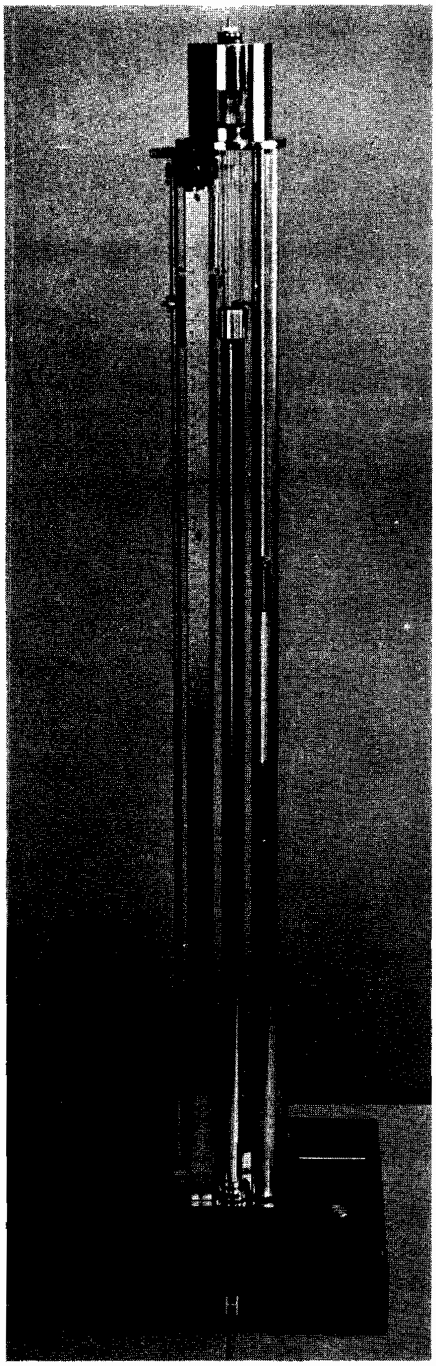

FIGURE A–2.4.0. Mercurial barometer (altitude test, type A–1) used by the U.S. Air Force in the calibration and testing of altimeters, rate-of-climb indicators, and other pressure-sensitive devices. It is a fixed-cistern barometer manufactured by Hass Instrument Corp., similar in many respects to apparatus shown in fig. A–2.5.2; its range is 0 to 800 mm. and −1,000 to 80,000 feet in pressure altitude. (See also fig. A–2.4.1.) (U.S. Air Force photograph.)

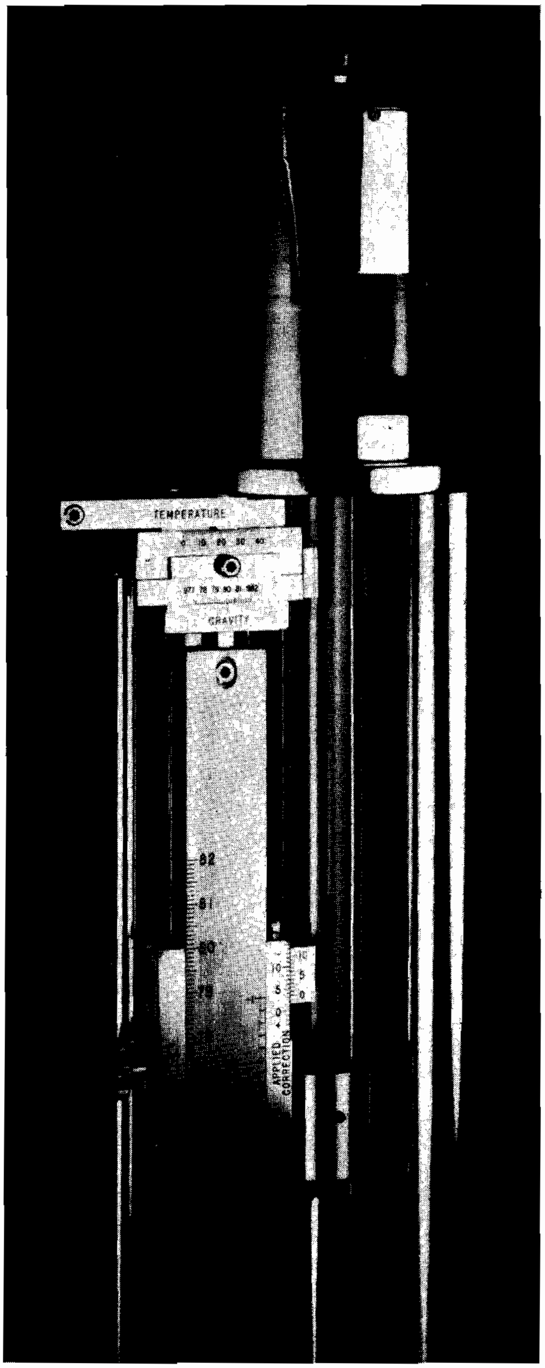

FIGURE A–2.4.1. Close-up view of upper portion of barometer shown in fig. A–2.4.0, revealing devices in upper left-hand part for compensating for the effects of gravity and temperature when the existing values are set in. Sighting edge for top of mercury meniscus in tube is provided by lower boundary of ring surrounding tube shown in lower central portion.

to facilitate the use of this instrument for calibration work it is provided with devices pictured in fig. A–2.4.1, which permit the operator to eliminate the need to apply corrections for gravity and temperature for each reading. This need is obviated by means of a simple, proper adjustment of those devices, depending upon the local value of gravity and the current temperature. In that event the corrections for those factors are automatically taken into account. Instruments of the general type shown in fig. A–2.4.0 have a nipple on the cistern in order to permit them to be connected with either a pressure-controlled chamber or a large volume manifold so that a group of pressure-responsive devices can be tested simultaneously. For purposes of this character the cistern should be airtight. In cases where the instrument is to be employed to determine pressures down to the vicinity of 0-1 inch of mercury, the cistern must be offset from the barometer tube, and therefore cannot be coaxial. Great care must be taken to assure that the instrument is accurately vertical (see sec. 2.7.2).

With further regard to the instrument depicted in fig. A–2.4.0, the top of the mercury tube is provided with a manually-operated mercury-sealed valve to permit renewal of the vacuum and purging of air bubbles above the mercury column. This instrument has an accuracy of about 0.2 mm. of mercury and is provided with an attached calibration card. Scanning of the meniscus in the tube is facilitated by the employment of a push-button controlled miniature lamp mounted on the scanner assembly. The specified barometer pictured in fig. A–2.4.0 is used throughout the U.S. Air Force for purposes of calibration and testing of altimeters, rate-of-climb indicators and other altitude sensitive devices. Two scales are provided for this instrument, one to permit readings in mm. of mercury and the other in feet of "pressure altitude" based on the standard atmosphere (see Appendix 8.0.1 and Chapter 8).

Special problems arise in connection with the transportation of barometers of various types, particularly in the case of some designs of the fixed-cistern barometer. For information regarding these matters the reader is referred to sec. 2.2.7. In any case it is worthy of special mention that the handling of mercury barometers must be such as to avoid getting air up into the barometer tube and to avoid loss of mercury. With these considerations in view it must be remarked that whenever it is necessary to invert a barometer, this must be done slowly.

The fixed-cistern instrument known as the "Tonnelot barometer," designed in France, is equipped with an arrangement that permits the cistern volume to be reduced by means of an adjusting screw, and enables one to fill the cistern and tube completely with mercury. (See also fig. 2.6.2 for an American design of a somewhat similar type of barometer.) This arrangement facilitates the safe transportation of the instrument.

A–2.5 SIPHON BAROMETER, NON-ADJUSTABLE LEVEL; PRIMARY STANDARD BAROMETERS

A–2.5.0 Siphon Barometer—General

Figure A–2.5.0 illustrates the principle of the type of siphon barometer which has no provision for adjusting the level of the mercury in the cistern with reference to the zero point of the scale. (See also the figure in Appendix 1.4.2, Chapter 12 which depicts a siphon barometer in the form of a U-tube of constant inside diameter.) The design is such that the inside diameter of the barometer tube is equal to that of the cistern, and the axes of these two cylindrical members are made to be on the same straight line (collinear), as indicated in fig. A–2.5.0. Owing to the uniform bore of the working portion of the tube and the cistern, it is theoretically possible for the capillary effects due to surface tension at the two menisci to cancel one another, provided the mercury in the neighborhood of both menisci is suitably vibrated before the observation in order to establish equilibrium and uniform conditions at both surfaces. Such a perfect balance may not always be realized in practice, for when the mercury level rises in one limb of the barometer it falls in the other, thereby tending to produce differences in height and shape of the two menisci. Furthermore, the line of contact between mercury

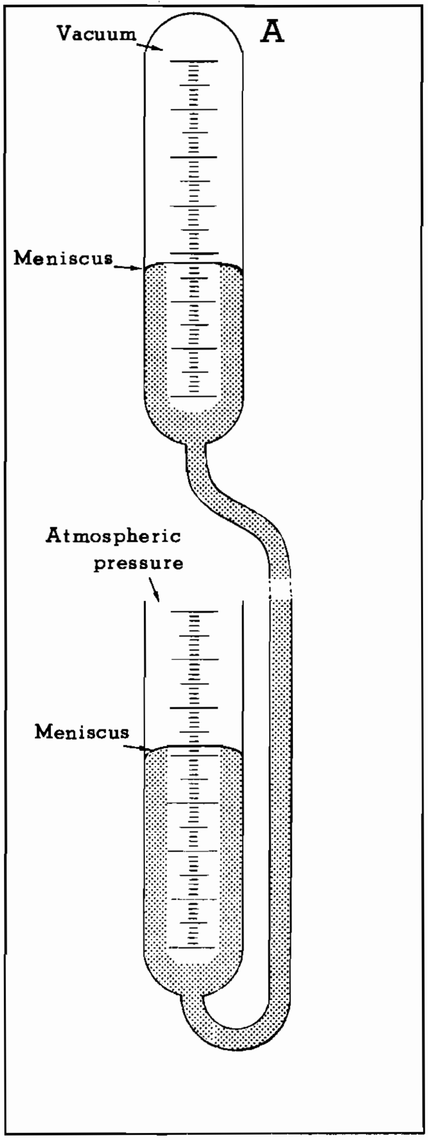

FIGURE A–2.5.0. Schematic drawing of basic siphon barometer (cistern non-adjustable).

and glass in a cylindrical tube may not be truly circular, the mercury rising more readily on one side of the tube than on the other, possibly owing to the imperfections in the glass or cylindrical form, and to the presence of inhomogeneous films of gas or moisture.[1]

The collinear arrangement is useful since it has the capability of rendering the influence of imperfect verticality negligible.

A–2.5.1 Primary Standard Barometer —General

By virtue of the advantageous features inherent in the siphon barometer, it may be adapted for use as a primary standard barometer if constructed of wide bore glass tubing about 30 mm. or more inside diameter, since the errors due to capillary action diminish as the bore increases. (See sec. 2.7.1.) When used as a primary standard barometer, it is necessary for vacuum-pump facilities to be provided in order to evacuate the space at the top of the closed barometer tube (see Appendix 1.4.2), and a McLeod gauge should be employed to measure the back pressure of residual gases in the space after the evacuation.[2] In addition, means must be available to permit accurate readings to be taken in order to ascertain the difference in height between the top of the meniscus in the cistern and that in the closed barometer tube. To accomplish this, a line standard of length (standard scale) of invar is usually mounted in a vertical position near the barometer and a cathetometer is employed to indicate the required difference in height. The cathetometer is generally designed as a vertical pillar capable of being rotated about a vertical axis and having a pair of micrometer microscopes mounted on it vertically above one another, with provisions for moving the microscope up and down so that their optical axes remain parallel.

In practice, the face of the standard scale and the vertical axis of the barometer should be equidistant from the vertical axis of the pillar of the cathetometer, while means should be provided to focus the microscopes with parallel optical axes alternately on the two menisci and on the scale, thereby permitting readings to be taken from which the difference in their height can be determined. Orientation of the microscopes can be controlled by rotating the pillar. However, in the primary standard barometer used at the National Physical Laboratory, Teddington, England, the vertical column which carries the microscopes may be moved sideways, parallel to itself in V-grooves on the base cast-

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[1] Whytlaw-Gray, R., and Teich, N., "The Mercury Meniscus in Precision Measurements on Gases," Trans. Faraday Soc., Vol. 44, pp. 774–783, (1948).

[2] Strong, J., et al., "Procedures in Experimental Physics," New York, Prentice-Hall, Inc. (1939).

ing of the instrument, so that the microscopes may be brought opposite either to the mercury surfaces or to the line standard as required.[3] A plumb line is suspended from the main support of the barometer, and this is used as a reference for adjusting the line standard in a vertical position with the aid of the microscopes.

With a view to determining the heights of the precise apexes of the two menisci, a suitable optical system must be provided. A method sometimes employed for this purpose involves the use of a very fine horizontal wire placed behind the mercury column with a collimator in front of the wire so that the parallel rays emerging from the collimator project a real image of the wire in the space above the mercury near the apex of the meniscus. A reflection of this image is produced by the mercury surface. By means of the microscope, readings are taken of the positions both of the real image and of its reflection. It is then assumed that the vertical position of actual apex of the meniscus is midway between the positions of two images, according to the method described by Marek in connection with the standard barometer constructed for the International Bureau of Weights and Measures.[4] In order to obtain well-defined images and precise results, it is necessary for the external and internal surfaces of the glass in the barometer in the neighborhood of the points of entrance and emergence of the light involved in the images to be polished so as to be optically perfect, insofar as practicable; and the readings at the lower meniscus should be made in precisely the same way as those at the upper meniscus.[5] The real image of the horizontal wire should be somewhere near the axis of the barometer over the relatively flat portion of the meniscus, and experiments may be performed in order to find the best position so that the direct and the reflected images are equally bright and equally well defined, as pointed out by Sears and Clark.[3]

A–2.5.2 Density and Thermal Expansion of Mercury

At this point a digression concerning the subject of the density and chemical composition of mercury is appropriate. As a standard practice it is generally assumed that the density of pure mercury at a temperature of 0° C. is 13.5951 grams per cubic centimeter under standard conditions of pressure. However, when mercury is purified by a process of distillation under vacuum (see sec. A–2.14), a partial separation of the isotopes of mercury occurs.[6] [7] Various authorities consider that the actual density of "pure" mercury used in a barometer may deviate from the assumed standard value by as much as 1 part in 200,000 or even 1 part in 150,000, depending upon the history of the sample of mercury involved, governed by such factors as the original source of the sample, the methods by which it was purified, and the impurities which may be contained in it when used. [3] [8]

Considering that some of the chemical materials in the glass or steel which come into contact with the mercury may dissolve very slowly in the liquid, and that the atmosphere which exerts pressure on the meniscus in the cistern may be a source of impurities, one should expect that the density of the mercury in the barometer will vary gradually over a period of years. Owing to the combined effects of various sources of error in primary standard barometers, it is usually concluded that an absolute accuracy of about 1 part in 100,000 is attainable with these instruments, that is, an accuracy to within about 0.01 mb. at ordinary atmospheric pressures.[8]

Re-investigations of the density of mercury have been recently conducted by Cook and others.[9] [10] [11] Beattie, Blaisdell, Kaye,

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[3] Sears, J. E., and Clark, J. S., "A New Primary Standard Barometer," Proc. Roy. Soc. London, Ser. A, vol. 139, pp. 130–146, (1933).

[4] Marek, Repertorium Experimentell Physik, vol. *16*, p. 585, (1880) ; and Travaux et Mémoires du Bureau International des Poids et Mésures, vol 3, D. 22, (1884), Sèvres, France.

[5] Glazebrook, Sir R., "A Dictionary of Applied Physics," vol 3, p. 152; article on "Barometers and Manometers," by F. A. Gould, Macmillan and Co., Ltd., London (1923).

[6] Laby, and Mepham, Nature, (London), vol. 109, p. 207, (1922).

[7] Mulliken, and Harkins, Jour. Amer. Chem. Soc., vol. 44, p. 61, (1922).

[8] Gould F. A., "The Barometric Standard," Proc. Roy. Soc., London, Ser. A, vol. 186, pp. 195–200 (1946).

[9] A. H. Cook, "The expansion of mercury and fused silica between 0° and 300° C.," British Journal of Applied Physics, vol. 7, 285–293 (August, 1956).

[10] A. H. Cook and N. W. B. Stone, "Precise Measurements of the Density of Mercury at 20° C—I. Absolute Displacement Method," Phil. Trans. Royal Soc. London, Ser A, vol. 250, 279–323 (28 Nov. 1957).

[11] James A. Beattie, B. Edwin Blaisdell, Joseph Kaye, Harold T. Gerry, and Clarence A. Johnson, "An experimental study of the absolute temperate scale. VIII. The thermal expansion and compressibility of vitreous silica and the thermal dilation of mercury," Proc. Amer. Acad. Arts & Sci., vol. 74, 370-388 (1941).

Gerry, and Johnson[11] measured the relative variations of the specific volume of mercury with temperature and were enabled to fit the following formula to their observations between 0° and 300° C. pertaining to the thermal cubical expansion of mercury:

$$
\begin{aligned}
10^8\ (V_t - V_o)/tV_o = 18{,}144.01 \\
&+ 70.16 \times 10^{-2}t \\
&+ 28.625 \times 10^{-4}t^2 \\
&+ 2.617 \times 10^{-6}t^3
\end{aligned}
$$

where t is in °C. Int. (1927), V_o = specific volume of mercury at 0° C., and V_t = specific volume of mercury at temperature t° C.

The density of mercury as a function of temperature may be easily computed from the reciprocal of V_t, provided V_o is known (see below).

It is customary to use the symbol m to represent the relationship

$$m = (V_t - V_o)/tV_o.$$

This quantity (m) represents the coefficient of cubical expansion of mercury, and the foregoing equation shows how it varies with temperature. It is conventional for routine meteorological practice to adopt the value $m = 0.0001818$ per °C. for temperature corrections of the mercury barometer in the ordinary range of room temperature, this value being considered as a satisfactory mean under these conditions (see Appendix 1.4.2).

Precise determinations by Cook and Stone[10] of the density of mercury at 20° C. at one (1) atmosphere pressure yield the result 13.5458924 g/cm³ for these conditions. By making use of the formula of Beattie et al.[11] Cook and Stone calculated the density of mercury of 0° C. at one (1) atmosphere pressure to be as follows: 13.5950861 g/cm³. The value of V_0 is the reciprocal of this quantity.

A–2.5.3 Primary Standard Barometer, Teddington, England

In the case of the primary standard barometer at the National Physical Laboratory, Teddington, England, described by Sears and Clark[3] (see fig. A–2.5.1), the body of the instrument is made of stainless steel, being essentially a U-tube bored in a block of this material. However, the portions of the tube and the cistern where the upper and lower menisci are observed represent rectangular reservoirs. The cross sections of the latter are square, 1.875 inches on a side,

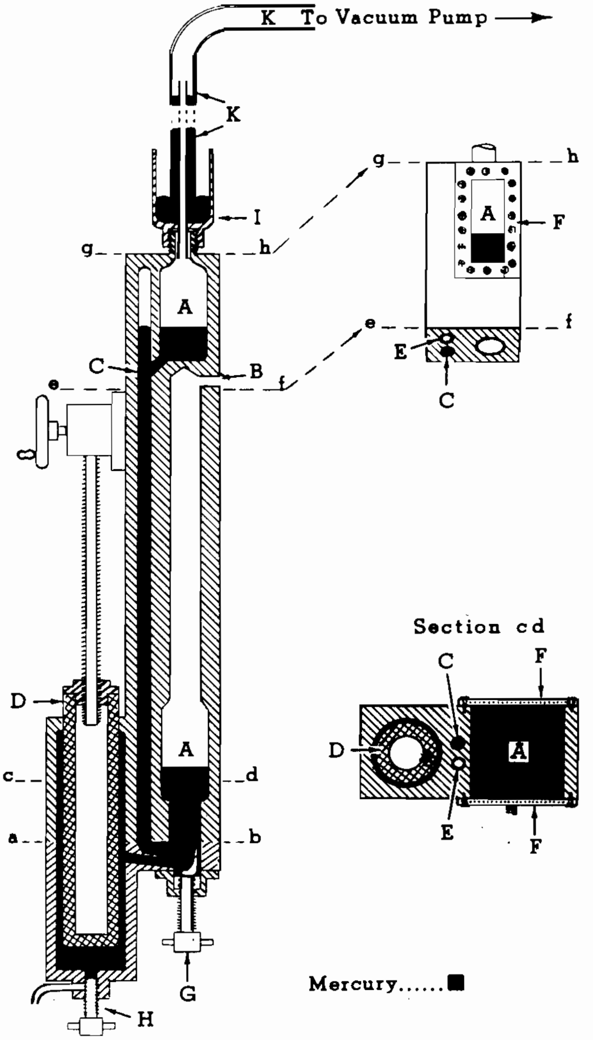

FIGURE A–2.5.1. Schematic diagram, not drawn to scale, of the primary standard U-tube barometer used at the National Physical Laboratory, Teddington, England. Barometer is constructed of two blocks of stainless steel joined at the plane *ab*. Parts: *A*. Collinear reservoirs, square in section. *B*. Vent for atmospheric pressure. *C*. Tube of small bore connecting upper and lower reservoirs. *D*. Piston operated in cylinder to raise or lower mercury levels in reservoirs. *E*. Small bore well in block, containing mercury in which a 30-inch thermometer bulb is immersed. *F*. Optically perfect and parallel glass windows. *G*. 4-way cock to connect together as required the various parts of the barometer. *H*. Needle-valve draining cock. *I*. Mercury seal which prevents vibrations being transmitted by solid connections from vacuum pump through pipe line *K* to barometer.

and their vertical height about 4 inches. Optically flat parallel glass windows are fastened in place over the faces of the vertical sections of these reservoirs, thereby permitting the two menisci to be observed. The space above the upper meniscus is evacuated before use of the instrument, by means of a vacuum pump. The average temperature of the mercury column is determined with the aid of a special mercurial thermometer having a bulb 30 inches long, immersed in mercury in a hole bored in the stainless steel body parallel to the barometric column. In order to ascertain the correction of the barometric height for temperature to an accuracy of 0.001 mm. of mercury, it is necessary to know the mean temperature of the mercury column to an accuracy of 0.007° C. Therefore, the instrument must be mounted in a closed, thermally insulated room which is maintained at a constant temperature by suitable means. The primary standard barometer at Teddington is provided with a cylindrical hole whose axis is parallel to that of the main barometer tube, while a passageway is bored from this hole to the bottom of the cistern below the lower reservoir. A stainless steel plunger may be caused to move up or down in this cylindrical hole; hence when down, it displaces mercury, forcing the liquid up into the cistern and thereby raising the entire column of mercury; and when up, it permits the mercury to fall in the system. Thus, by withdrawing the plunger it is possible to allow the mercury levels to sink below the levels of the glass windows when the barometer is not in use. In this manner the chemical action of the mercury on the inside of the glass windows is kept to a minimum, so that the rate of discoloration of the interior glass surfaces is exceedingly slow.

A–2.5.4 Extended Range Standard Barometer at Teddington

The design, construction, and installation of a new standard barometer was reported by members of the staff of the National Physical Laboratory, Teddington, England. (Reference: Elliott, K. W. T.; Wilson, D. C.; Mason, F. C. P. and Bigg, P. H., "Primary Standard Barometer of Range 0 to 1200 Mb.," Jour. Sci. Instrum., vol. 37, 162–166 (1960).) This instrument is essentially a mercury U-tube which involves the use of a stainless steel tube to connect the lower extremities of two vertically-arranged Inconel hollow cylinders, having each an inside height of 51 cm. and an inside diameter of 11 cm. The metal Inconel, an alloy composed of nickel, chromium, and iron, was employed for the two working limbs of the barometer largely because it was considered free from attack by mercury and water, while it could be spun-cast for homogeneity. Different levels are used for the two cylinders which constitute the working sections of the U-tube, the base of the lower cylinder being at a level 46 cm. beneath that of the base of the upper cylinder. When the same pressure is applied at the top of the mercury in both working sections, the surface of the mercury in the two limbs of the barometer assumes a common level which is 2.5 cm. below the top of the lower cylinder and 2.5 cm. above the base of the upper cylinder. The maximum pressure capable of being measured with this barometer is equivalent to 92 cm. of mercury. An evacuated space is produced above the mercury surface in the higher limb of the U-tube by connecting the top of the upper cylinder to a mercury-diffusion vacuum pump. The residual pressure then existing over the mercury in the upper limb is measured with the aid of a directly-attached Pirani gauge head, thus enabling a correction for the back pressure to be determined. Due to the large diameter (11 cm.) of the working sections in which the free surfaces of the mercury operate, the effective capillary depression is negligible, and the central portion of those surfaces is relatively flat in each limb of the U-tube. At the top of each of the two Inconel cylinders there is located a glass coverplate, 16 mm. thick, which seals their uppermost portions. These coverplates are nearly optically flat and parallel. A beam of light is projected through each of the glass coverplates at an angle of 5° from the vertical, this beam being involved in an optical probe which is designed to be set at a reproducible distance from the reflecting mercury surfaces. (This device is described in the following reference: Elliott, K. W. T. and Wilson, D. C., "An *Optical*

Probe for Accurately Measuring Displacements of a Reflecting Surface," Jour. Sci. Instrum., vol. 34, 349–352 (1957).)

Arrangements are such that the two probes can be brought to operate simultaneously either on the mercury surfaces in the working sections of the two limbs or on a common mercury reference pool contained in a chamber located at the side of the U-tube assembly. The reference level provided by the surface of the pool is very nearly at the mean level of the mercury surfaces in the U-tube when the pressure acting at the top of the upper limb is the same as that acting at the top of the lower limb. By design, the projected light beam in the given type of optical probe illuminates a grating through which the light is transmitted. After emerging from the grating, the light passes through a lens which focuses the beam on the mercury surface under consideration where an image of the grating is formed. Light from the grating image reflected on the mercury surface passes through another lens by means of which the light is focused on an exactly similar grating where an image of equal size is produced. After transmission of the light beam through the second grating, it passes to a photocell which measures the amount of light energy received. Since the incident beam from the probe in each case was inclined at an angle of 5° with reference to the normal at the mercury surface, the reflected beam will be inclined at the same angle on the other side of the normal. When the surface of the mercury is located with respect to the probe at a distance such that the reflected image of the first grating as projected on the second grating comes to a position of coincidence with the latter grating, thus causing every image of a transparent line to fall on a transparent line with the result that a maximum amount of light is transmitted and the photocell indicates a maximum intensity of energy received. If the mercury surface is displaced slightly from the relative position with respect to the probe where this condition of maximum light transmission occurs, the energy incident on the photocell drops rapidly since the displacement of the reflecting surface causes the final image projected on the second grating to shift laterally relative to its original position, with the result that some opaque portions of the second grating between the transparent ruled lines obscure light received from the images of the transparent lines of the first grating.

By virtue of this characteristic of the optical probe the readings of the photocell afford a very sensitive indication of displacement from the relative position at which a maximum reading is yielded. In view of the steady behavior of the photocell and the maintenance of uniform, consistent design parameters, the above described operating features of the probe permit it to be employed in such a manner that a pre-determined amount of light received on the photocell under the condition of maximum sensitivity can be interpreted as equivalent to the location of the probe at a fixed and reproducible distance relative to the reflecting mercury surface. In other words, the probe serves as a precise reference indicator of distance relative to the mercury surface on which the image of the original grating is formed, and thus it provides, in effect, a fiducial marker. When the probe is to be applied for this purpose, it is necessary to adjust the distance of the probe from the mercury surface under consideration until the photocell yields the maximum reading pre-determined by the design characteristic of the probe, and under this condition the probe can be regarded as located at a definite distance with respect to the meniscus.

In order to simplify the operations the optical probes are mounted on a stiff casting supported on a kinematically designed horizontal ball trackway. The horizontal portions of the optical paths of the probes are deflected into vertical paths by means of inclined mirrors freely supported on adjustable mountings fixed to the casting at the end of the guideways. Pneumatic pressure is employed to move the whole casting along its trackway, and by this means the two probes can be properly set to yield indications of a predetermined distance either with respect to the mercury surfaces in the working sections of the above-mentioned cylinders or with respect to the surface of a common mercury reference pool, as already stated. Accurately graduated and verified line standards *(linear* scales) constructed of Invar are mounted on the probe carriages parallel to the longitudinal axis of the optical probes. Measurements of the displacement of the optical probes along their ways between settings on the U-tube and the reference pool are made by referring to the line standards by means of micrometer microscopes attached rigidly to the casting.

With a view to exercising close control of the temperature of the apparatus the U-tube barometer is equipped with water jackets through which water circulation provided by a pump is continued between observations. In this manner the temperature in each jacket around any given part can be maintained uniform within about 0.005° Celsius. The apparatus as a whole is enclosed in a barometer case equipped to yield air circulation which serves firstly to remove most of the pump energy transferred to the water and secondly to equalize the water and air temperature to about 0.1° Celsius. A sensitive and accurate mercury-in-glass thermometer is set in a brass block at a point halfway up the jacket of each cylinder. Immediately prior to an observation the pump is switched off and the thermometer readings are then taken. These readings show that the temperature within the jackets remains steady within ±0.002° Celsius for some minutes.

The entire U-shaped barometer and associated apparatus yielded a weight of about 285 kilograms, of which nearly 55 kilograms are due to the mercury. An anti-vibration mount was used for the support of the unit in order primarily to obviate rippling of the mercury surface. This mount consists of a concrete block weighing about 680 kg., supported on four helical compression springs with which the natural frequency of the system in the vertical was observed to be about 1.33 cycles per second. Small open dashpots, filled with silicone fluid, were then added to reduce the amplitude of the residual low-frequency oscillation. When mercury is shifted from one cylinder of the U-tube to the other, it causes the mount to tilt slightly thus giving rise to an error. In order to prevent the tilting of the mount from being more than 0.2° due to the transference of the mercury from one limb of the barometer to another, four horizontal restraining strips composed of brass sheet were fitted to the mount, each having a large single corrugation running parallel to the plane of the U-tube.

Various sources of error affecting the readings of the instrument must be taken into account. Among these may be mentioned those relating to the cover-plates. Thus, where there is a difference in pressure across a coverplate as in the case when a vacuum exists within the upper cylinder while atmospheric pressure exists outside, the indices of refraction of the air above and below the coverplate are different and, at the same time, the plate itself bends slightly. These phenomena affect the passage of light involved in the optical probe and give rise to errors. Corrections for the various known sources of error are applied. It has been estimated after careful study and analysis that a single determination of pressure with the instrument may be considered as accurate within ±0.01 mb. at the confidence level of 99%. In order to check on the comparability of the new primary standard barometer with two units of the older design of primary standard barometer previously described as employed at the National Physical Laboratory, Teddington, England, twenty comparative measurements of a common pressure (about 1000 mb.) were carried out. The mean difference between the readings was within 0.0021 mb., while the standard deviation associated with the pressure determinations by means of the new instrument was apparently about 0.0024 mb.

A–2.5.5 United States Primary Standard Barometer

The standard barometer established at the National Bureau of Standards, Washington, D.C., consists of a U-tube made of precision bore glass, 25 mm. in inside diameter. It is supported by a suitable frame anchored to a heavy foundation. The equipment is located deep underground in a sub-basement with the temperature maintained constant at 25° C. within a tolerance of 0.2° C. Readings of the instrument are to the nearest 0.01 mm., reproducible to better than 0.02 mm., while the overall accuracy is considered to be about 0.02–0.03 mm. of mercury. Technically, it is possible to regard this instrument as a large U-tube manometer with one leg exposed to the atmosphere. The top of the other leg of the manometer has a mercury seal, and is connected to a diffusion pump to permit continuous renewal of the vacuum above the mercury meniscus, and a McLeod gauge to enable the operator to observe the degree of vacuum in the space.

About one meter away from the U-tube is a comparator (cathetometer) carrying a pair of telescopes for reading the instrument scale. The latter, 800 mm. in length and ruled in 0.5-mm. divisions, is mounted on a frame adjacent to the U-tube. A reticule (ruled scale on the eye piece) in the telescopes is used as a vernier, with the magnification of the telescope kept fixed. Suitable illumination is provided for the top of the meniscus in each leg of the manometer (e.g., miniature electric lamps together with a green translucent material between the lamp and the meniscus). The lamps are installed behind each mercury column and are capable of being moved vertically to the position that will enable the observer to set the cross hair of the telescope most accurately to the level of the meniscus. When the meniscus is thus sharply defined without any glaring reflections from the lamp, the cross hair of each telescope is brought precisely to the level of the top of the meniscus, and then the cathetometer is rotated about its vertical axis until the scale is in the line of sight of the telescope. A reading of the scale to within 0.01 mm. is made by means of the reticule. This is done in turn for each of the menisci. Appropriate corrections are then applied for known sources of error in order to determine the existing atmospheric pressure (see Chapters 2–6).

Since it has been found that vibrations cause irregularities in the menisci, and errors, both the comparator and the standard barometer are mounted on a massive concrete base which rests on two inches of cork, thus permitting the equipment to be isolated from vibrations within the building.

Careful attention has been given to the solid construction of the cathetometer with a view to eliminating any possibility that it will bend under the action of such forces or torques as may be applied. Extreme care is taken also that the cathetometer is accurately vertical and that the optical axes of the telescopes are horizontal and parallel. The distances from telescopes to menisci and from telescopes to scale are made equal. In order to check whether the optical axis of the telescope is horizontal, one sights the telescope on the scale and observes the scale reading; then one reverses the telescope in its mounting, rotates the cathetometer 180°, and observes the scale reading a second time. When the two readings thus obtained are equal, this is an indication that optical axis of the telescope is horizontal as required.

In the standard barometer constructed at the Massachusetts Institute of Technology, great care was taken with regard to the method of sighting based on the use of telescopes.[11] [12] [13]

A–2.5.6 Finnish Primary Standard Barometer

In Finland a standard barometer was constructed by the late Professor E. T. Levanto, Director of the Weights and Measures Office, Helsinki.[14] This instrument is equipped with a McLeod gauge to measure the vacuum above the mercury in the working section of the upper barometer tube, which has an inside bore of 32 mm. A tube coaxial to the former and of the same inside diameter is connected by means of a smaller glass tubing to the first-mentioned tube, but being at the lower end of the instrument is capable of having its mercury meniscus exposed to the atmosphere. The barometer is housed within a ventilated, thermostatically controlled cabinet. Its scale is to be constructed of invar which has a coefficient of thermal expansion of 0.8×10^{-6} per degree Celsius. An index of iron floats on the free mercury surfaces of each of the two tubes mentioned above. The index is composed of an iron ring, with two supports and a pointer. These rings have an outside diameter which

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[12] James A. Beattie, B. Edwin Blaisdell, and Joseph Kaye. "An experimental study of the absolute temperature scale. IX. The determination of the capillary depression and meniscus volume of mercury in a manometer," Proc. Amer. Acad. Arts & Sci., vol. 74, 389–397 (1941).

[13] James A. Beattie, David D. Jacobus, John M. Gaines, Jr., Mason Benedict, and B. Edwin Blaisdell, "An experimental study of the absolute temperature scale. VI. The gas thermometer assembly and the experimental method," Proc. Amer. Acad. Arts & Sci., vol. 74, 327–342 (1941).

[14] E. T. Levanto, "A new normal barometer," Annales Academiae Scientiarum Fennicae, AI, No. 191, Helsinki, (1955).

is only about 0.1 mm. smaller than the inside diameter of the working sections of the glass tubes. The lower end of the pointers is about 0.2 mm. away from the mercury. Observations are made by microscope of both the end of a pointer and its reflection in the mercury surface. The mean of these two positions yields the location of the mercury surface. Vessels containing reservoirs of mercury are connected to the barometer system and employed to control the level of the mercury when the barometer is not actually being used for observations. The level of the free mercury surfaces in the two tubes mentioned above may thus be lowered so that the working sections are not in contact with mercury when the instrument is not in use.

A–2.5.7 United States Weather Bureau Standard Barometer

Another design of standard barometer used by the Weather Bureau and other agencies is that shown in figs. A–2.5.2, A–2.5.3, and A–2.5.4. It will be noted that the cistern is not collinear with the barometer tube in this instrument; hence special care must be taken to assure verticality. This barometer is provided with a micrometer by means of which an index is adjusted to the level of the mercury meniscus in the cistern, thus permitting its height to be measured. A vacuum pump is operated during the period of use of the instrument with a view to maintaining a vacuum at the top of the tube, and a McLeod gauge is employed to determine the amount of back pressure within the space above the upper meniscus. When dry ice is used within the cold trap box at the top of the tube, it is possible to secure a vacuum of excellent quality for barometric purposes during the period of operation of the vacuum pump, after a suitable starting stage. (See fig. A–2.5.4.) On the basis of comparisons with other standard barometers, it is judged that an absolute accuracy of about 0.002 inch of mercury is obtainable with this instrument.

A–2.5.8 Japanese Absolute Standard Barometer

A new standard barometer was installed at the Japan Meteorological Agency, Tokyo, in

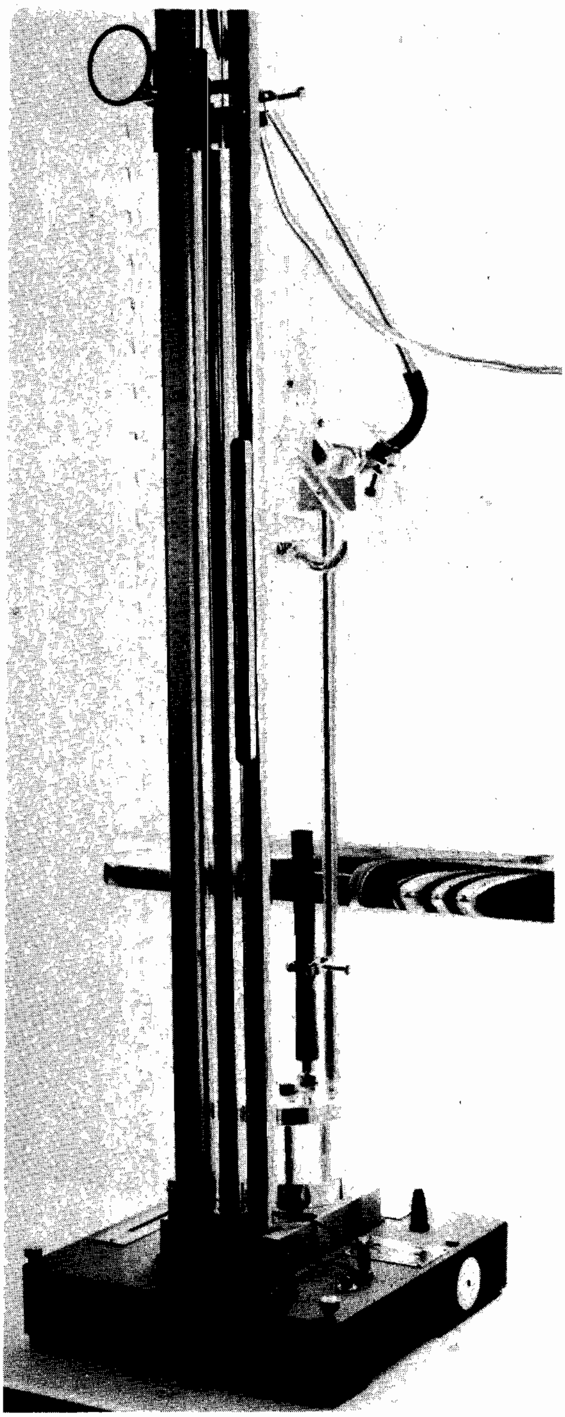

FIGURE A–2.5.2. Standard barometer manufactured by Hass Instrument Corp. Bore 12 mm. Space above meniscus in tube evacuated by means of a vacuum pump (see fig. A–2.5.4), and McLeod gauge used to measure actual back pressure in the space. Micrometer employed to measure height of mercury in cistern. Range of scale readings from 0 to 810 mm., or 0 to 1080 mb.

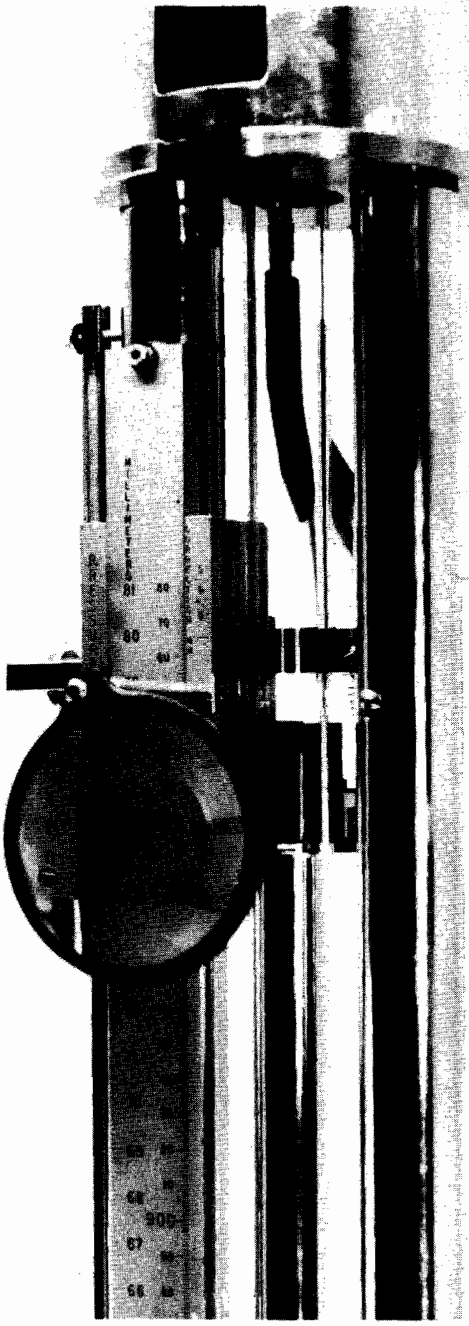

FIGURE A–2.5.3. View of upper portion of Hass Instrument Corp. standard barometer, showing magnifying glass used to read vernier. Rubber tubes connect to the vacuum pump which controls quality of vacuum in space at top of tube.

1959. (Reference: Yoshitake, M.; Shimizu, I. and Takeuchi, K. "An Absolute Standard Barometer," Jour. Met. Soc. Japan, Ser. II, vol. 37, 105–110 (1959).) This instrument is essentially a siphon barometer having two similar cylindrical glass cisterns whose axes are on the same straight vertical line separated by a distance of 760 mm. The inside diameter (working section) of each cistern is 30 mm., while the cisterns are connected at their lower extremities by means of a glass tube, the inside diameter of which is about 10 mm. Two bends occur in this small bore tube at short distances below the uppermost cistern. The top of the lower cistern can be exposed to the ambient atmosphere by opening a stopcock. A single rotary oil pump is employed to produce a vacuum (pressure less than 0.01 mm. Hg.) above the mercury surface in the upper cistern. Attached to the top of this cistern is glass tubing connected with a Geisler tube the discharge of which is capable of indicating qualitatively a pressure down to about 0.001 mb. Below this pressure the discharge in the Geisler tube ceases, and the tube therefore will indicate a lower pressure when it becomes nonluminous and nonconducting.

A siphon is connected to the bottom of the 10-mm. bore tube on the side opposite to that on which the lower cistern is joined. The upper (inverted-U) end of this siphon is immersed in a quantity of mercury contained in a bottle-like reservoir which is provided with an extra orifice near its shoulder. With this arrangement the raising or lowering of the reservoir can be employed to produce a corresponding rise or fall of the level of the mercury in the two cisterns mentioned above. By keeping the reservoir in a lowered position during periods when the barometer is not in use the free surfaces (menisci) of the liquid are then held in a position near the bottom of each cistern away from the portions of the glass walls where the surfaces make contact under ordinary operating conditions. Thus, through a proper application of the reservoir contamination of the interiors of the working sections of the cisterns by the action of impurities in the mercury is greatly diminished. In addition, the reservoir is used in connection with the processes of filling the barometer with mercury and removing the mercury for the purpose of cleaning the fluid.

In order to facilitate temperature control

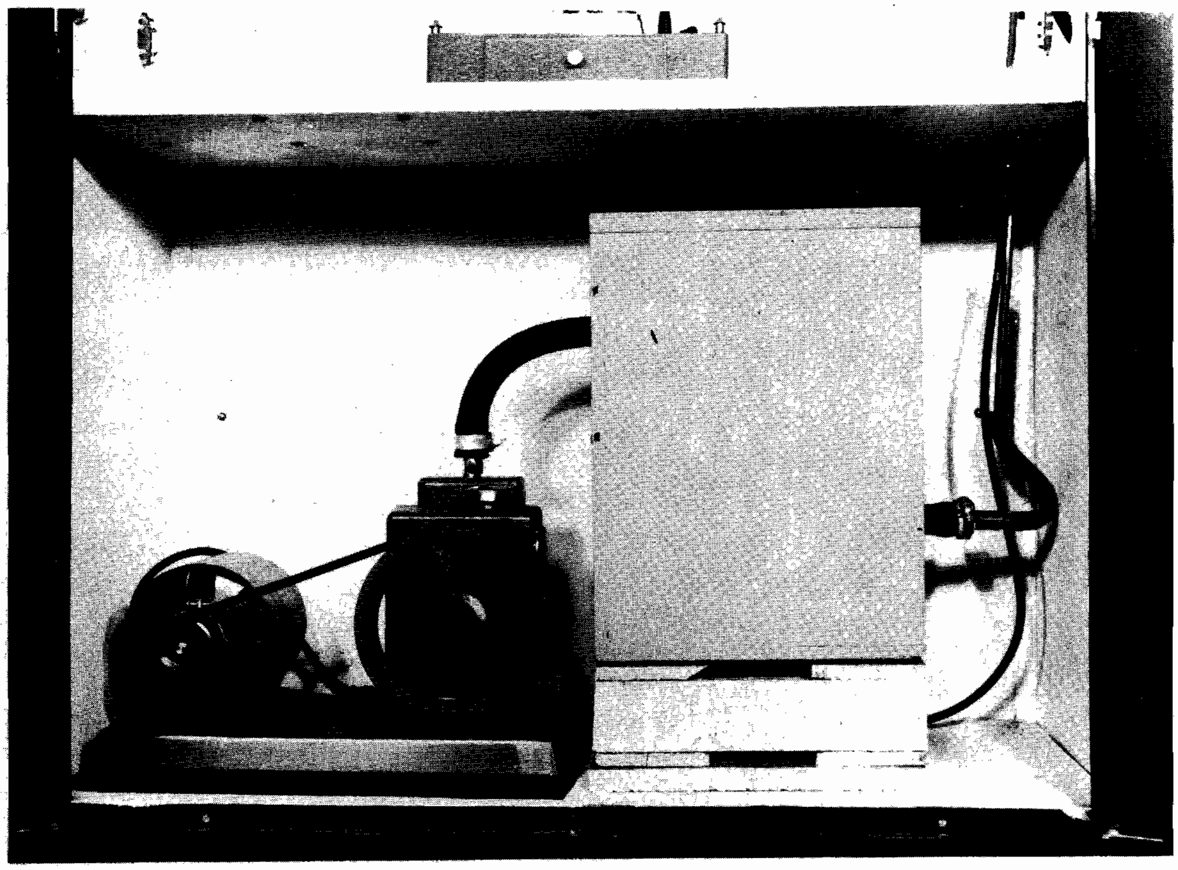

FIGURE A–2.5.4. Pump used to evacuate space in the tube above the meniscus of the Hass Instrument Corp. standard barometer. Cold trap box has glass "boot" on inside that can be surrounded with dry ice.

of the mercury column there were incorporated in the barometer design three separate glass jackets for the circulation of water. The glass jackets are placed to cover various major sections of the 10-mm. bore tube used for connecting the lower portions of the two cisterns. Two of these glass jackets are located around the short tube sections that project down from each cistern. The third jacket envelopes the long vertical part of the tube running from the base of the barometer to the first bend in the tube which occurs at a short span of distance beneath the upper cistern. Mercury-in-glass thermometers engraved to 0.1°C. are hung in the two higher glass jackets to permit the determination of the temperature of the mercury column. Two electric fans are operated to circulate the room air before measurements.

In order to permit the making of measurements by means of the apparatus described above, a standardized scale composed of pure nickel and having an H cross section is mounted vertically on a rigid frame in a location adjacent to the siphon barometer. Nearby there is installed a cathetometer equipped with two telescopes each having an eye-piece micrometer and a level. (See references: Zigman, P., "Improved Measurement of Mercury Heights in a U-Tube Manometer with a Micrometer Cathetometer," Rev. Sci. Instrum., vol. 30, 1060–1062 (1959); and Reynolds, C. A.; Pearson, G.; Burchbuckler, F. and Burnham, J., "Illumination Source for Manometers," Rev. Sci. Instrum., vol. 30, 1050–1051 (1959).) Before undertaking an observation the reservoir is raised until the mercury levels ascend to about the middle of the two cisterns. In making an observation the telescopes are first adjusted in height until the micrometer cross wires are set on the menisci of the lower and upper cisterns; and then the cathetometer is turned on to the standard scale by means of which the relative vertical positions of the micrometer cross wires are read. The capillary depressions due to the two menisci are both small and nearly equal (see fig. 2.7.0(a) & (b)). Moreover, the difference between these two capillary depressions, which is involved in the vertical distance between the cross wires nearly cancels out when the subtraction of the scale readings is made. Thus, the effect of capillarity is considered to be negligible in the siphon barometer of the given dimensions. On the basis of comparative readings it was concluded that the value of 0.03 mm. Hg could be considered reasonable for the accuracy of a single reading with the specified absolute standard barometer.

A–2.6 CISTERN-SIPHON BAROMETERS, ADJUSTABLE LEVEL

Instruments of the cistern-siphon type have been used to some extent on the European continent, especially Germany where this type was developed and is still manufactured. Such instruments have been employed to serve particularly as standard or control barometers owing to their unique characteristics which are summarized and explained in the text below. By referring to fig. A–2.6.0, the principle of this type of barometer may be readily understood.

Briefly, the basic advantages of the cistern-siphon barometer may be summarized as follows:

(1) The indications of this type of barometer are independent of the mass of mercury employed to fill it; and the scale of the instrument is graduated in the regular manner like any standard scale (i.e., not contracted or specially corrected as in the fixed-cistern barometer described in secs. 2.6 and A–2.4).

(2) The correction due to the joint effects of capillarity at both menisci is negligible or very small when the instrument is properly handled and kept clean.

(3) If a correction is necessary owing to imperfection of the vacuum, this correction can be determined directly by means of the instrument itself, without the need to employ another barometer as a standard or control instrument for calibration purposes.

(4) The corrections for temperature are the same as those for the Fortin-type barometer, assuming that the coefficients of linear thermal expanison of the scales are identical. It is unnecessary to determine special factors by appropriate calibrations or measurements, depending upon the volume of mercury, etc., as in the case of the fixed-cistern barometer (see sec. 5.3).

With regard to mechanical details of the cistern-siphon barometer as indicated in fig. A–2.6.0, it may be pointed out that the upper part of the cistern is made of iron (or a steel which dissolves little in mercury), while the lower portion of the cistern usually consists of a flexible leather bag (*j*). A glass tube of large bore projects up from the center of the iron cistern, and has a mercury meniscus indicated by *m* in the figure. The atmosphere has access to this meniscus by means of the air vent (*c*). On the same axis with the glass tube mentioned above there is located, higher up, another glass tube of equal inside diameter, having a mercury meniscus indicated by *a* in the figure.

These two collinear tubes of the barometer are connected by means of a tube of small bore (*h*), which penetrates into the iron cistern. A vacuum (*d*) of good quality is provided above the mercury in the upper tube. When the adjusting screw (*s*) below the cistern is turned in such a manner as to push up on the leather bag (*j*), the volume of mercury in the cistern decreases, thus causing the mass of mercury in the barometer to move upward so that the level of each meniscus (*m* and *a*) is raised. This similarity of upward motion affecting the shape of each meniscus, taken in conjunction with the equality of the inside diameters of the two tubes, tends to produce equal shapes and heights of the two menisci, thereby causing a tendency for the capillary effects at the two free surfaces of the mercury to balance out. In actual practice this ideal objective of cancellation of the capillary effects may not be fully realized, even if the column of mercury is vibrated in order to promote attainment of equilibrium, owing to reasons explained in sec. A–2.5 (see reference

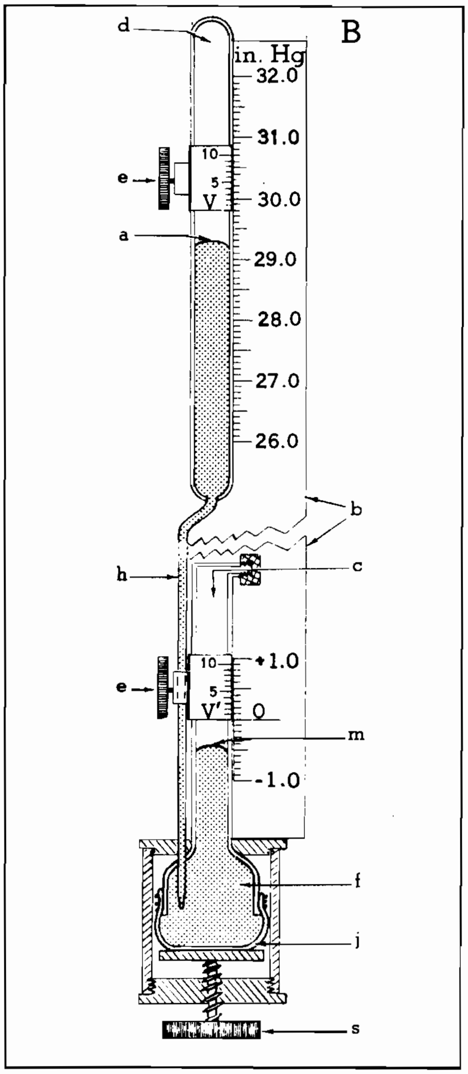

FIGURE A–2.6.0. Schematic drawing of siphon barometer with adjustable cistern (protective metal sheath and attached thermometer not shown). Explanation of symbols: *a*. Meniscus in upper collinear* tube of large bore. *b*. barometer scale. *c*. Air vent through which atmosphere exerts pressure on the mercury column. *d*. Vacuum. *e*. Adjustment mechanism for vernier. *f*. Mercury cistern. *h*. Small bore mercury tube. *j*. Flexible leather bag. *m*. Meniscus in lower collinear* tube of large bore. *V*. Sighting edge at zero of vernier; used in conjunction with upper barometer tube. *V'*. Sighting edge for zero of lower vernier which in the case of routine observation is locked in place on the line of the zero (0) of the barometer scale. In such barometers of high quality, the mechanism connected with (*s*) is replaced by a combination of coarse- and fine-setting adjustment screws.

1 in that section). Therefore, when the instrument is to be used for pressure measurements of the highest possible degree of absolute accuracy, both tubes are provided with optical measuring devices (not illustrated in fig. A–2.6.0) which permit the observer to measure the actual height of the meniscus in each case.[15] From a knowledge of the height of the meniscus and the inside diameter of the tube, it is possible to refer to tables which give the capillary depression in each instance, assuming a reasonable value for the surface tension of the mercury (see fig. 2.7.0 in sec. 2.7).

For purposes of measuring the height of the meniscus, Kleinschmidt[15] developed a sighting device which includes a plane parallel glass plate which covers half of the meniscus, while the other half of the meniscus is directly visible. The glass plate is capable of being rotated, so that, owing to refraction, the half of the meniscus viewed through the glass plate appears to move up with respect to the directly-viewed, remaining half as the plate is oriented from the vertical. The observer turns the glass plate until the lower margin of the meniscus (i.e., the ring of contact of the mercury with the glass barometer tube) appears to be at the same height as the top of the meniscus which is directly viewed beside it. A measuring drum is provided on the axle of rotation of the glass plate so that the height of the meniscus can be read from the scale graduated on the drum. See fig. A–2.6.3.

It is evident from fig. A–2.6.0 that the observed height of the column of mercury is equal to the difference between the readings on the barometer scale corresponding to the tops of the two menisci (*m* and *a*). While the scale in this figure is shown graduated in inches, most barometers of this class are actually graduated in millimeters or "millibars" (see sec. 1.4).

When the instrument is used as a "control barometer," i.e., for calibrating other barometers, the scale is extended to cover a wide range, and two verniers are provided, one for each meniscus. The verniers are equipped with a fine adjustment (*e*) in order

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* Vertical axes of upper tube and lower tube where meniscuses occur lie in same straight line, in order to obviate errors due to lack of verticality. When observations are made the adjusting screw (*s*) is turned until the meniscus (*m*) becomes coincident with the sighting edge (*V'*) of the lower vernier.

[15] Kleinschmidt, E., "Handbuch der Meteorologischen Instrumente," (Berlin, Springer-Verlag, 1935). The basic optical device was described in the German periodical: Meteorologische Zeitschrift, vol. 46, p. 344, (1929).

to permit these devices to be set precisely. As long as the instrument is used routinely, the sighting edge of the lower device (V') is allowed to remain set on the zero graduation of the barometer scale, as illustrated in the figure. Under those circumstances, the mercury is first lowered by means of the adjusting screw (s) before making an observation so that the meniscus m is below the sighting edge V' as shown, and then the level of the mercury is raised by means of the screw until the top of the meniscus m is exactly coincident with the lower sighting edge V'. Next the upper vernier is finely adjusted (by means of the knurled nut e), until the sighting edge V becomes exactly coincident with the top of the meniscus a. Thus, provided V' is set on the zero of the scale, the reading of the scale at the upper sighting edge V with the aid of the vernier will yield the observed height of the column of mercury directly, under the specified procedure.

For situations where the cistern-siphon barometer is to be used in a routine manner, the manufacturer provides a simple ring in place of the lower vernier (V'), and this ring is clamped by means of a screw in such a manner that its lower sighting edge remains exactly aligned with the zero of the barometer scale. Division marks are graduated on the ring to permit accurate alignment of the edge to the zero of the scale.

Actual photographic reproductions of a cistern-siphon barometer and the various mechanisms that pertain to it as described in the foregoing discussion are shown in figs. A–2.6.1, A–2.6.2, A–2.6.3, A–2.6.4, and A–2.6.5.

When a suitable, given type of mercury barometer is designed to serve as a standard, it is considered that one should have accurate information regarding: (1) the density of the mercury at 0° C., (2) its coefficient of cubical thermal expansion, (3) the spacings of the barometer scale graduations relative to its zero and to those on a standard scale at 0° C., (4) the coefficient of linear thermal expansion of the scale, (5) the local acceleration of gravity, (6) the correction for capillary depression, and (7) the correction for imperfect vacuum (see

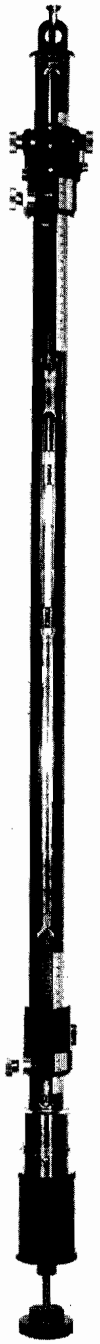

FIGURE A–2.6.1. Cistern-siphon "station barometer" designed by the firm of R. Fuess, Berlin-Steglitz. (Modified collinear U-tube type. Effective operating cross-section areas of tube and cistern are equal and the cistern is adjustable. A vernier is provided for reading position of top of upper meniscus and devices are employed for measuring heights of both lower and upper menisci. The lower sighting edge of clamping ring is fixed at zero of scale for setting lower meniscus. Range: 865—1090 mb. Bore: either 10 or 14 mm.)

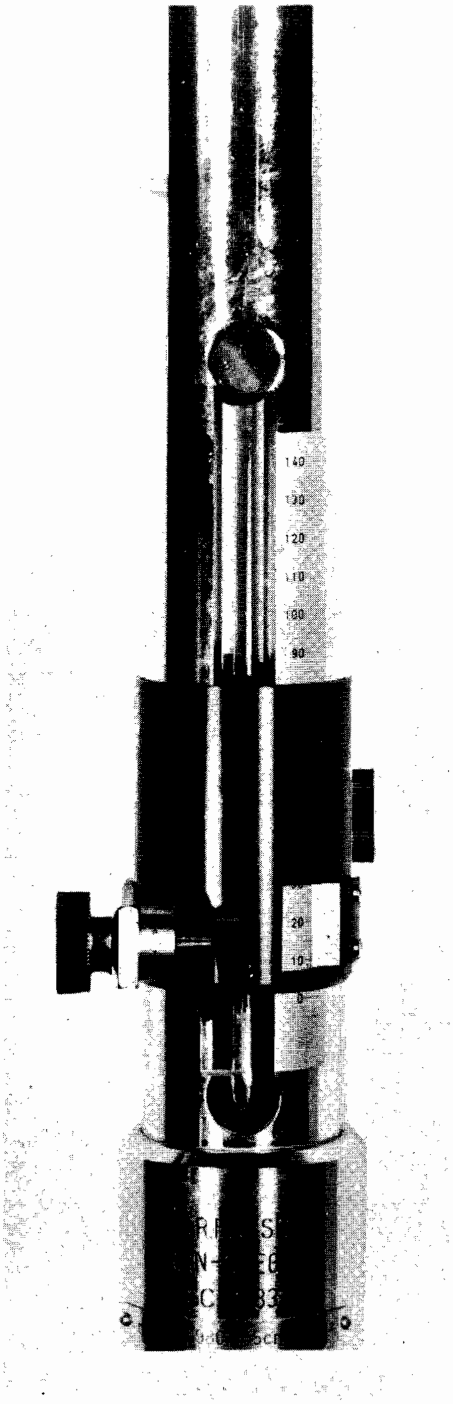

FIGURE A–2.6.2. Cistern-siphon station barometer. Close-up view of clamping ring for setting on lower meniscus and also prism device for measuring height of meniscus in tube associated with cistern. Lower sighting edge of ring is generally adjusted to zero of scale (see fig. A–2.6.1).

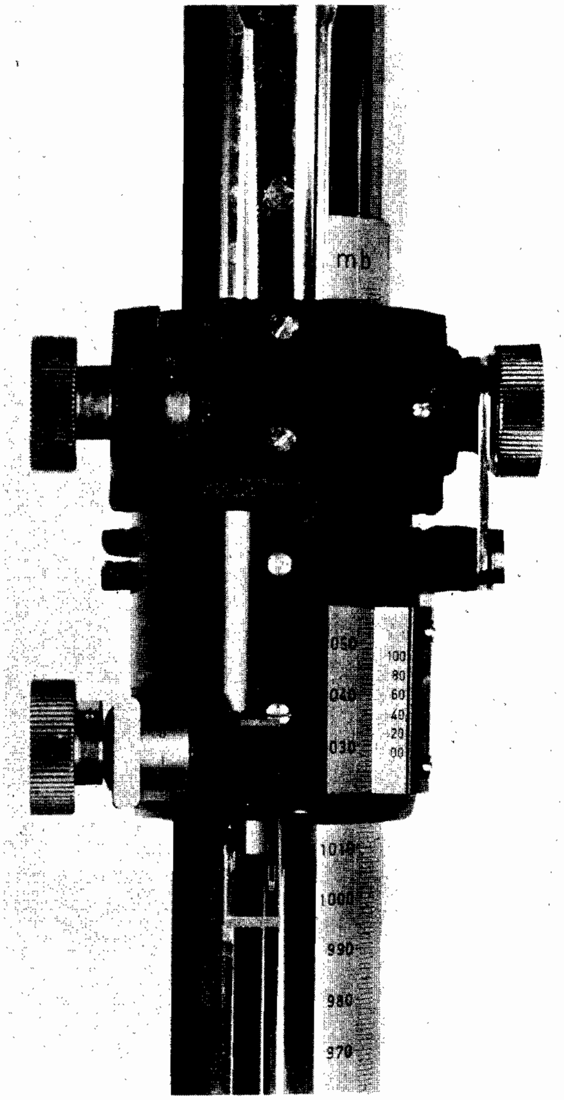

FIGURE A–2.6.3. Cistern-siphon barometer. Close-up view of vernier and prism device for measuring height of upper mercury meniscus (see figs. A–2.6.1 and A–2.6.4).

Appendix 1.4.2). Usually the first five items of the foregoing list are known or can be determined by the appropriate laboratory techniques and relevant methods of calculation. It has already been mentioned that in the case of the cistern-siphon barometer the total correction for capillary depression (item 6) is very slight, owing to the similarity of the two menisci and the tendency of the opposing capillary effects to cancel out. In addition, one may apply corrections for the capillary depression as *previously*

Figure A–2.6.4. Cistern-siphon "control barometer" designed by firm of R. Fuess, Berlin-Steglitz. (Modified collinear U-tube type. Effective operating cross-section areas of tube and cistern equal. Cistern adjustable. Verniers provided for both lower and upper menisci to permit reading positions of their tops against a common scale, and means provided for reading heights of the two menisci. Scale graduations extend from zero (0) to 1100 mb., useful for calibrating barometers over range from 55 to 1090 mb. Bore 11 mm.)

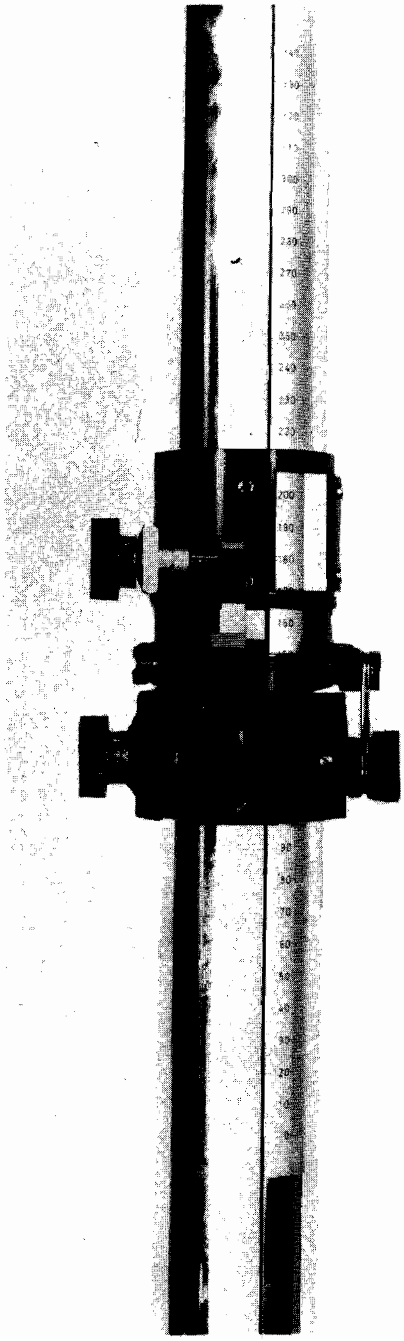

Figure A–2.6.5. Cistern-siphon control barometer: Close-up view of vernier and prism device for measuring height of lower mercury meniscus (see figs. A–2.6.3 and A–2.6.4).

pointed out, on the basis of measurements of the meniscus heights and the bore of the tube. This leaves the question of the last item of the list, viz., the correction for imperfect vacuum.

At this stage, therefore, one may emphasize that a paramount advantage of the cistern-siphon type of barometer is that it has inherent features which permit the observer to determine the correction for imperfect vacuum, if any, without requiring another standard barometer for the purpose of calibrating the given instrument, provided the information necessary in connection with the first six items of the foregoing list is available.

The validity of these considerations pertinent to the cistern-siphon barometer enables one to place it in the category of "absolute or normal barometers," since it is capable of yielding absolute values of atmospheric pressure from first principles.

In order to determine the factors which govern the correction for imperfect vacuum pertaining to a cistern-siphon barometer the operations next described must be conducted during a period when the ambient pressure and temperature are steady and constant, hence they cannot be carried out under conditions of strong or gusty winds, nor under conditions involving drafts from sources of heat or cold. Thus, it is useful to have a barograph and thermograph near the instrument during the course of the measurements to check on the steadiness and constancy of the pressure and temperature. To commence, the screw (s) beneath the cistern is turned to lower the mercury in the barometer so that the level of the lower meniscus m is below the lowest graduation on the scale, and then the screw is turned in the reverse direction until the level of the meniscus m is at or just above the specified graduation. At this stage careful readings of the barometer scale and both verniers are taken in order to record the positions of both menisci (m and a). Next, the screw is turned further in the same direction until the level of the mercury at the upper meniscus (a) just reaches a pre-selected graduation (denoted by h') which is about midway down from the highest graduation on the scale to the reading on the scale corresponding to the position of meniscus a mentioned in the previous sentence. Of course, the sighting edge V is set at the selected graduation (h') in advance. Again, careful readings of the barometer scale and both verniers are taken to ascertain the positions of both menisci. Finally, the screw is turned an additional amount further in the same direction as before, thus raising the mercury until its level at the upper meniscus (a) is at or just below the highest graduation on the scale. Under the conditions of these final settings, the barometer scale and both verniers are carefully read in order to measure the positions of the menisci m and a.

It will be noted that the direction of turning of the screw is always the same prior to the three sets of readings, in order to secure a high degree of consistency in regard to the forms and equilibrium of the two menisci; that is, there should be no reversal of direction once the process is begun. With a view to obtaining a check on the results based on the data thus far observed, the procedure described above should be reversed, commencing with a downward motion of the mercury and the taking of readings near the top of the scale for meniscus a; but making certain that the middle reading h' for this meniscus is the same as in the earlier operations.

Care should be taken not to turn the screw so far that damage will occur to the leather bag owing to the back pressure of the residual gases in the vacuum space d as they are compressed by the upward displacement of the free surface of the mercury (a) in the closed tube. When the results are to be used for precise barometry, the procedure described above should be repeated several times in order to secure additional data on which to base the computations outlined below, and to verify results.

The theory involved in the determination of the factors which govern the correction for imperfect vacuum is based on elementary physics and will not be fully given here; however, the basic considerations involved are outlined in what follows. First of all, it may be remarked that the correction for imperfection of the vacuum consists of the sum of two terms, denoted by $(p+p')$, where p = the partial pressure in the vacuum space due to foreign gases such as air and water vapor, and p' = the vapor pressure of the mercury at the existing temperature in the space. The value of p' can be ascertained by referring to a table of the vapor pressure of mercury as a function of temperature, such as that given in sec. 2.4.1. Secondly, the value of p, the partial pressure due to the foreign gases, is governed by the general gas law which, for present purposes, may be expressed in the form

$$p = CT/v.$$

The terms used in this relationship are defined as follows: T = absolute temperature (degrees Kelvin); v = volume of the vacuum space divided by the cross-sectional area of the bore of the barometer tube where the upper meniscus moves; and C = constant, which depends upon the composition of the foreign gases and which is proportional to the mass of these gases divided by the cross-sectional area of the bore as stated above.

In establishing these definitions and as a basis for the relationships employed in the present analysis of the problem, certain assumptions are made. These include the assumptions that we can regard as constant the cross-sectional area of the bore of the tube, and the composition and mass of the foreign gases in the vacuum space. We shall assume that any water vapor present in the vacuum space will not be compressed to such an extent that condensation of this vapor occurs (the reasons for this being clear from sec. 2.7.3 and fig. 2.7.4). Finally, the correction $(p + p')$ calculated in accord with the specified relationships involves the assumption that the two component partial pressures (p and p') are exerted by the respective constituents of the mixture of gases and vapors as though the other constituents were not present; i.e., we shall assume that Dalton's Law is fulfilled with regard to the mixture of foreign gases and mercury vapor.

Let v represent the volume of the vacuum space divided by the cross-sectional area, as defined above, when the true reading of the barometer scale, corrected for temperature, at the upper meniscus (a) is given by the height h. Consider now the pre-selected height h', mentioned in connection with the procedure outlined above, and treat this also as a true reading of the barometer scale corrected for temperature. Suppose that when the height h becomes h', the quantity v assumes the value v'. Then we have the relationship

$$v = v' - (h - h'),$$

for unit cross-sectional area, valid so long as the two menisci have the same forms in each case and as the cross-sectional areas of the barometer tube where the menisci move are uniform and equal. Substituting this expression in the equation representing the general gas law, one obtains the result

$$p = CT/[v' - (h - h')]$$

It is evident that if one knew the values of C and v', this equation could be employed to calculate the desired quantity p, since h is based on the observed barometer reading and h' is a known, adopted constant.

With a view to determining the values of C and v', which are unknown at the start, use may be made of the data collected under the procedure already described. In order to compute C and v' from the data, it is necessary to apply the last equation given together with the hydrostatic equation pertinent to the mercury column under constant temperature and ambient atmospheric pressure. The latter equation yields the following result in C.G.S. units:

$$(h - h_1)Dg + (p + p') = P,$$

where

h = true height of the upper meniscus (a),
h_1 = true height of the lower meniscus (m),
D = density of mercury at the existing temperature,
g = acceleration of gravity,
P = ambient atmospheric pressure,

and the other terms (p and p') have already been defined.

In writing the last equation, we assume that the capillary effects acting on the two menisci are balanced out. The expression for p given in the previous equation is next substituted in the hydrostatic equation, and thus one obtains a result which relates the unknown quantities C and v' with certain other determinable values which are either based on observation (such as h and h_1) or may be computed from known data.

The heights of the lower and upper menisci observed in accord with the procedure already described should be corrected for temperature by means of equation (4) of Appendix 1.4.2, while the density of the mercury should also be corrected for temperature by means of equation (2) of the Appendix. It will be recalled that the procedure involved three sets of readings. When these are corrected and substituted in the appropriate terms of the last two equations expressed above, considered simultaneously, it is possible to eliminate the quantity $(P - p')$. After this has been done, there will be left two equations in the two unknowns C and v'. These two equations can be solved for C and v', provided the readings have been made very accurately. When the solution yields the result that $C = 0$, this implies that the mass of foreign gases in the vacuum space is negligible, indicating that $p = 0$ in all cases. However, when C and v' both turn out to be positive quantities, verified by results based on several repetitions of the procedure, it is possible to employ the values to compute p as previously indicated. This is desirable in connection with barometric measurements of the highest degree of absolute accuracy. Under these circumstances, it would be well to consider whether v' varies significantly with temperature depending upon the coefficient of thermal expansion of glass; and if so, to correct v' for such variations if the temperature at the time of observation differs appreciably from that at the time the procedure was carried out.

The foregoing analysis has been based on the assumptions that the capillary depressions are the same for both menisci and that the ambient atmospheric pressure (P) does not change during the period of carrying out the procedure described above. If neither of these assumptions is valid, it is possible to make corrections which will take into account the deviations. Thus, if b = capillary depression pertaining to the upper meniscus, and b_1 = capillary depression pertaining to the lower meniscus, then P in the foregoing should be replaced by $P - (b - b_1)Dg$. Values of b and b_1 may be obtained to a certain degree of approximation from the tables in fig. 2.7.0, which permit the making of some allowance for the effect of unequal capillary depression at the two menisci. With regard to the second assumption, one may overcome this problem by making use of a very sensitive, precise change-of-pressure indicator and observing the changes of pressure which occur between the times of making the three sets of readings. If it is assumed that the value of P is known at the time that the upper meniscus is set to the height h', then the values of P pertinent to the other two times of setting the menisci will also be determined relatively, by applying the changes of pressure as were observed between the specified times by means of the change-of-pressure indicator. When the relevant equations are solved simultaneously to determine C and v', it will be found that the assumed value of P cancels out, thus having no effect, but leaving the effects of the terms involving $(b - b_1)Dg$ and the changes of pressure between the specified times.

In cases where the cistern-siphon barometer is used as a "normal or standard barometer," certain special provisions are necessary. For example, (a) the barometer tube should be of relatively large bore in order to minimize the effects due to capillary action; (b) suitable optical devices should be included to permit the measurement of the heights of both menisci (see reference 15); (c) some optical means should be provided to enable the observer to determine very precisely the top of each meniscus, considering that the meniscus has a form with relatively little convexity in a tube of large bore; and (d) convenient arrangements must be made to permit interchangeability of the two verniers and the sighting devices in order to check their parallelism. When these devices are parallel, they yield the same readings after being interchanged as before, provided the ambient atmospheric pressure remains constant. Thus, the North Instrument Division of the German Weather Service at Hamburg has embodied these features in its cistern-siphon barometer used as a standard instrument.[16]

The standard barometer at Hamburg requires the use of a cathetometer equipped with two parallel micrometer microscopes to permit accurate readings to be made of the height of the mercury column (see sec. A–2.5). In connection with item (c) of the list given in the last paragraph, the technique employed in this barometer for the stated purpose involves the use of a light source behind the instrument with a collimator between the source and the barometer. On the transparent face of the light source there is formed a series of parallel, sloping black stripes, each 1 mm. in width, while the clear space between each stripe has the same width. The angle of inclination of the stripes is 45° from left to right. A real image of this series of alternating black and clear stripes is projected by the optical system over the top of the meniscus. Consequently, a reflection of this image is observed in the surface of the meniscus, which is practically flat over the central area; however, the stripes seen in the middle of the reflection are inclined 45° from right to left. It follows that in this area of the meniscus the stripes of the real image and of its reflection appear to join at a 90° angle along a horizontal line When making an observation to determine the height of each meniscus, the horizontal cross hair of the cathetometer microscope is set on this segment of horizontal line where the two sets of sloping stripes appear to meet (as along the line of the apexes of some nested V's placed on their sides). The principle of this optical method of establishing the position of the top of the meniscus was introduced many years ago by Koch,[17] who employed a sloping filament behind the barometer as an object which yielded an inclined, real image projected over the meniscus center for the same purpose. Another alternative method is to employ a horizontal filament for the object, in the manner suggested by Marek (see reference 4 in sec. A–2.5).

With further regard to the details of standard barometer at Hamburg referred to in the previous paragraph, this instrument is constructed with a glass tube 32 mm. in bore and has an iron cistern in the form of a cylinder. Instead of using a leather bag to enable the mercury levels to be controlled, the cistern has a piston for its floor, which can be moved up or down by means of coarse and fine adjusting screws. Between the cistern and the lower barometer tube of large bore there is inserted a disk having a 4-mm. hole intended to damp out oscillations of the mercury, while the small-bore connecting tube (*h* in fig. A-2.6.0) has an inside diameter of 3 mm. With these dimensions the upward motion of the mercury in the two barometer tubes is equalized as the piston is raised.

It may be pointed out that if the mercury of the lower meniscus (*m*) becomes fouled or if the interior of the glass tube over which this meniscus moves becomes covered with a film of foreign material (such as an amalgam of a base metal or a sulfur compound of mercury), the capillary effects at the two menisci will probably not balance; hence for barometery of the highest degree of accuracy, it is advisable to measure the heights of both menisci and to apply corrections for the pertinent capillary effects.

Experience indicates that lower meniscus (*m*) can become readily fouled, depending upon the atmospheric pollution in the place where the instrument is installed, the frequency of adjustments of the menisci up and down, the frequency and amounts of pressure rises and falls, etc. This experience suggests that the cause of the fouling is primarily the drawing in of polluted air and moisture to the lower leg of the barometer, thereby increasing the degree and frequency of exposure of the lower meniscus to sources of pollution. Owing to the effects of impurities on the mercury and on the inside of the tube in the lower leg, the surface tension pertaining to the lower meniscus (*m*) is generally not equal to that pertinent to the upper meniscus (*a*). Under these conditions it is not proper to assume that the same value of surface tension applies to both menisci. Generally, one does not know the pre-

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[16] Goedecke, K., "Das Hauptnormalbarometer mit 32 mm Rohrweite des Instrumentenamtes Nord des Deutschen Wetterdienstes," Germany, Federal Republic, Wetterdienst, Technische Mitteilungen der Instrumentenabteilung des Meteorologisches Amt für Nordwestdeutschland, Nr. 26, (Dec. 1953), Hamburg.

[17] Koch, K. R., Wiedemanns Ann., vol 55, p. 391, (1895).

cise values of surface tension which are pertinent to the two menisci, thereby introducing an uncertainty in the results. It is clear from these considerations that an error is produced if one assumes the same value of surface tension to be appropriate to both menisci and obtains the correction for capillary depression for these menisci from the same table (such as one of those shown for a single value of surface tension in fig. 2.7.0). The surface tension pertinent in any given case depends upon such factors as the following: the type and purity of the glass of which the tube is composed, the humidity conditions both current and in the recent past, the oxidation of the mercury surface, the deposits of impurities on the meniscus and glass, the formation of amalgams and other chemical substances on or within the mercury, etc. As a result of these facts it is readily possible for an error of the order of magnitude of 0.05 mb. to appear in the pressure data determined by the specified barometer, merely from uncertainty in the capillary corrections.

Laboratory evidence reveals that the surface tension of mercury with some degree of fouling is somewhat less than that of pure mercury (see sec. 2.7.1). Therefore, it can be considered that if the lower meniscus is slightly fouled, then its surface tension will be less than that of the upper meniscus. This consideration can be taken into account in work of the highest precision by referring to the tables in fig. 2.7.0 for the purpose of ascertaining the respective capillary depressions for the two menisci.

It is possible to obtain an accuracy of reading with the cistern-siphon barometers of between plus and minus 0.05 and 0.1 mb., depending upon the instrument design, its size, etc. Scale and vacuum errors of the standard cistern-siphon barometer may vary in magnitude between 0.0 and 0.1 mb., approximately. An error of about 0.05 mb. might also be present owing to the uncertainty in the capillary depression mentioned above. Still another source of error exists in the case of some instruments in which the chamois bag used in the adjustable cistern does not maintain its volume after the lower meniscus is set and the observer proceeds to make a reading of the upper meniscus; in other words the lower meniscus may not hold its position even though the ambient pressure remains constant. Such a characteristic is perhaps due to the deformation of the chamois bag under stress. A possible drift in the difference of height between the two menisci resulting from such deformation during the period between settings or readings of the menisci is undesirable, and must be overcome when it occurs. Care is also necessary to bring the instrument to temperature equilibrium when used for standardization purposes.

A–2.7 SIPHON BAROMETERS, FLOAT AND WHEEL MECHANISM

Large-bore siphon barometers of ingenious design have been constructed with a float which rides on the mercury in the cistern. Fastened to the float is a fine platinum wire or ribbon which runs over a small pulley, affixed to a large concentric wheel. Running over the latter is another fine wire of noncorrodible metal carrying a pen, and held taut. This combination of pulleys serves as a wheel and axle mechanism to yield a magnification of the float movement. As the level of the float varies with rise or fall of the mercury accompanying changes in atmospheric pressure, the rotation of the wheel will reveal variations in the barometer readings. When the float moves vertically with changes in pressure, the pen produces a continuous record of the barometric variations on a chart wrapped around a clock-driven, cylindrical drum. Special temperature compensation features must be provided in the mechanism. Calibration against a standard barometer is necessary. Some details regarding the designs of this type of barometer by Marvin and Dines, respectively, are presented below (see figs. A–2.7.0(a), A–2.7.0(b), and A–2.7.1).

Certain unusual provisions are generally necessary for filling large-bore siphon tubes. To this end the glass tube of the Marvin siphon barometer is made in three parts, as shown in fig. A–2.7.0(b) to facilitate filling. The Dines barometer is filled by use of a funnel attached to a rubber tube which is inserted tightly into the bottom of the lower

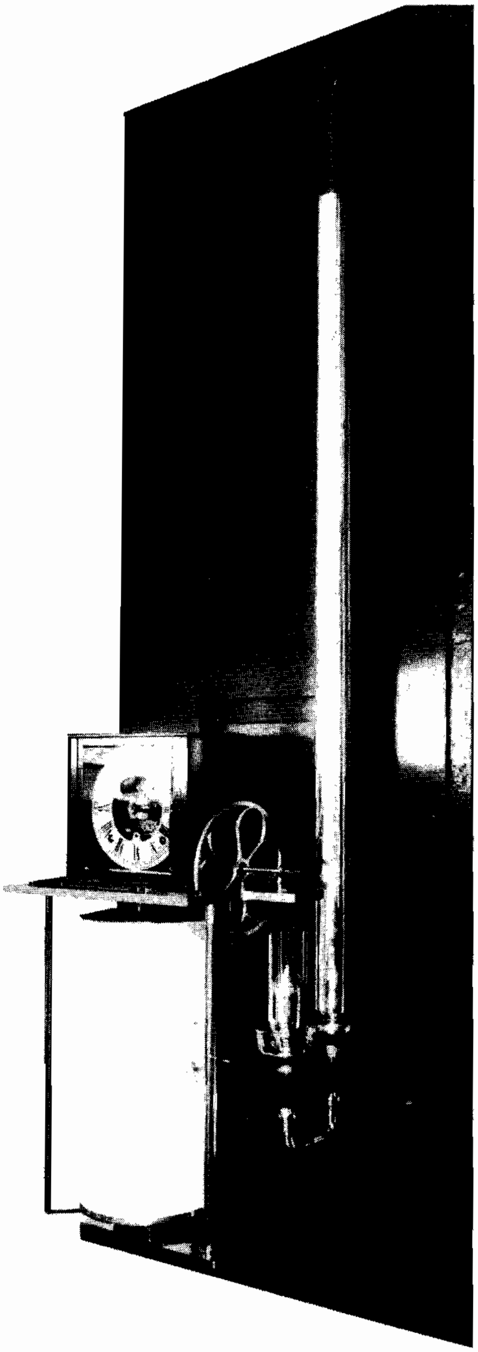

FIGURE A–2.7.0(a). Siphon tube float barometer of Marvin design.

cistern; mercury is then poured into the funnel as it is gradually raised from the level of the lower cistern to that of the top of the tube, so that the upper reservoir is filled and mercury flows into the U-tube shown on the extreme left in fig. A–2.7.1. This results in exhausting the air from the upper chamber which is then sealed by the mercury which has flowed into the U-tube.

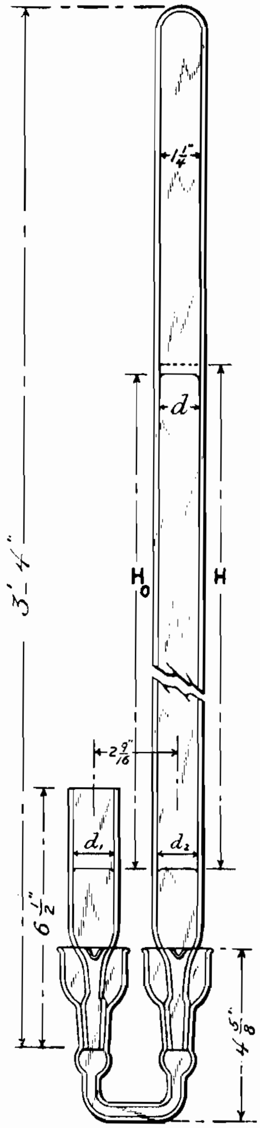

FIGURE A–2.7.0(b). Cross-section of Marvin siphon barometer tube.

(For additional information the reader is referred to: (A) Weather Bureau Circular F on "Barometers and the Measurement of Atmospheric Pressure," by C. F. Marvin, published by the Government Printing Office, Washington, D.C., Seventh Revised Edition, 1941, now out of print; and (B) Quarterly Journal of the Royal Meteorological Society, London, vol. 55, pp. 37–53,

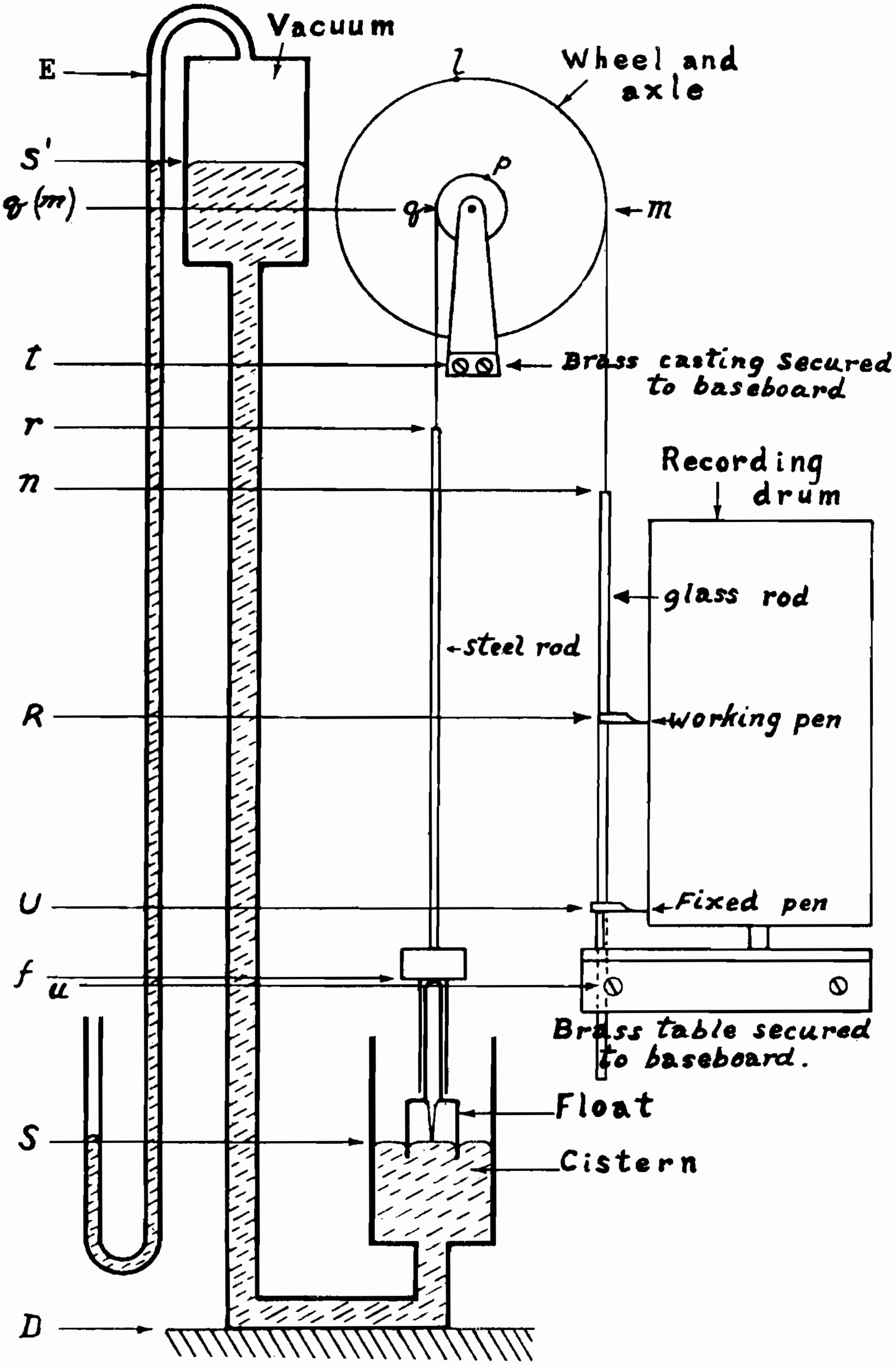

FIGURE A–2.7.1. Schematic cross-section diagram of the Dines siphon barometer with float and wheel mechanism. (q is point of tangency of platinum wire on pulley.)

January 1929, article by L. H. G. Dines, entitled "The Dines Float Barograph.")

When the difference in height between the two surfaces of the mercury in the J-shaped siphon tube increases by *d* inches, the level of the float will fall half as far, viz. *d*/2 inches. The wheel and axle mechanism is designed for a tenfold magnification of movement in the apparatus of Marvin and fourfold in that of Dines. Consequently, the barometric changes are magnified five times in the former case, and two times in the latter.

Some siphon barometers involving a float have been designed to be of an indicating character rather than recording. In these makes, designated as dial or wheel barometer, a needle is fastened coaxially to the wheel, so that the movement of the needle over a suitable calibrated dial indicates the changes in atmospheric pressure. Fig. 12.2.1.11 shows an example of the earliest form of siphon barometer of this character, invented by Hooke, and described just 22 years after Torricelli first discovered the principle of the original mercury barometer. (Note: The letter *M* in the figure denotes mercury.)

A–2.8 TWO-LIQUID, EXPANDED-SCALE BAROMETER

Fig. A–2.8.0 serves to illustrate one design of this interesting type of barometer, which is not used for scientific work. It contains mercury and a light fluid having certain characteristics. The arrangement of this instrument is such that when the mercury rises one inch in the Fortin-type barometer, the lighter liquid in the device shown in fig. A–2.8.0 will rise *M* inches, *M* being termed the "magnification." From theoretical considerations the value of the reciprocal of *M* may be computed by means of the following equation:

$$1/M = (d/D)(1 - a/A_2) + a/A_1 + a/A_2$$

where

d = density of light liquid,
D = density of mercury,
a = cross-section area of slender tube containing the light liquid,
A_1 = cross-section area of the upper mercury reservoir, and
A_2 = cross-section area of the reservoir containing both liquids.

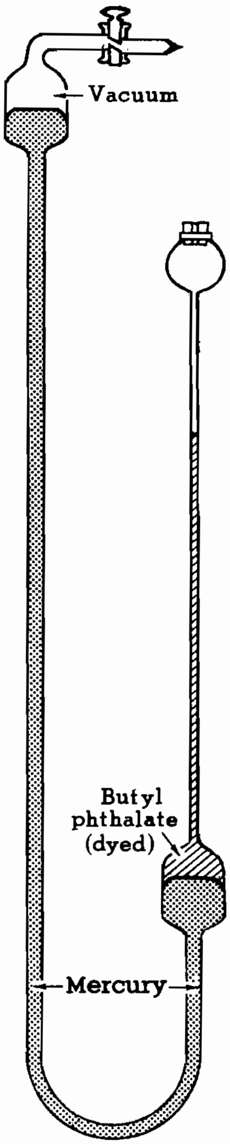

FIGURE A–2.8.0. Two-fluid magnifying siphon barometer.

As an example, if $a = 0.01096$ square inch, $A_1 = A_2 = 1.578$ square inches, and $d/D = 1.045/13.6$, representing the density ratio of butyl phthalate and mercury, one obtains $M = 11.09$. A barometer of this design has been described by Charles Williamson (American Journal of Physics, vol. 23, pp. 492–494, November 1955). He states that the light liquid should ideally possess the following characteristics: "It should be low in vapor pressure, viscosity, density, and thermal expansion; it should be without action on mercury, should exhibit only a small capillary rise or depression in a glass tube, should not freely dissolve the gases of the atmosphere, and if not itself colored should be easily dyed." Williamson's model contains the light fluid butyl phthalate dyed with a pinch of azobenzene. It is a colorless oily liquid having a density of 1.0465 grams/cm^3. Among the light liquids which have been considered for this type of barometer are octane, methyl salicylate, and n-dibutyl phthalate. A characteristic of the design shown in fig. A–2.8.0 is that the level of the light liquid will fall when the Fortin-type barometer indicates a rise of atmospheric pressure, and vice versa. One important deficiency of the two-liquid barometer is that the corrections are uncertain. Anyone interested in fabricating one of these instruments should consult the article cited above, especially with regard to precautions necessary.

The history of the two-liquid, expanded scale barometer goes back a long way as may be seen from the information given in fig. 12.2.1.13, for this instrumental design was invented by Huygens about 1666.

A–2.9 WEIGHT BAROMETERS

In this type of instrument a vertical glass tube containing mercury is suspended on the arm of a weighing balance. The space above the mercury in the tube is a vacuum, while the tailpiece of the tube is immersed in mercury contained in a cistern. By making the outside diameter of the tailpiece equal to the inside diameter of the remainder of the tube, the weight on the balance becomes independent of the distance to which the tailpiece is immersed. An ingenious method for temperature compensation, devised by A. Sprung (1886 and 1905), simply involves a cylindrical enlargement of suitable volume in any portion of the tube *between* the two mercury surfaces, i.e., the one in the cistern and the other near the top of the tube. The principle of the weight barometer has been adapted to provide a basis for a weight barograph which yields a continuous record of atmospheric pressure variations. For details and references on this subject the reader may consult the book by W. E. K. Middleton and A. F. Spilhaus, "Meteorological Instruments," Toronto (1953), and the article by J. Patterson and W. E. K. Middleton, entitled "A New Electrical Weight Barograph," Quart. Jour. Roy. Met. Soc., vol. 67, p. 19, (1941).

New developments in the field of weight barometers have occurred since the time of the references cited above. Thus, one company, whose device is illustrated in fig. A–2.9.0, has produced a type of mercury barometer which operates on a weight balancing principle. It makes use of a weigh beam developed for precision measurements in aerodynamic applications. The instrument includes two reservoirs containing mercury. Fundamentally, the barometer shown in fig. A–2.9.0 is a null balancing electro-mechanical instrument, designed to provide indications of pressure on a counter mechanism in digital form to the nearest 0.001 inch of mercury, said to be repeatable to the nearest 0.002 inch of mercury. The manufacturer of this device describes its operation in the following words:[18] "Pressure applied to either of the reservoirs causes the transfer of a corresponding weight of fluid to the other column, unbalancing the moment beam on which the reservoirs are mounted. An electrical pickup senses this unbalance and signals a servo motor which repositions a poise weight within the beam thus restoring equilibrium. Pressure is measured in terms of the position of the calibrated poise weight. The weight balancing principle completely eliminates temperature errors which are common to the conventional weight measuring systems."

See also the barostat illustrated in fig. 2.9.8.

A–2.10 ANEROID BAROMETERS

This type of instrument which does not involve any liquids, is illustrated in figs. 2.3.0, 2.3.1, 2.3.2, 2.3.3, and 2.8.0. Its principal advantages lie in portability, and quickness and ease of reading, without need for gravity and temperature corrections such as required for mercurial barometers. The latter

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[18] Fig. A–2.9.0 and the quotation given are published by permission of the manufacturer, Dynametrics Corporation, Burlington, Massachusetts, U.S.A.

FIGURE A–2.9.0. Digital barometer designed by the Dynametrics Corporation. This instrument is motor driven with a mechanical counter mounted on the balance beam. The output shaft motion can be converted to digits, meter motions or printer motions.

feature is only valid on condition that means of first-class temperature compensation is provided. Sensitivity may be very high in aneroid barometers of the best quality. Details regarding the characteristics of this type of barometer are presented in secs. 2.8, 2.9, and 2.10. Instructions regarding calibration of aneroid instruments are contained in Chapter 6; see sec. 6.7. The following references will be of interest to those wishing to pursue the subject further:

(1) U.S. Bureau of Standards, "Testing of Barometers and Altimeters," Circular No. 46, Third Edition, 22 pp., Washington, 1922.

(2) P. G. Exline, "Pressure-Responsive Elements," Trans. ASME, vol. 60, pp. 625–632, 1938.

(3) A. F. C. Pollard, "The Mechanical Amplifications of Small Displacement," Jour. of Scientific Instruments, London, vol. 15, pp. 37–55, 1938.

(4) W. A. Wildhack and V. H. Goerke, "Corrugated Metal Diaphragms for Aircraft Pressure-Measuring Instruments," National Advisory Committee for Aeronautics, Technical Note 738, Washington, 1939.

(5) W. A. Wildhack and V. H. Goerke, "The Limiting Useful Deflections of Corrugated Metal Diaphragms," National Advisory Committee for Aeronautics, Technical Note 876, Washington, 1942.

(6) L. B. Hunt, "The History of Pressure-Responsive Elements," Jour. of Scientific Instruments, London, vol. 21, pp. 37–42, March 1944.

(7) A Pfeiffer, "A Note on the Theory of Corrugated Diaphragms for Pressure-Measuring Instruments," Rev. Sci. Instruments, vol. 18, pp. 660–664, September 1947.

(8) W. G. Brombacher and T. W. Lashof, "Bibliography and Index on Dynamic Pressure Measurement," National Bureau of Standards, Circular C558, Government Printing Office, Washington 25, D. C., 1955, 124 pp., 850 references, author and subject index.

(9) G. H. Lee and L. M. Van der Pyl, "A Bibliography on Diaphragms and Aneroids," Paper No. 55–A–180, American Society of Mechanical Engineers, New York, N. Y., presented at the ASME Diamond Jubilee Annual Meeting, Chicago, Ill., November 13–18, 1955. (This bibliography of 426 items includes all relevant published references on the subject available to the compilers up to the end of 1954.)

(10) W. A. Wildhack, R. F. Dressler, and E. C. Lloyd, "Investigations of the Properties of Corrugated Diaphragms," Trans. ASME, vol. 79, pp. 65–82, January, 1957.

(11) F. B. Newell, "Diaphragm Characteristics, Design and Terminology," A manual published by the American Society of Mechanical Engineers, New York, 1958.

A–2.11 SYMPIESOMETER

This is a sensitive device, illustrated in fig. A–2.11.0, sometimes useful for giving indications of pressure variations on an expanded scale. A correction for temperature has to be taken into account. Best results are secured when the instrument is subjected to constant temperature conditions while in use. The liquid used in the apparatus must be of low specific gravity compared to mercury; in fact, for optimal performance of the device the liquid should have the characteristics described in sec. A–2.8 with regard to the light liquid employed in the "two-liquid, expanded-scale barometer"; hence, butyl phthalate would be satisfactory. By using this liquid, it is easily possible to secure a sensitivity magnification of about 10 to 12 compared to the mercurial barometer. In the upper, closed vessel, a gas usually consisting of dry air is employed at a pressure substantially lower than atmospheric. Hence, atmospheric pressure exerted on the free surface of the liquid in the cistern elevates the fluid in the other arm of the U-tube, where the rarefied gas exerts an opposing pressure. The pressure of reaction of the gas on the top of the meniscus of the liquid in the tube beneath the vessel depends upon several factors, including temperature of the gas and vapor pressure yielded by the liquid. To obtain maximum accuracy, the device should be calibrated at various temperatures and barometric pressures, thus providing a basis for the temperature corrections. A scheme which has been employed to take account roughly of these corrections is shown in fig. A–2.11.0. This consists of two scales one of which slides vertically and shows the readings of pressure; while the other, a fixed scale, refers to the temperature indicated by an attached thermometer. In practice, the sliding scale is adjusted until the arrow reference mark points to the temperature value on the fixed scale. To obtain maximum sensitivity, it is necessary primarily that the liquid be light and of low vapor pressure. Secondarily, the ratio of the mass of gas to its molecular weight must be small, while the square of the volume of the closed vessel should be large in relation to the cross

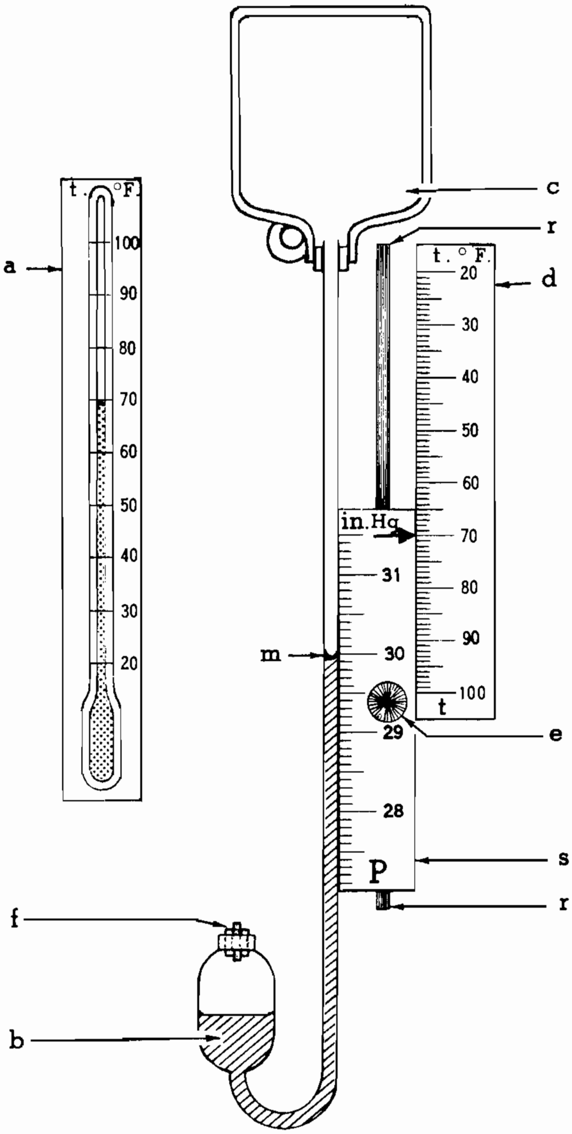

FIGURE A–2.11.0. Schematic drawing of the sympiesometer, an apparatus for determining atmospheric pressure, or its variations, on a magnified scale. Explanation of symbols: (*a*) attached thermometer; (*b*) dyed butyl phthalate; (*c*) dry air under low pressure; (*d*) fixed, calibrated temperature scale used in referring arrow index of *P* scale to observed temperature shown by (*a*); (*e*) knob to set *P* scale; (*f*) cotton filter in perforated stopper; (*m*) meniscus; (*s*) the *P* scale, a movable pressure scale on a magnified basis; (*r*) slide for *P* scale.

section area of the connecting tube which should be fairly small. See Appendix 2.1.

A–2.12 HYPSOMETER

This instrument makes use of the measurement of temperature of a liquid in a boiling state when it is exposed to the pressure which is to be determined. The principle of the hypsometer depends upon the fact that the saturation vapor pressure of the liquid at the temperature of the boiling point is equal to the ambient pressure exerted on the surface of the liquid. For example, when the liquid consists of pure water, reference may be made to the hygrometric or psychrometric tables to ascertain the saturation vapor pressure corresponding to the observed boiling-point temperature, and this value would equal the ambient pressure. Before any liquid may be employed for the instrument its saturation vapor pressure must be accurately known as a function of temperature. The precision attainable by means of the hypsometer depends upon both the accuracy of the temperature measurement and the rate of variation of saturation vapor pressure with temperature. Equilibrium between the vapor and the boiling liquid is assumed. In some of the early days of exploration and surveying the hypsometer was widely used to determine the atmospheric pressures at the foot and top of any chosen mountain, for purposes of computing its height. For historical interest the Encyclopedia Britannica (14th Edition, 1929, vol. 12), describes it in the following terms: "The instrument consists of a cylindrical vessel in which the liquid, usually water, is boiled, surmounted by a jacketed column, in the outer partitions of which the vapor circulates, while in the central one a thermometer is placed." The hypsometer is illustrated in fig. A–2.12.0.

Although the use of hypsometers suffered a decline with the advent of the aneroid barometer and altimeter, it has had a renewed application in recent years with the employment of precise temperature measuring techniques. The hypsometer has the following advantages: (1) it can be made very compact and relatively light in weight, factors which facilitate portability; (2) it is relatively simple in principle and operation, requiring no correction except in regard to the temperature measuring device; (3) it requires very little servicing and maintenance; (4) it will function satisfactorily with very little power output for boiling the water; (5) for use at fixed stations its accuracy is mainly limited by the accuracy with which the temperature measurements can be made; (6) relatively little time is required to make a fairly accurate determination of pressure with the aid of the hypsometer for standardization purposes.

Koppl[19] has described a hypsometer which employs distilled water for the fluid and a resistance thermometer for the determination of the liquid's boiling point. This author states that by a careful design of the elements, an accuracy of 0.02 mm. of mercury can be attained. By arranging the design of the hypsometer so that essentially full recovery of the condensate is achieved, very little water is required for its operation; in fact the amount may be as little as 0.25 cubic inch. Use of a small amount of water for the device permits its operation with but a small expenditure of power; for example, when 0.25 cubic inch of water is employed, the electrical power requirements for heating the water and keeping it boiling range only from 10 to 30 watts.

Measurement of the temperature of the water vapor in equilibrium with boiling distilled water is made by means of a sensitive platinum resistance element forming one arm of a Wheatstone bridge. In order to obtain suitable readings from the terminals of the Wheatstone bridge one may employ either a sensitive voltmeter or a recording potentiometer. It is possible to calibrate either of the latter devices to yield direct indications of the ambient atmospheric pressure corresponding to the saturation vapor pressure of water at the observed boiling point temperature. Heating of the water may be controlled by use of a suitable relay in the Wheatstone bridge circuit or by means of a separate thermostat coupled to a potentiometer in the circuit of the heater element.[19]

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[19] F. Koppl, "Recent Progress in the Measurement of Atmospheric Pressure," Rev. Sci. Instruments, vol. 18, 850–851, (1947).

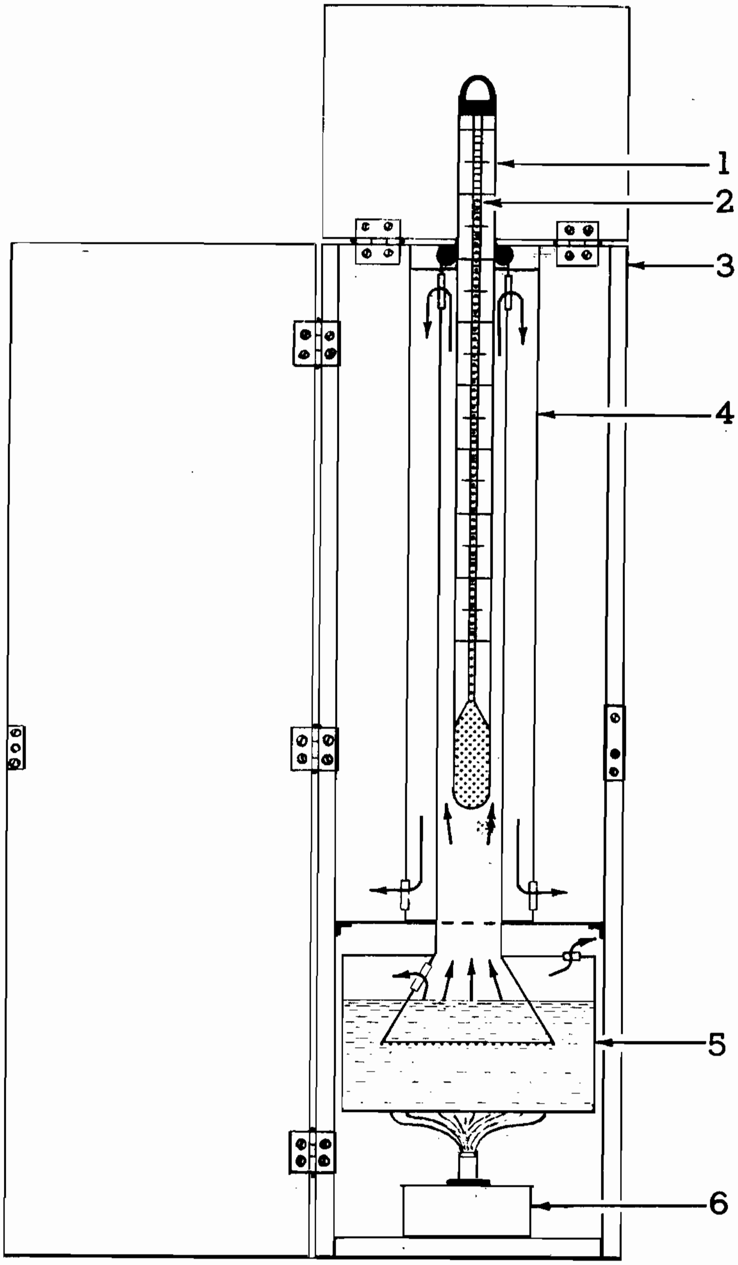

FIGURE A–2.12.0. Schematic drawing of a hypsometer. Indicated parts are: (1) Hypso-thermometer stem graduated in units of pressure; (2) Meniscus at a short distance from the top of the steam chamber; (3) Heating and carrying case; (4) Steam chamber; (5) Non-corrosive basin filled with distilled water, with inner funnel and screen also of non-corrosive material; (6) Heating unit.

The West German Weather Service has indicated that barometer comparisons at field stations are mostly performed by hypsometers. Comparative readings between the hypsometer and the regular station mercury barometer can be obtained within about five minutes, allowing for the water to be brought to a boil and equilibrium to be established between the saturated water vapor emitted by the boiling distilled water. An electric power source is used for heating the water. The hypsometer, used by the German Weather Service for the purposes described above and manufactured by Messrs. Bosch, Freiburg, is designed in such a manner that the vapor is led through a *special* casing device so that no water drops are condensed on the thermometer during the operation of the instrument. Each comparison consists of at least 3 or 4 measurements, since in the case of some thermometers only the third or fourth measurement yields accurate readings. Very sensitive, aged mercury-in-glass thermometers are employed for making the measurements; but only those at least 15 years of age are considered sufficiently stable in their readings to be used for the purpose. Similar thermometers of lesser age are subject to variations in their correction, and therefore are not regarded as suitable for such applications. When the hypsometer observation is made by means of a mercury-in-glass thermometer, and the mercury thread appears to have reached its maximum reading, the thermometer should be tapped with a pencil until the thread no longer rises. After each measurement, action must be taken to shake off from the thermometer any water that might have condensed on it.

The very sensitive thermometer utilized for hypsometric work is graduated in whole millibars equivalent to the saturation aqueous vapor pressure at the observed temperature; hence in order to obtain a reading accuracy of 0.1 mb., the corresponding thermometric accuracy must be 0.003° C.[20]

By calibrating the thermometers frequently with requisite precision and accuracy, then applying necessary corrections to the observed results yielded by those instruments, it is possible to achieve a measuring accuracy of plus or minus 0.2 mb.; although it is believed that the mean error of the hypsometer-thermometer is plus or minus about 0.12 mb.

Modern improvements and adaptations have been carried forward by the U.S. Army Signal Corps so that the hypsometer may be applied to determine pressures under conditions where conventional aneroid and mercurial barometers cannot be conveniently used. For example, to determine pressures in the range of 1.5–0.06 inch Hg by means of apparatus borne by a balloon in the free atmosphere, an experimental hypsometer is under development which employs carbon disulphide as the liquid. At the beginning of the observation, the liquid is poured over cotton batting contained in a thermos bottle. Subsequently, the boiling-point temperature is measured by means of a small, bead thermistor embedded in a slender glass rod which extends down to the bottom of the bottle through the center of the mass of cotton.

The above-mentioned development of a radiosonde hypsometer at the U.S. Army Signal Engineering Laboratories, Ft. Monmouth, N. J., has been described by Conover and Stroud.[21] In laboratory tests this hypsometer was found to measure pressure to an accuracy within one per cent in the range 300 to five (5) mb., and within two (2) per cent in the range five (5) to two (2) mb. When flight tests were conducted using only an aneroid capsule as the pressure "standard," the specified model of the hypsometer yielded an apparent accuracy of two (2) to five (5) per cent in the pressure range 30 to two (2) mb.

A–2.13 MISCELLANEOUS TYPES OF BAROMETERS

Since the discovery of the principle of the liquid barometer in 1643 by Torricelli (see Appendix 2.1), a number of changes in the form or variations on the theme of the orignal instrument have been conceived and developed, usually with working liquids other than mercury, and generally with a view to magnifying the movement of the meniscus surface of the working liquid relative to the movement of the upper meniscus in the tube of an ordinary mercury barometer due to variations in ambient atmospheric pressure. One may define the *magnification* (or sensitivity) as the ratio of the movement of the working liquid's meniscus surface to that of the upper meniscus of the ordinary mercury barometer resulting from any given variation in ambient atmospheric pressure (see sec. A–2.8). A number of miscellaneous types of barometer have been constructed involving one or more liquids other than mercury, which permitted the attainment of a

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[20] R. J. List, Editor, "Smithsonian Meteorological Tables," 6th Edition, Washington, D. C., 1958, p. 353.

[21] W. C. Conover and W. G. Stroud, "A high-altitude radiosonde hypsometer," Jour. Meteorology, vol. 15, 63–68, (1958).

magnification ranging between 9.5 and 13.59, depending upon the particular liquids and the design of the instrument.

Appendix 2.1 contains a number of illustrations of such miscellaneous types of liquid barometers. (See also secs. A–2.8 and A–2.11.)

Some words of caution are necessary with regard to liquid barometers of the special categories referred to above. When these are constructed so that the cross-sectional areas of the vessels and tubes, where the various liquid surfaces move, are uniform, it is likely that satisfactory results can be attained in regard to the specified high degrees of magnification, at least in respect to relative changes of reading over limited periods of time, *provided* that the instruments are carefully calibrated against a precise standard barometer at constant temperature and subsequently operated at this temperature.

However, in situations where these conditions are not fulfilled, it is probable that errors from various sources are magnified more or less in proportion to the design magnification of the instrument. Should this be the case, it is likely that the expected degree of precision and accuracy will not be realized. In this event, it probably would be better to employ a large-bore, standardized Fortin barometer whose performance has been established, rather than to make use of the special instrument having the magnified scale but suffering from the disadvantage that its corrections are relatively large and uncertain to a considerable degree.

When use is made of the special category of liquid barometers under discussion, many of which are illustrated in Appendix 2.1, careful consideration must be given to a number of factors that affect the results obtained. Thus, variations in temperature produce corresponding variations in such parameters as the vapor pressure, density, viscosity, surface tension and capillary phenomena pertaining to the liquid or liquids involved (see secs. 2.7.1 and 2.7.3). In addition, changes of temperature produce variations in the effective cross-sectional areas and volumes of the vessels and tubes forming the equipment. Also, the departure of temperature from that which prevailed at the time of calibration causes changes in the volumes of the liquids, gases, and vapors involved; as well as expansion or contraction of the scale of the instrument. It is likely when certain liquids are employed (e.g., water) that the back pressure in the space, which normally should be practically zero (a vacuum) for good instrumental practice, will undergo relatively large variations as the temperature changes (see for example Table 7.6.1 which shows the saturation vapor pressure of water). Some liquids (e.g., water) also have the capacity of dissolving, to a certain extent, gases from the atmosphere with which they come into contact; and this is a phenomenon that varies with temperature and pressure. Among the effects of such solution of gases are changes of the density, capillarity correction, coefficient of thermal expansion, etc.

Thus, it is clear that some liquid substances, such as water, do not have properties which lend themselves to the obtainment of reliable results when they are used for barometric instruments, especially if they are characterized by a high saturation vapor pressure, and a tendency to absorb gases and to wet glass. (See sec. A–2.8.) However, there exist relatively light liquids, such as butyl phthalate and n-dibutyl phthalate, which do not have these properties, and therefore are considered superior for manometry. The relevant properties such as density, saturation vapor pressure, coefficient of thermal expansion, viscosity, character and form of meniscus including capillary error, adsorption on glass, etc., must be taken into account, when considering the design of a liquid barometer or manometer.

Various ingenious forms of liquid barometers have been produced during the history of the subject. Many of these forms are shown in Appendix 2.1; but the latter is not intended to be exhaustive. For example, fig. 12.2.1.14 illustrates a "sloping tube barometer"; however, this does not exhaust the possibilities along this line of approach, for someone in the seventeenth century suggested the replacement of the sloping tube with a helical coil of glass. Thus, from trig-

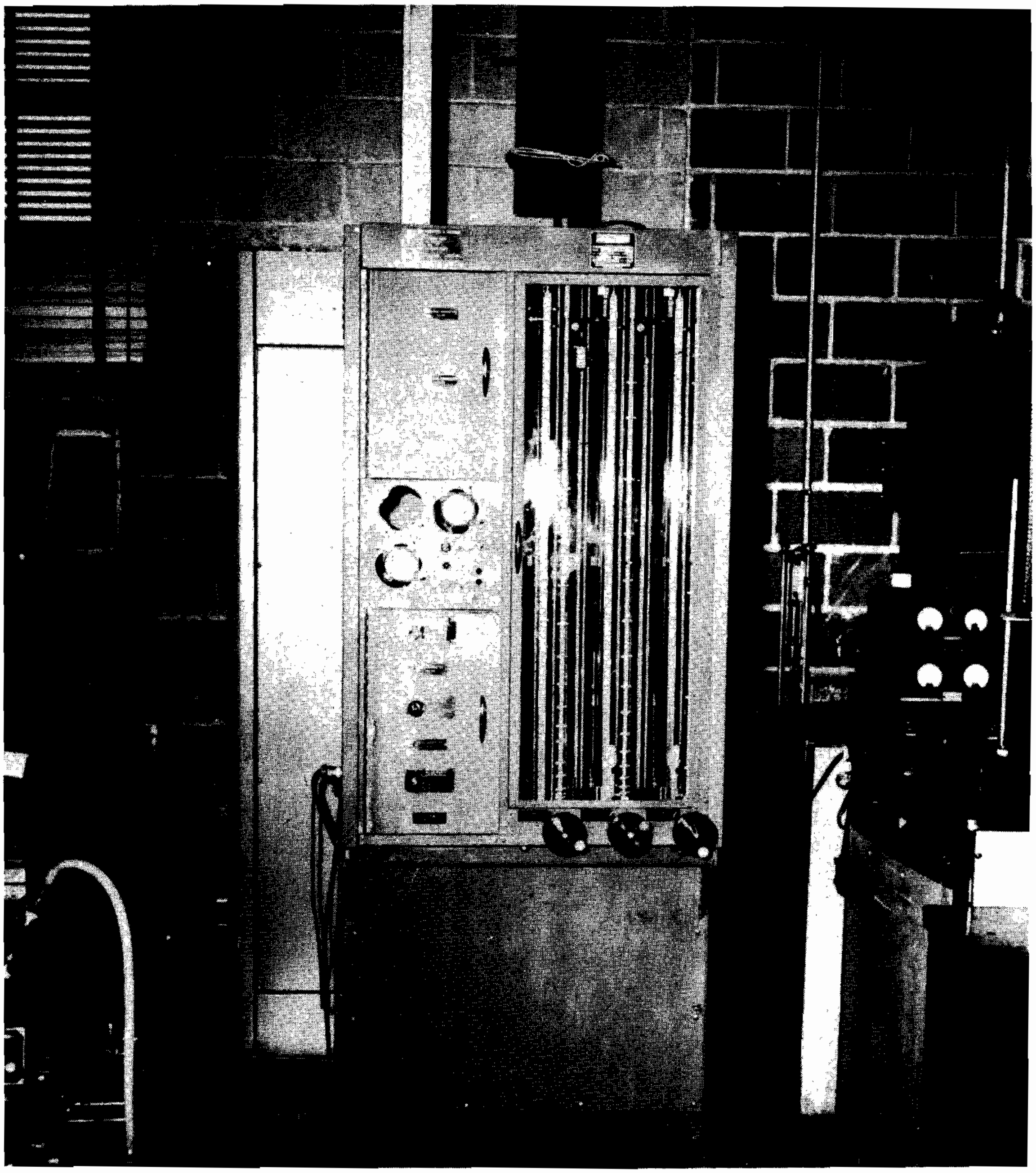

FIGURE A–2.13.0. Pressure manometer (differential and absolute, type E–1) used in instrument shops and overhaul depots of the U.S. Air Force for calibration and testing of pressure-actuated aircraft flight instruments. (Manometer designed to apply, regulate, and indicate *absolute pressure* and *differential pressure* independently of one another; the former to simulate "pressure altitude," for example, to calibrate altimeters, and the latter to simulate indicated airspeed for calibration of airspeed indicators at various pressure altitudes.)

onometry it is clear that if the angle of inclination of the bent tube is denoted by A, a rise of h cm. in a vertical barometer will be manifested by a rise of $(h/\sin A)$ cm., along the bent tube. Therefore, if the value of A pertaining to the helical coil is less than that pertaining to a sloping tube, the magnification secured with the aid of the coil would be greater than that obtained by means of the sloping tube, within a given limited space.

Other forms of barometers than those thus far considered have been developed for serious scientific investigations. Many of these are manometers which could be readily adapted for the purpose of making absolute pressure determinations, while others are designed specifically with a view to obtaining relative measurements of pressure. References may be cited pertaining to several examples of such devices, but it must be pointed out that the number cited does not exhaust the list.[22-39]

Since the list is so great, it is deemed appropriate to discuss briefly only several examples:

(a) Koppl[25] has described a quartz-barometer, which is characterized by freedom from hysteresis and from variation of its calibration with changes in temperature over the ordinary range of atmospheric temperature. The quartz barometer consists of an evacuated Bourdon tube of quartz glass. Although the sensitivity of the instrument is only between 0.0005 and 0.001 mm. per mm. of mercury, a considerable magnification can be obtained by at least several methods, for example, an optical or a capacitance method (see sec. 2.9.3.2). Use has been made of the quartz barometer for the measurement of pressure at low altitudes.

(b) Stripling, Broding, and Wilhelm[27] have developed a gas barometer of high sensitivity. Fig. A–2.13.1 illustrates in a schematic manner the essential structure of their instrument. It consists of an inner cham-

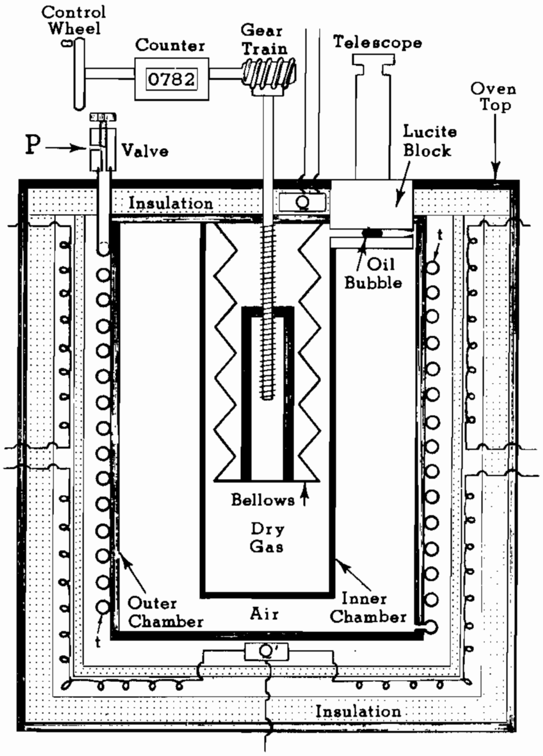

FIGURE A–2.13.1. Schematic diagram showing cross section of sensitive gas barometer operated at constant temperatures by thermostatic control and based on Boyle's law (PV = constant), thus yielding pressure P as inversely proportional to the measured volume V of the dry air contained within the inner chamber, t = copper tubing in helical form; Q, Q′ = thermostatic controls. (Developed by A. A. Stripling, R. A. Broding and E. S. Wilhelm.)

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[22] C. H. Meyers and R. S. Jessup, "A multiple manometer and piston gauges for precision measurements," National Bureau of Standards Jour. Research, vol. 6, RP 324, 1061–1102, (1931).

[23] A. Michels, "The calibration of a pressure balance in absolute units," Proc. K. Akademie Van Wetenschappen, Amsterdam, vol. 35, 994–1003, (1932).

[24] D. J. LeRoy, "An automatic differential manometer," Ind. Eng. Chem. (Anal. ed.), vol. 17, 652–653, (1945).

[25] Frederick Koppl, "Recent Progress in the Measurement of Atmospheric Pressure," Rev. Sci. Instruments, vol. 18, 850–851, (Nov. 1947).

[26] I. E. Puddington, "Sensitive mercury manometer," Rev. Sci. Instruments, vol. 19, 577 (1948).

[27] A. A. Stripling, R. A. Broding and E. S. Wilhelm, "Elevation Surveying by Precision Barometric Means," Geophysics, vol. 14, 543–557 (1949).

[28] F. P. Price and P. D. Zemany, "A simple recording manometer," Rev. Sci. Instruments, vol. 21, 261 (1950).

[29] S. Haynes, "Automatic calibration of radiosonde baroswitches," Electronics, vol. 24, 126–129, (May 1951).

[30] J. M. Los and J. A. Morrison, "A sensitive differential manometer," Rev. Sci. Instruments, vol. 22, 805–809, (1951).

[31] R. Meaken, "Determination of mercury level in steel-tube manometer," J. Sci. Instruments, vol. 28, 372–373, (1951).

[32] C. A. Heiland, "New Precision Barometer and Barograph," Mechanical Engineering, 971–974, (Dec. 1951).

[33] H. J. Svec and D. S. Gibbs, "Recording mercurial manometer for pressure range 0–760 mm Hg," Rev. Sci. Instruments, vol. 24, 202–204, (1953).

[34] George R. Thomas and Norman N. Lichtin, "An Inexpensive Recording Differential Manometer Suitable for Reaction Kinetics Measurements," Rev. Sci. Instruments, vol. 24, 661–664, (August, 1953).

[35] T. F. W. Empleton, "A semi-automatic electrical manometer designed to calibrate a Mack-Zehnder interferometer system for the recording of transient pressure changes," Rev. Sci. Instruments, vol. 25, 246–247, (1954).

[36] M. Ross and E. E. Suckling, "Permanent record from a mercury manometer," Rev. Sci. Instruments, vol. 27, 409, (1956).

[37] J. B. Johnson, "Convection Type Manometer," Rev. Sci. Instruments, vol. 27, 303–305, (1956).

[38] J. Farquharson and H. A. Kermicle, "Precise automatic manometer reader," Rev. Sci. Instruments, vol. 28, 324–325, (1957).

[39] G. A. Bottomley, "A method of obtaining accurate relative pressures in the range 20 to 200 mm of mercury," Jour. Sci. Instruments, vol. 35, 254–257, (1958).

ber contained within a somewhat larger outer chamber constructed of aluminum which is surrounded by an electrical heating element and thermal insulating material, all enclosed in an outside aluminum case. This system, in effect, forms an oven which permits the temperature within the inner chamber to be maintained at a constant value (to about 0.001° C.) by means of thermostatic controls at top and bottom. The volume occupied by the bellows within the inner chamber can be controlled from outside by means of a screw and gear train mechanism. The reading of the counter attached to the control wheel axis on the outside is correlated with the volume occupied by the bellows within the inner chamber provided that the oil bubble is centered. A constant mass of dry gas occupies the space within the inner chamber between the inside walls of this chamber and the outside of the bellows.

When the valve is opened, air at ambient atmospheric pressure (P) exerts the pressure P on the outside meniscus of the oil bubble. This pressure is transmitted through the copper tubing wound in helical form around the outer chamber. Since the temperatures of both the inner and outer chamber are maintained constant and equal during the period of operation of the instrument, Boyle's law applies to the dry gas contained within the inner chamber. Thus, if $P =$ ambient atmospheric pressure acting on the outside of the oil bubble, and $V =$ volume of the dry gas, the product of these two quantities is a constant (C); hence $PV = C$.

When the oil bubble is centered, the pressure on both menisci of the bubble is equal since the bubble is in equilibrium, being stationary with its center coincident with the index line etched on the transparent tube which connects both chambers. Viewing of the bubble is accomplished through the telescope, while the position of the bubble at the equilibrium index is set with the aid of the control wheel. The oil selected for the bubble has a low viscosity and low vapor pressure. It produces almost no friction in the tube. Hysteresis in the bellows is considered negligible since the bellows is maintained at constant temperature and is operated between the limits 10 per cent compression and 25 per cent compression. On these grounds, the value of the constant C may be determined for the given constant temperature by calibrating the apparatus with the aid of a standard mercury barometer. The value of V pertaining to any observation can be ascertained from the counter reading provided that the relationship between these two is checked by a suitable calibration. By virtue of Boyle's law one can compute the ambient pressure from the relationship $P = C/V$. For surveying work an overall accuracy equivalent to about 0.001 inch of mercury was obtained, while the sensitivity was apparently one tenth of this.

The apparatus of Stripling, Broding, and Wilhelm has found application on the part of geophysical exploration field groups for surveying elevations (see sec. 2.9.3.2).

(c) Heiland[32] has described a so-called "Micro-Barometer" which has as its pressure-sensitive element a helical Bourdon tube. Deflections of the tube are magnified by an optical method. The instrument is little affected by ordinary departure of its axis from the vertical, and is also only slightly affected by deviation of its temperature from that which prevailed during calibration. It is quite portable, weighing 8 pounds, and is of reasonably small dimensions. Thermostatic control is not considered necessary, since the instrument is essentially temperature compensated by partially filling the Bourdon tube with dry air of a few centimeters of mercury pressure. Each division of the barometer scale corresponds to about 0.1 mm. Hg, so that a reading can be estimated to about 0.01 mm. Hg. A recording instrument, termed "Micro-Barograph," working on the same principle has been fabricated, giving about the same sensitivity. Both instruments have found use in precise surveying work by means of hypsometry (see sec. 2.9.3.2.8, where reference is made to the instrument manufactured by the Askania-Werke in Berlin).

(d) Svec and Gibbs[33] developed a recording mercurial manometer which covers the pressure range from 0 to 760 mm. Hg. A resistance wire composed either of Nichrome V or Chromel A is positioned concentrically in the mercury column of a large bulb manometer. The resistance of this wire forms part of a direct current bridge circuit, with a recording potentiometer used as the balance indicating device. When the pressure being measured is zero, as shown by the mercury levels of the manometer, the entire resistance of the concentric wire is part of the bridge. However, as the mercury column rises, owing to increase of pressure acting on one leg of the manometer, the resistance of that portion of the wire in contact with the mercury is shorted out. Thus, the effective resistance of the wire under these conditions (when allowance is made for this shorting) is dependent upon the height of the column of mercury in the manometer. In this manner the indications of the recording potentiometer are related to the height of the mercury column. When the device is checked, it is found that the calibration curve indicates a linear relationship between pressure and chart reading.

(e) Farquharson and Kermicle[38] developed an instrument to find automatically the level of mercury in a glass tube and to indicate on a digital register the height of the mercury column. The first model had a range of 80 cm., with a precision of better than plus or minus 0.05 mm., and a maximum deviation of plus or minus 0.11 mm. This instrument was designed for the purpose of measuring gas pressure rapidly and precisely. The precision obtained with the device depends upon the precision with which a suitable metric screw can be produced. The metric screws obtained for the apparatus had a guaranteed accuracy of plus or minus 0.01 mm., with a pitch of 1 thread per mm. A 4-inch aluminum channel is employed for mounting the manometer tube centrally in a vertical position. On one side of the channel is the screw and on the other a guide rod. An optical unit is also employed, consisting of a photo tube and a pilot lamp. The optical carriage is driven on one side by rotational movement of the elevating screw, while it is guided on the other side by means of a ball bushing on the guide rod. Use is made of a two-phase, 13.5-watt servo motor to turn the metric screw and digital register. The electronic circuit consists of the optical carriage system, the alternating current bridge circuit, and the servo amplifier. A Cadmium Selenide Photo Cell is used in the optical system, and the light from the lamp is collimated, thus providing the basis for the optical sighting system. This is employed for sighting automatically across the meniscus, with the circuit so designed that a null signal is produced when the axis of the collimated light beam is centered at the top of the meniscus of the mercury column.

The operation and performance of the automatic manometer reader has been described in the following words by Farquharson and Kermicle:[38]

"Operation. When the optical sighting carriage is positioned at the meniscus of a column of mercury, the mercury intercepts a portion of the collimated light impinging on the photocell. The resistance of the photocell then balances the bridge circuit of Fig. 2 [omitted here]. With a balanced bridge circuit the input to the amplifier is at null, the alternating current voltage in the reference and quadrature windings of the servo motor are in phase, and no vertical motion is imparted to the optical sighting carriage.

"When the meniscus moves, the portion of the collimated light falling upon the phototube is changed. The change in resistance of the phototube then unbalances the alternating current resistance bridge. The unbalanced bridge feeds a signal to the servo amplifier which in turn causes the quadrature winding in the servo motor to be out of phase with the reference winding. The servo motor then turns at maximum speed in the proper direction to raise or lower the optical sighting carriage and to restore balance. The speed of response and the rate of travel of the optical carriage are approximately 13 cm per minute.

"The elevation of the optical sighting carriage at the meniscus is registered directly through the mechanical linkage of the metric screw to the digital indicator. The digital indicator registers 10 digits for a change of 1 mm or a single rotation of the metric screw.

"Performance. As a test of the precision of measurement of a typical unit, the optical sighting carriage was caused to move from its position at the meniscus and then allowed to reposition. In repeated tests the digital indicator did not show deviations greater than ± 0.05 mm.

"The accuracy was determined by direct comparison against a precise scale incorporated in a cathetometer; the data indicate a maximum deviation of ±0.11 mm. The best of four carefully measured screws had a deviation of ±0.025 mm. The deviation of any unit depends on the precision with which the metric screw is made. Screws are available with a guaranteed accuracy of ±0.01 mm and may be obtained on special order with a guaranteed accuracy of ±0.002 mm."

(f) Bottomley[39] has pointed out that owing to refraction errors at the glass walls of a manometer (or barometer), and the problem of sighting on the summit of a mercury meniscus, together with other difficulties, one cannot rely upon conventional mercury-in-glass manometers to yield pressures accurate to better than 0.01 mm. of mercury. In order to overcome this deficiency, he has constructed an apparatus whose principal feature is the use of a null manometer in which mercury surfaces are set to the same horizontal plane by being brought just into contact with tungsten points. He has found that the point setting can be made reproducible to about 0.0002 mm., thereby permitting it to be about fifty-fold more delicate than a cathetometer setting. In this laboratory technique Bottomley employs precise measurements of gas volume as a means of determining, on a relative basis, the unknown pressure (say P) of any given sample of gas. In order to do this he commences with a quantity of a reference gas. At a pressure, say P_r, which is known approximately, he measures the volume of the reference gas with high precision, thus obtaining its volume V_r. Then, the sample of reference gas is expanded until its pressure is equal to that of the given sample of gas at pressure P, this equality of pressure between the reference gas and the given sample being established by means of the null manometer. At this stage the volume of the reference gas is once again measured with high precision, yielding volume V. If all of the measurements are made at constant temperature, e.g., under thermostatically controlled conditions, then one can assume Boyle's law to apply, under suitable restrictions.

The main part of the apparatus was enclosed in a large water bath, which was maintained at a steady temperature within 0.02° C. by thermostatic control. On this basis, one has $P_rV_r = PV$; from which it is possible to compute P relatively, since V_r and V are known accurately, while P_r is known only approximately. If the absolute temperature (T) were to vary in such a manner that T_r is associated with P_r and V_r, while T is associated with P and V with relation to the reference gas, then under the assumption of the ideal gas laws $P_rV_r/T_r = PV/T$. On this basis, one can also solve for P, thus obtaining a result whose relative accuracy depends upon the combined accuracy of the remaining factors. Bottomley has found that by use of the tungsten reference points and the differential (null) manometer he was enabled to establish a scale of relative pressures which is self-consistent to better than two parts in 100,000.

(g) The U.S. Air Force makes use of the apparatus shown in fig. A–2.13.0. It is employed in the organization's instrument shops and overhaul depots for the calibration and testing of pressure actuated aircraft flight instruments. This manometer has been designed to apply, regulate, and indicate absolute pressure simulating pressure altitude and differential pressure simulating indicated airspeed independently of one another. The differential pressure uses the controlled absolute pressure as the reference (low) pressure. Pressure regulation and control is accomplished by means of 3 manually positioned photo cell scanners which detect whether the mercury meniscus is above or below the airspeed or altitude setting and transmit an appropriate signal to a servo amplifier which drives a motorized pressure and vacuum valve to control the pressure (±) in the system and bring the mercury meniscus to the control point. Adjustments are provided on the valve mechanism for setting up limits on the rate of pressure change. The device is provided with three sections; one is a barometer covering the absolute altitude pressure range from — 1000 ft. to + 150,000 ft., the 80 inch differential pressure range is accommodated by 0 to 40 inch and 40 to 80 inch differential manometer sections. Range changeover is accomplished automatically from 0 to 40 to the 40 to 80 inch range. Compensation for existing conditions of temperature and gravity can be set in by means of a compensation mechanism which is part of the apparatus.

A–2.14 EFFECTS OF IMPURE MERCURY, AND PROCEDURES FOR CLEANING IT

A–2.14.0 Introduction

Pure dry mercury is essential for use in mercurial barometers in order to secure the highest accuracy obtainable. To this end, moisture and entrapped air must be removed. When mercury is in its pure state, the liquid metal is very mobile, especially in the form of small droplets on a clean, dry glass surface. Pure mercury is characterized by a strong ability to reflect light (reflection coefficient 0.712 for light having a wave length of 550 millimicrons which is in the yellowish-green portion of the spectrum). The free surface of pure mercury contained in a glass vessel and directly exposed to air always forms a rounded meniscus, convex side up, as in the case of the liquid in the cistern of a clean Fortin-type barometer. In addition a convex meniscus is generally produced at the free surface which forms the top of the column of mercury within the glass tube of a barometer filled by ordinary procedures. However, it is possible for the meniscus of pure, dry mercury in a glass tube to be flat under certain conditions. (See sec. A–2.19 for more details.)[40]

Whenever the surface of mercury is significantly fouled, it tends to lose its characteristic shiny appearance and to cling to glass or porcelain vessels. A noticeable effect of some impurities in the mercury is to cause the meniscus to become relatively flattened, rather than convex, even in small tubes; this being a manifestation of a decrease in the surface tension of the fluid.

A–2.14.1 Effects of Impurities in Mercury

The principal objections to the use of polluted or fouled mercury in barometers may be summarized as follows: (1) The correction for capillary error determined in the laboratory when the mercury was clean and had normal menisci is no longer valid after either meniscus becomes flattened owing to the effect of impurities. (2) In cases where the meniscus in the barometer tube is flattened, the observer cannot set the sighting edge of the vernier as precisely to the exact top of the mercury column as he could if the meniscus were convex. (3) If the surface of the mercury in the cistern of a Fortin-type barometer is fouled, it is likely that the observer will not always be able to adjust the cistern so as to establish exact contact between the tip of the ivory point and the meniscus; and there is the possibility that a foreign substance may adhere to the tip; both of which causes can give rise to an erroneous zero setting of the instrument. (4) Some impurities in the mercury or foreign matter on the meniscus in the cistern of a Fortin-type barometer may produce a coating on the inside of the glass cylinder which forms the upper part of the cistern and thereby reduces the visibility of the tip of the ivory point against the background, thus hampering accurate settings. (5) The addition of impurities to the mercury will generally cause its density to deviate from that which the substance had previously.*

Mercury has the capacity to dissolve slight amounts of all or nearly all metals, and some other substances. As the concentration of any soluble metal in mercury increases, a point may be reached at which the solution becomes saturated, and the excess metal beyond that required for saturation of the mercury will generally be deposited out in some solid form. Chemical and metallurgical investigations reveal that mercury in combination with other metals will produce alloys, called "amalgams." As examples of some of the substances which

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[40] L. J. Briggs, "The Limiting Negative Pressure of Mercury in Pyrex Glass," Journal of Applied Physics, vol 24, pp. 488–490. (1953).

* The density of pure mercury will also vary with its composition as regards isotopes. See sec. A–2.5.

can dissolve in mercury and form amalgams in combination with it, mention may be made of the following: cadmium, bismuth, antimony, copper, lead, tin, zinc, metals like sodium, potassium, barium, calcium, caesium, magnesium, and rubidium; and the noble metals like gold, silver and platinum.[41] Mercury has the remarkable property that it takes but a very minute amount of a base metal like zinc, tin, or lead added to the liquid in order for a noticeable degree of surface fouling to occur, provided the liquid is exposed to air or oxygen. This action takes place more rapidly and completely if the contaminated mercury is agitated in the presence of these oxidizing agents. For example, in experiments involving the addition of small amounts of the base metals zinc, antimony, copper, lead, and tin, to pure mercury exposed under air, it was observed that a concentration of only 1 or 2 parts of such a base metal in 10 million parts of mercury was sufficient to reveal the presence of the impurity, initially present as an amalgam.[42]

As a rule, oxygen reacts with the base metals contained in these impurities and will produce a film or skin on the surface of the mercury, but the noble metals will not manifest this effect. Another evidence of the presence of a base metal in the impurity is the formation of a deposit on the surface of the glass container or by a wetting of the glass. The mercury thus contaminated with a base metal exhibits the phenomenon known as "tailing," which represents the formation of adherent, pointed trails left by traces of an amalgam or an oxide of a base metal when droplets of the impure mercury are caused to roll along a surface, such as that of a porcelain dish. This behavior reveals that mercury contaminated with a base metal loses some or all of its normal mobility, depending upon the concentration and type of the metal, also upon the degree of oxidation which has taken place. On the other hand, when small amounts of the noble metals, such as gold or silver, are added to the mercury in concentrations up to 0.1 percent, they are not detectable by the appearance of their amalgams, since these do not form a film on the surface. It has been observed that serious fouling of a mercury surface may occur when the surface is exposed to certain substances which contain sulfur, such as the gases hydrogen sulfide and sulfur dioxide. The presence of moisture and grease in the mercury or on any surfaces with which it comes into contact is also objectionable. In this regard it may be noted that water vapor and air reaching the exposed mercury surface seem to accelerate the chemical changes which lead to the formation of a film on the surface. The facts summarized above help to explain the more rapid rate of fouling of the mercury in the cisterns of barometers located within moist, heavily industrialized regions where there is much pollution of the air in the form of chemicals, dust, smoke, etc., as compared with dry, rural areas where there is considerably less pollution.

One may readily observe the marked changes in characteristics of the mercury which occur when transformed from the pure state to a fouled condition by the addition of a minute mass of some base metal like lead, tin, or zinc. Thus, at the commencement of the experiment a small amount of pure mercury exposed to the air in a clean, dry porcelain or glass bowl can be caused to separate into brilliant, shiny globules which move about very readily as the bowl is oriented and tipped in various ways. However, a similar amount of mercury which has been fouled by adding a small piece of base metal in the presence of air and stirring up the mixture will exhibit a radically different behavior; for then as the bowl containing the fouled droplet of mercury is moved about, the mercury tends to produce slender, extended formations which draw out into sharply pointed, tapering "tails." The tips of these tails cling to the vessel owing to the formation of a film containing the amalgam, as affected by the oxygen. A noticeable feature is that the film produced as a result of the oxidation soils and discolors the surface over which the "tails" occur. On

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[41] Charles L. Gordon and Edward Wichers, "Purification of Mercury and Its Physical Properties," Annals of the New York Academy of Sciences, vol. 65, pages 369–387, April 11, 1957.

[42] E. Wichers, "Pure Mercury," Review of Scientific Instruments, vol. 13, p. 502–503, (1942). See also E. Wichers, Chem. Eng. News, vol. 20, pp. 1111–2, (1942).

the other hand, a dilute amalgam of a base metal formed when not exposed to an oxidizing agent (as for example when covered with acetone or a light oil) will remain substantially clean and bright (Wichers, 1942).[42] Oxidation of such an amalgam as a result of exposure to air will cause it to tarnish. The presence of a film on the surface of the mercury makes it possible to detect impurities which have this effect and permits one to remove the major portion of the solid material by a simple mechanical process, as described below.

A–2.14.2 Filtering Method of Cleaning Mercury

The old-fashioned method was to press the mercury through leather; and later other filtering substances were used, such as muslin or silk cloth, and filter paper which has fine pin holes or slits. An excellent arrangement is to filter the dirty mercury through a fritted glass funnel. This is a funnel whose pointed end has a glass frit consisting of a glass cylinder having fine pores or capillary tubes capable of retaining the solid materials but permitting the liquid mercury to flow through. A method still convenient when only limited facilities are available is to employ a paper cone for the filtering process. This will work fairly well in experienced hands for the removal of solids, for example a film of oxides produced from amalgams of base metals on the surface of the mercury, a thin coat of dust, or even those portions of amalgams which have precipitated out as solids owing to their presence in high enough concentrations. However, no filtering process will remove from the impure mercury those constituents which remain in solution, for example any dissolved metals or amalgams present in such low concentration that they have not precipitated out.

The method of using a paper cone is as follows: A sharp cone is made of a clean sheet of so-called "book paper," letter paper (not glossy), or filter paper. Then, a minute pinhole is made in the apex of the cone. If the cone is produced by rolling up a sheet of suitable paper, the size of the opening at the apex can be checked by looking through it towards a light; and it should be noted that the size of the opening can be readily controlled to the required diameter by twisting the folds of the cone. By pouring the dirty mercury into the cone, the liquid may be filtered through the fine hole in the apex. It is desirable, as a rule, when cleaning the mercury from a barometer, to keep the cone pretty well filled as the filtering progresses until all of the mercury taken out of the instrument has been added. Near the end of the filtering process, it is necessary to exercise caution to retain on the cone the dross and film which is left, as this is likely to contain most of the materials capable of being removed by the filtering process. The character of the mark left on the paper cone by the film after the mercury has been filtered may serve to some extent as an index of the effectiveness of the procedure for removing surface dust and other solids, since a well soiled mark sometimes indicates a heavy oxidized film of amalgams of base metals and possibly some other substances.

One objection to the use of a paper cone for filtering mercury is that the character of the ring left on the cone after the filtration is not always an indication of how impure the mercury is. This conclusion is reached because the character of the ring depends upon the type of surface of the paper even in the case of pure mercury. (For example, when a microscope was used to examine the ring left on filter paper following the filtration of pure mercury, it was observed that the ring was composed of very minute globules of mercury adhering to the fibers of the paper.) Therefore, if facilities are available, it is preferable to use, instead of paper, a glass frit which can be procured with capillaries of such diameter as to yield excellent filtering characteristics without the problem of uncertainty regarding the nature of the ring which is posed when a paper cone is employed. For this purpose a suitable frit may be specified as a sintered glass filtering crucible of medium porosity. While the filtering method of cleaning mercury, as described above, is useful in connection with the cleaning of barometers at field stations or as one stage in a more extensive procedure, it is not capable of yielding pure mercury under all circumstances. For this reason a more thorough set of operations is used in laboratories, with a view to obtaining a very high degree of purity of the mercury, as outlined below.

A–2.14.3 Laboratory Operations for Purifying Mercury

In laboratories where there are suitable facilities for purifying mercury which may contain impurities of various chemical compositions, an extensive procedure is carried out to eliminate these substances in various stages, such operations being necessary since there is no simple one-step process which is capable of freeing mercury of all kinds of impurities. The following stages representing a series of successive processes in a general procedure for purifying mercury are recommended where relatively large quantities of dirty mercury must be handled:*

(1) **Mechanical filtering.**—The dirty mercury should be first filtered through a fritted funnel, in order to remove films generally consisting of oxides of base metals and to eliminate large particles such as those of dust and solid amalgams, if any.

(2) **Removal of grease.**—Grease may be removed from the mercury by means of an organic solvent. Acetone is generally suitable for dissolving most types of grease.

(3) **Acid wash with air agitation.**—The operation described here is designed to employ a suitable acid wash and the action of air bubbles for the purpose of removing a majority of base metals and sulfides which may contaminate the mercury. To this end the apparatus shown in fig. A–2.14.0 is found convenient. As indicated in the diagram it consists of two 4-liter heavy walled suction flasks, which are connected in series to a suction device, such as a water aspirator. Between the second flask and the aspirator a trap is included in the train for the purpose of catching the acid spray and droplets of mercury that may be carried by it. At the National Bureau of Standards, a reagent found to be effective for the wash solution

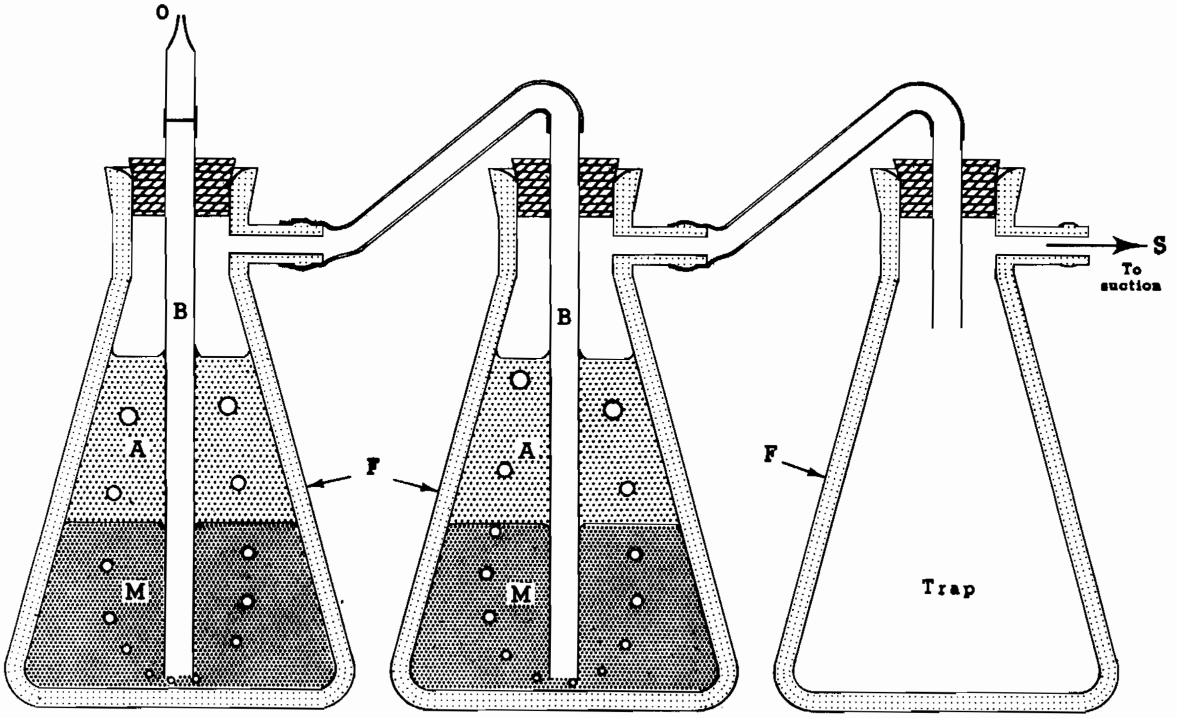

FIGURE A–2.14.0. Cross section of apparatus for washing mercury, using an acid wash with air agitation, showing the following parts: *A*, dilute solution of nitric acid and hydrogen peroxide; *B*, air inlet tube; *F*, heavy walled suction flask; *O*, metering orifice with built in air filter; *M*, mercury; *S*, source of suction (e.g., water aspirator).

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* The items in the list of stages and the information given thereunder are based on material provided by Dr. E. Wichers and Mr. C. L. Gordon, of the National Bureau of Standards, Division of Chemistry; see references in footnotes 41 and 42 of this section.

is dilute nitric acid to which a little hydrogen peroxide is added. The purpose of the peroxide is to aid in the removal of sulfides. A satisfactory composition is obtained for the acid solution by combining one part of concentrated nitric acid (specific gravity 1.42) with 9 parts of distilled water. As the suction is applied, bubbles of air rise vigorously through the mercury and acid solution, agitating and mixing the two continually. This process is maintained for from 12 to 16 hours. If there are certain base metals contaminating the mercury, it will be found that a scum has formed above the mercury and perhaps in the acid solution. This generally contains oxides and excess nitrates of some or all of these metals, depending upon the composition of the impurities present in the mercury. In addition, the wash liquid contains some substances in solution. Therefore, upon termination of the first washing process the layer of acid together with the scum which has formed on its surface must be drawn off. Finally, in order to obtain a higher degree of purification than is possible with one operation, the entire process of acid washing the mercury with air agitation is repeated, starting with a fresh acid solution.

Investigations by chemical analysis of the constituents of the scum and of the substances dissolved in the acid solution have revealed that the process described above is capable of causing the removal from dirty mercury of many base metals which contaminate it, including sodium, magnesium, zinc, cadmium, lead, tin, thallium, aluminum, chromium, manganese, nickel, and copper. The air agitation serves at least two purposes: oxidation of certain base metals and mechanical mixing of the acid with the mercury which facilitates the reaction between the acid and some of the impurities contained in the mercury. Dissolved mercury may be recovered from the nitric acid solutions by electrolysis.†

(4) **Washing of Mercury with Distilled Water.**—In order to remove the remains of the acid left in the mercury after the process described under (3) above, an apparatus like that shown in fig. A–2.14.0 is employed for agitating the mercury in contact with distilled water, replacing the dilute acid. This procedure is carried out several times, using fresh distilled water for each change, but shorter times of operation than specified under (3).

(5) **Drying of Mercury.**—The mercury must be thoroughly dried before it is ready for the remaining steps in the procedure or for use. This is accomplished readily by placing the mercury in a porcelain dish and heating it on a hot plate in a hood which is well ventilated. During this process a watch glass is kept over the dish.

(6) **Testing of Surface Criterion for Impurities Regarding Base Metals.**—The surface of the dried sample of mercury which has undergone the treatments described under paragraphs (1) — (5) above should be carefully examined. If the sample is completely freed of dust, solid amalgams, surface impurities, grease, base metals, and moisture, it will seem highly mobile and its surface will generally be characterized by a bright shiny appearance, without any visual evidence of a film or "skin" formed on the surface. However, if the concentration of base metals in the sample of mercury exceeds certain limits, depending upon the chemical nature of the metals, a film or "skin" will usually be apparent on the surface of the mercury since the film appears to be tarnished in contrast to the bright, reflecting surface which is characteristic of pure dry mercury. In view of this, the appearance of the surface may be used as a criterion with respect to the possible presence of certain base metals as impurities in the mercury. To give some idea regarding the sensitivity of this criterion, it may be pointed out that the following proportions of the specified base metals in 100 million parts of mercury have been detected visually by the appearance of a film on the surface: 6 to 9 parts of zinc, 9 parts of copper, 18 parts of lead, 15 parts of tin, and 14 parts of antimony. If the surface criterion indicates the presence of a film on the surface, operations (1) to (5) above *should be re-*

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† If two platinum wires are immersed in the dilute acid which contains the mercury in solution and the output of an ordinary battery charger is applied to the wires, it is possible to recover the mercury.

peated until the criterion of purity is satisfied.

(7) **Filtering.**—The sample of mercury should then be filtered through a glass frit. to remove any dust or other solids that may have gotten into it since it was previously processed.

(8) **Distillation of the Mercury While Air is Bubbled Through it Under Reduced Pressure.**—This is the first distillation stage for the purification of mercury (see paragraph 10 below, regarding the last stage). At this point in the procedure, mercury should be distilled under reduced pressure while bubbles of air flow up through the liquid. Fig. A–2.14.1 shows a diagram of an apparatus used for this purpose at the National Bureau of Standards. The functioning of the air bubbles is threefold: (a) the oxygen in the air oxidizes the base metals and some other substances, so that their oxides float on the surface as a scum and can be readily removed; (b) the action of the air bubbling up through the mercury prevents "bumping" or boiling effects, such as ejection of spray which could cause contamination to be carried along; and (c) the mechanical agitation of the surface of the mercury by the bubbles prevents the formation of a continuous film of traces of base metals (if present), such a film being undesirable since it retards evaporation.[41] [42] The apparatus shown in fig. A–2.14.1 is largely based on a design by Hulett (1900, 1905, 1911)[43] modified somewhat, including an extra barometric column for an electrical cut-off in case of suction failure. It is advisable to conduct the distillation process at a relatively low temperature (perhaps 200° C.), since silver becomes volatile at a significantly higher temperature, and gold also, but to a lesser extent.[42] Under these conditions of distilling mercury most of the impurities are left behind, but not all.

NOTES PERTINENT TO PARAGRAPH (8)

In discussing the operation of this stage of the procedure, Hulett (1911)[43] has presented the following remarks: "The distillation was carried out in a flask where the air pressure was about 25 mm. (of mercury) or about 5 mm. partial pressure of oxygen, and the temperature was about 200° C. Any metallic vapor will completely oxidize under these conditions if the dissociation pressure of its oxide is less than the partial pressure of the oxygen maintained in the still. This is eminently true of all the common base metals. These oxides collect on the distillate and when they are present in considerable quantity as in the case of quite impure mercury, the distillate may then look dirty but when filtered through a pinhole in a filter paper is found to be free from the metals (i.e. base metals), provided sufficient air passes over with the vapors." Hulett added the following relevant information: (a) "When the partial pressure of the oxygen is much more than 5 mm., mercury oxide appears." (b) "The oxides of silver, gold, and the platinum metals would not form under the conditions in our still so their vapors would condense with the mercury vapor and be found as amalgams." (c) It required three distillations of a solution of mercury saturated with silver at 200° C. in order to obtain mercury which if distilled once more would leave no visible residue. (Note: The previous distillations all left a visible residue containing silver amalgam. Commenting on this matter Hulett stated: "It would therefore appear to be necessary to distill mercury at least three times if it contains silver and it is quite impossible to entirely remove silver from mercury by chemical means or any other method. It was noticed that mercury containing these small traces of silver very readily became 'dirty' when agitated and was noticeably different from pure mercury in its behavior.") (d) After two distillations of a solution of mercury saturated with gold at 200° C., the resulting distillate contained very much less than 1 part of gold in 6.75 hundred million parts of mercury. (e) Mercury which is distilled from a platinum saturated amalgam at 200° C. contains about one part of platinum to one hundred million parts of mercury. (f) According to Hulett: "Mercury does not oxidize readily under ordinary conditions although the dissociation pressure of mercury

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[43] Hulett, G. A. Zeitschr. physik. Chem., vol. 33, pp. 611–621, (1900); Hulett, G. A., and Minchin, H. D., Phys. Rev., vol. 21, pp. 388–398, (1905); Hulett, G. A., Phys. Rev., vol. 33, pp. 307–316, (1911).

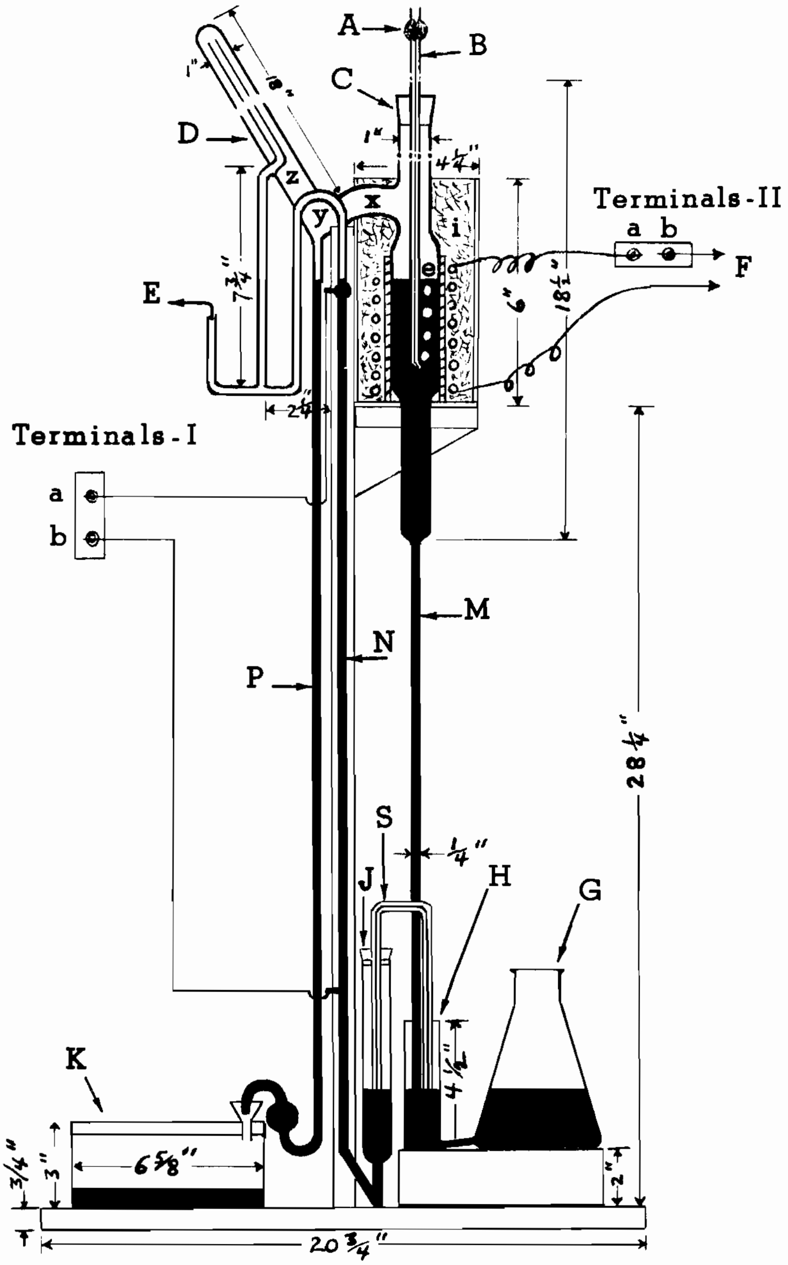

FIGURE A–2.14.1. Electrically Heated Hulett Mercury Still (modified). Explanation: *A*, cotton air filter; *B*, glass tube with very fine capillary, and with lower orifice immersed in mercury, permitting bubbles of air to enter the mercury for purposes of oxidizing base metals (see surface *e*) ; *C*, ground glass stopper; *D*, condenser chamber; *E*, to vacuum pump; *F*, electrical power source supplying energy to the heating coil; *G*, heavy walled 750 cc. Erlenmeyer flask; *H*, reservoir for mercury in column *M; J*, reservoir for column *N* with sufficient capacity to prevent an overflow when the level of column *N* falls owing to vacuum failure; *K*, covered receiving container for purified mercury; *M*, column of mercury to be purified; *N*, glass tube, provided with platinum electrical contacts near top and bottom which connect to Terminals–I, *a* & *b*. The latter are connected to Terminals–II, *a* & *b*, respectively, so that if the mercury in *N* falls below the upper contact owing to vacuum failure, the circuit to the heating coil is broken; *P*, column of mercury formed from condensation which drops down from chamber *D; S*, siphon which transfers mercury automatically so as to maintain equal levels of the surfaces in *J* and *H; e*, evaporating surface in the distillation chamber; *i*, insulating material with an inner protective collar; *x-y-z* is a continuous passageway from the distillation chamber (see *e*) to condenser area *z*. Figure not drawn to scale.

oxide is very small at ordinary temperatures. Evidently it is a question of rate, for pure mercury will remain bright in contact with air or oxygen almost indefinitely, but a little ozone soon causes the mercury to tarnish * * *." (g) It was demonstrated that a base metal like zinc readily distills over with the mercury, and on the basis of experiment Hulett reached the conclusion that the chemical effect of the oxygen in the air bubbled through the still is to oxidize the base metals while they are in the vapor phase (that is, following evaporation of these metals from the surface of the amalgam), rather than while they are in solution in the mercury. This means that the oxides of the base metals thus produced may be carried over to the distillate, so that it is necessary to separate them out from the latter.

(9) **Filter into Vacuum Still.**—After the mercury has gone through the process of distillation referred to in paragraph (8) above, it should be filtered through perforated filter paper into the reservoir of the vacuum still referred to, in paragraph (10) below. This filtration process is largely intended to remove oxides which may have formed owing to the contact of air with base metals that might have been present as impurities in the mercury during the distillation described under paragraph (8).

(10) **Distillation from a Quiet Surface of Mercury Under Vacuum.**—This final stage of the procedure is intended to complete the separation of the mercury from impurities not fully removed in the earlier stages, such as the noble metals (silver, gold, platinum, etc.). To this end, the mercury is volatilized under vacuum in a still, such as illustrated in fig. A–2.14.2, which shows a diagram of the apparatus used for this purpose at the National Bureau of Standards. It is desirable that the apparatus be provided with an adjunct in the form of a suitable type of trap to capture spray which may be ejected from the surface of the mercury in the still, especially if there is "bumping" (violent boiling or explosive evolution of bubbles and vapor which splashes droplets of the liquid). Such droplets of spray from the mercury in bulk are objectionable, since they may contaminate the liquid which is condensed. Various types of traps have been designed for this purpose, and some are described in the literature.[41]

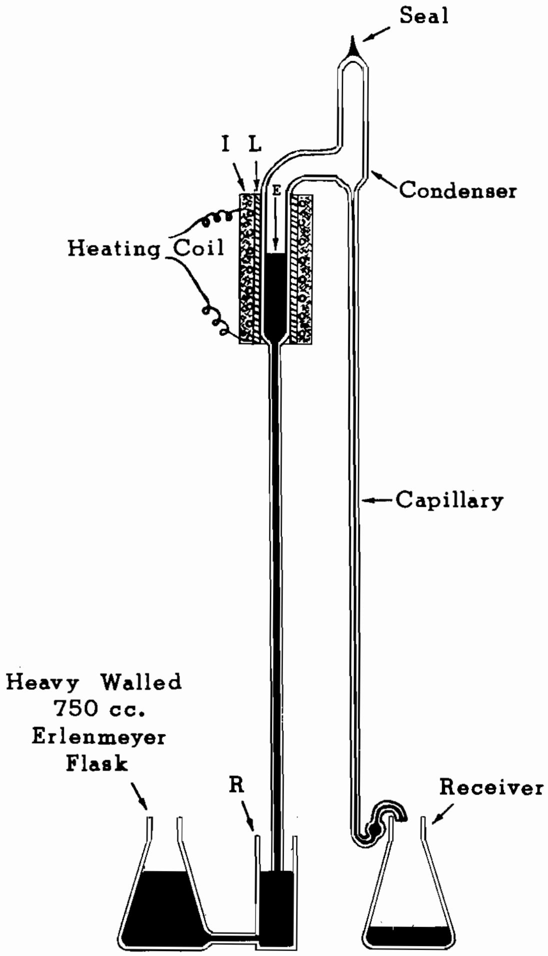

FIGURE A–2.14.2. Electrically heated vacuum mercury still. A Torricellian vacuum is maintained in the distillation and condensing chambers by the two columns of mercury. (*E*, evaporating mercury surface; *I*, thermal insulating material around coil; *L*, layer of thermally protective material; *R*, reservoir).

This improvement and others have been made use of by various investigators. For example, Hickman[44] has designed the condensing chamber in the form of an alembic so that the area over which the mercury volatilizes is relatively large, while the surface of the glass alembic on which condensation occurs is also relatively large and close to (several centimeters from) the evaporating surface, thereby increasing the efficiency of the operation. Hickman has also arranged

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[44] Hickman, K., "A Sublimation Mercury Still," Jour. Opt. Soc. Amer., vol. 18, pp. 62–68, (1929).

a unit of three mercury stills in series so that the distillate from the first alembic is transferred to the second, from the second to the third, and lastly from the third to the outside receiving bottle where the final product of the three successive distillation processes is found to be very pure mercury, when the normal precautions are taken. This multiple still unit which operates automatically is capable of yielding 400 cubic centimeters of mercury distillate in 24 hours. Robeson[45] has also devised a single-stage mercury still of roughly similar character. In all of the designs of stills referred to above the vacuum is maintained by two mercury columns, after the initial vacuum is introduced in the distillation chamber by means of a vacuum pump; thus the pump need not run continuously during the entire operation of the still. Heat is applied around this chamber electrically by means of high-resistance wire heating coils in order to supply the energy for a rapid rate of distillation. Mercury which has been processed through the sequence of stages described in the preceding paragraphs, culminating in the vacuum distillation stage just referred to, should be in a highly purified state, assuming that regular precautions are taken to use clean glassware, to avoid contamination from the air and other sources, etc. Such mercury should then be ready for storage or use.

(11) **Storage of Mercury.**—Since some types of containers can produce contamination of mercury, it is essential to employ those which yield the least amount. At the National Bureau of Standards it has been found by experience that soft-glass bottles give the most satisfactory results in this regard. The bottles should be scrubbed, thoroughly washed, and dried by baking before use for storage of mercury. If it is necessary to clean the bottles with acid, it is recommended that nitric acid be chosen for the purpose. An excellent closure of a bottle containing mercury is effected by using a cork stopper, protected by parchment paper, with an inverted beaker covering the stopper and top of the bottle. Some idea of the purity of the mercury may be obtained, at least so far as freedom from base metals is concerned, by agitating the mercury in the bottle for a few minutes, and observing the surface. If the mercury is pure in this respect, there should be no visible film or scum on the surface.

In a discussion regarding this matter, Gordon and Wichers have presented the following remarks:[41] "It should be added that the appearance of a slight film on mercury after *prolonged* exposure to air does not necessarily indicate the presence of base metals. In our experience, every bottle of purified mercury will show, after some weeks or months, some evidence of surface impurities and, usually, a slight ring on the glass at the mercury surface. It is not known whether this is the result of slight oxidation of the mercury itself, promoted by contact with certain types of glass or by moisture in the air, or whether it is foreign matter sloughed off from the glass, or dust settled from the air. These films are so slight as to defy chemical examination. They can be removed by filtration and are not significant if they do not reappear promptly."

Experience indicates that it is important for the mercury, its container, the glass barometer tube, and the cistern of the barometer to be dry when the mercury is used in the instrument.

Those who use mercury or work in laboratories and shops where mercury is employed are urged to take cognizance of the hazards of absorbing this substance into the human system, for it is known to be toxic. See sec. A–2.18 for more details.

A–2.15 FILLING OF MERCURY BAROMETERS

This information is inserted for those especially interested. Barometers may be filled by either of two processes: (A) Vacuum pump method; and (B) Boiling method.

Under (A), by means of glass-blowing techniques, a long, slender-stemmed, clean glass tube is constructed with double walls and a side tube near its upper end for a vacuum pump connection. This is sealed to the barometer tube, while the latter is held in a nearly vertical position with its closed

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[45] Robeson, F. L., "An Automatic Mercury Still," Jour. Opt. Soc. Amer., vol. 18, pp. 72–74, (1929).

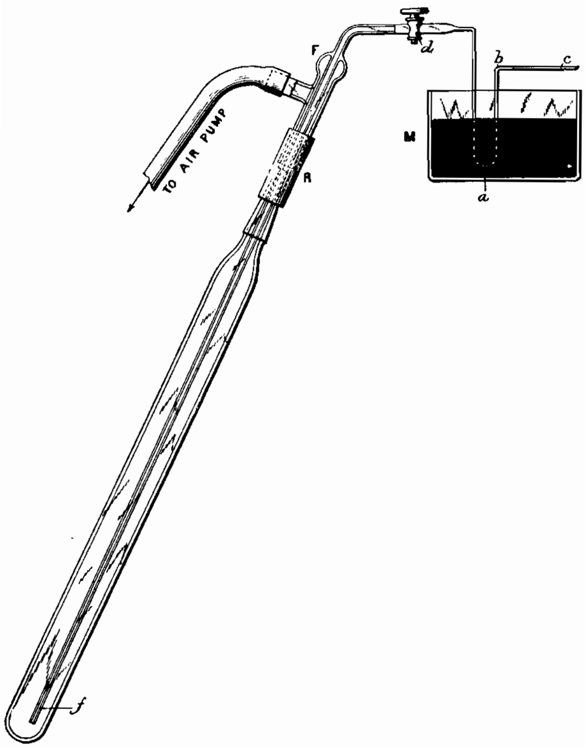

FIGURE A–2.15.0. Air-pump method of filling barometers. The parts listed below are identified by letters in the illustration: *Ff*, funnel tube; *R*, rubber tubing; *d*, stopcock; *M*, mercury; *a b c*, capillary tube. This tube is sealed at "*c*" and may be broken off at "*a*" to permit mercury to flow into the tube.

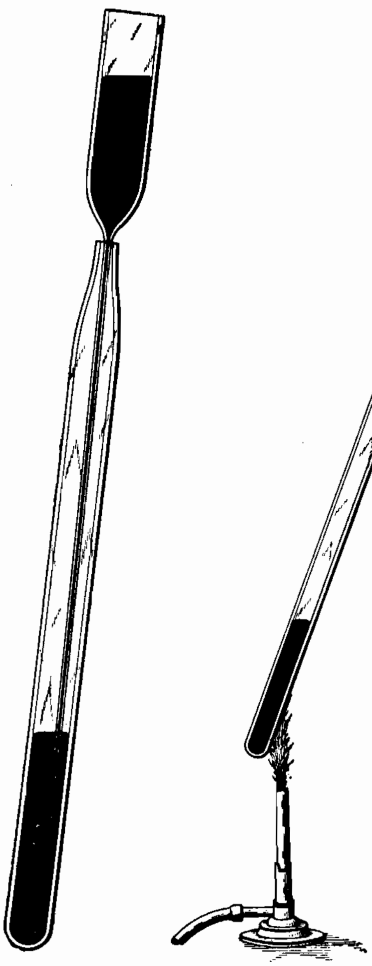

FIGURE A–2.15.1. Funnel tube and boiling method of filling barometer tubes.

end down. The lower end of the slender-stemmed tube thus almost touches the bottom (closed end) of the barometer tube, but the upper end of the slender-stemmed tube is connected through a stopcock to a vessel of clean, warm mercury. See fig. A–2.15.0. First, keeping the stopcock closed, the barometer tube is evacuated by means of the vacuum pump used in conjunction with a good drying agent, while the tube is heated to 300° C. in order to promote outgassing and drying. Then the stopcock is opened, permitting the mercury to flow from the vessel through the slender-stemmed tube to the barometer tube by siphon action.

When many barometer tubes are to be filled at one time, it is possible to employ the apparatus developed by J. Patterson of Toronto. (See: book by W. E. K. Middleton and A. F. Spilhaus, "Meteorological Instruments," Third Edition, University of Toronto Press, Toronto, (1953).) This apparatus includes three mercury stills operated in series, arranged so that the last still delivers mercury directly into a header. Beneath the latter there are held in suspension the inverted, previously dried out barometer tubes which are connected to the interior of the header. First the header and barometer tubes are exhausted by means of a diffusion pump backed by a mechanical pump. Then heat is applied to the stills while the pumps are kept in operation. Distillation of the mercury purifies it in the process of conveying it to the header, whence it condenses and drops down into the barometer tubes.

In the case of the so-called "boiling method" (B), great care in handling the barometer tube is necessary, since mercury vapor is dangerous to the human system when inhaled in excess. Under method (B), clean, warm mercury is carefully introduced into the inverted, previously-dried barometer tube, three or four inches at a time. For this purpose the mercury is conveyed by means of a long, slender-stemmed glass funnel which nearly reaches the bottom of the barometer tube. See fig. A–2.15.1. Then, the mercury in the tube is carefully boiled over a Bunsen burner flame, while the tube is moved and rotated continuously through the flame in order to avoid undue local heating of the tube. Heating and boiling of the mercury has the effect of driving off air and moisture vapor, first evidenced in the form of very small silvery-white bubbles, which give the tube a frosted appearance. Continued heating of the tube and boiling of the mercury cause the bubbles to enlarge, permitting them to escape until there is no further evidence of bubbles on the walls. Repeating this process, mercury is added in steps, until the tube contains the shiny quicksilver to within about three inches from the tip of the open end of the tube. Finally, the latter remaining part of the tube is completely filled by careful addition of warm mercury through use of a clean, slender-stemmed glass funnel and a glass syringe equipped with a hypodermic needle. If one wishes to perform the Torricellian experiment (see Appendix 2.1) one should close the tip of the tube with a finger encased in a sulphur-free rubber glove, erect the tube, and immerse the tip end in clean mercury contained in a cistern. When all necessary precautions have been taken to exclude air, moisture, dust and other pollution from the mercury and the interior of the tube, the column of mercury comes into balance against the atmospheric pressure exerted on the surface of the mercury in the cistern and a vacuum of good quality may be attained in the space above the top of the mercury in the closed tube. This upper surface of the mercury, domed upward, is termed "meniscus." In the handling of barometers care should be taken to avoid touching with the fingers surfaces which come into contact with the mercury.

If one wishes to complete the assembly of a Fortin barometer one should follow the relevant instructions in sec. A–2.17.

A–2.16 GENERAL RULES FOR HANDLING AND MAINTENANCE OF BAROMETERS

A–2.16.0 Introduction

Each type of barometer has its own distinctive characteristics which govern the methods of proper handling and maintenance for the purpose of obtaining maximum accuracy, protection, and service life for each type. Some rules that relate to the handling and maintenance of the instruments are fairly general and apply broadly to all types; while other rules are only pertinent to specific types, depending upon their particular construction and characteristics.

At this point a few general rules may be laid down:

(1) The instrument should be protected from mechanical shocks and excessive vibration.

(2) Tampering with the instrument should not be permitted.

(3) A site should be selected for the instrument where it will have a relatively steady and uniform temperature in the environment, without exposure to strong sources of heat or cold; safeguarded against currents of air or drafts which can cause sudden, significant changes in ambient conditions. Therefore, exposure of the instrument to direct radiation from the sun must be avoided.

(4) It is essential to mount the instrument securely in a reasonably safe location so that it will neither fall nor be subjected to jolts or other possible harmful things.

(5) The position of the instrument mechanism at its final installation site must be the same as that in which the instrument was originally calibrated.

(6) The instrument should be kept in a reasonable state of cleanness and must be kept dry.

(7) In view of the mechanical characteristics peculiar to each type of barometer which render the instruments in the given class susceptible to damage, special rules must be observed in regard to the method of handling each type when it is desired to clean, move, pack, ship, or transport such an instrument. Owing to these considerations special instructions are presented *in*

this manual with regard to the proper methods of performing these operations for each class of instrument.

While it has not been practicable to cover all contingencies and possible circumstances in these instructions, it has been the intention to lay down sufficient general rules for guidance to enable a careful person to handle any kind of barometer with a proper consideration for safeguarding it. In addition, within certain limits specific instructions relating to the proper method of handling each class of instrument will be given in the sections which follow this introduction.

Personnel in the military services who have occasion to clean, maintain, move, pack, ship or otherwise handle any type of barometric instrument should familiarize themselves with pertinent instructions in Technical Orders, Technical Manuals, Instrument Handbooks, etc., relating to the particular equipment utilized by their services.

Special note should be taken with regard to the individual appropriate means of handling of mercury (mercurial) barometers which are highly susceptible to damage if improper procedures are employed. Users who will or may be called upon at some time to move such an instrument over a considerable distance should ascertain the relevant instructions which apply to the given type (for example, Fortin, fixed-cistern, etc.). In particular, it should be noted that when *certain* types of mercury barometer are to be moved some distance from one installation site to another, it is necessary to tilt and invert the barometer, e.g., as in the case of the Fortin type. Everyone who is concerned with the moving of such barometers is cautioned first to read the instructions in sec. 2.2.7 pertinent to the given type before endeavoring to undertake such action, and second to follow the instructions carefully. A similar injunction is applicable with respect to the other various kinds of barometric instruments and any of the different operations that might be entailed in connection with the handling of the equipment.

The information and instructions relative to the handling and maintenance of the various categories of barometric instruments have been organized in the sections presented below, as follows: sec. A–2.16.1 on Mercury Barometers; sec. A–2.16.2 on Aneroid Barometers and Altimeter-Setting Indicators; sec. A–2.16.3 on Land-Station Barographs; and sec. A-2.16.4 on Marine Barographs.

A–2.16.1 Handling and Maintenance of Mercury Barometers

A–2.16.1.0 Introduction.—There are manifold aspects of the problem concerned with the proper methods of dealing with mercury barometers. Many of these matters are considered in secs. A–2.16.1.1 through A–2.16.1.8.

Thus, the choice of a good installation site for the barometer is crucial in respect to the future obtainment of good observational data from the instrument. Secs. A–2.16.1.1 and A–2.16.1.2 relate to this subject, from the standpoints of avoiding harmful effects of extreme thermal factors and pollution sources, respectively. The reader should consult sec. 2.2 for more details; specifically sec. 2.2.4 which provides definite instructions concerning the installation of mercury barometers.

Sec. A–2.16.1.3 deals with the precautions that one must take when moving, tilting, or inverting mercury barometers; giving brief explanations which show how a barometer might be damaged by improper handling. Sec. A–2.16.1.4 is concerned with the safeguarding of barometers against rough handling and shocks, special attention being given to the problem of protecting such instruments when installed on board vessels which are sometimes subjected to strong concussions. In sec. A–2.16.1.5 it is emphasized that there are certain limitations that one must place on the turning of the adjusting screw or jackscrew of barometers thus equipped, in order to avoid causing damage to the instrument. Sec. A–2.16.1.6 refers to relevant instructions given elsewhere with regard to the packing and shipping of mercury barometers.

It is the intention in sec. A–2.16.1.7 to emphasize the reasons which justify the requirement for a regular program of comparative readings of every barometer against another barometer which serves as a reference datum and which should be itself compared with a standard barometer at suitable intervals. The need for regular inspections of the equipment is pointed out as necessary with a view to detecting as early as practicable signs of damage, impairment, or malfunctioning of the barometers. Sec. A–2.16.1.8 contains general instructions under whose terms special comparative readings are necessary for any barometer when it is moved or subjected to any unusual mechanical shock. Such readings between the instrument which is moved or jarred and its reference standard are required in order to determine whether the former has retained its calibration or has suffered an abrupt change, with possible attendant mechanical damage.

A–2.16.1.1 Choice of Installation Site, from Standpoint of Thermal Factors.—Barometers yield best results when they have a steady temperature, uniform over their entire length. Significant errors are generally introduced when the ambient air or the surroundings of the instruments vary rapidly in temperature or when the barometers are affected by gains and losses of heat at relatively high rates, which act to produce a non-uniform distribution of temperature within them. Therefore, an exposure should be selected for barometric instruments which will provide the best available conditions, specifically a minimum of temperature variation and of heat exchange. Consequently, barometers should not be exposed to direct sunlight or to any sources which can cause rapid gains and losses of heat. Thus, they should not be in a location such that currents of cold or warm air will strike them, and they should not be mounted on any support which itself is subject to relatively large variations of temperature (for example, an outside wooden wall facing the sun during a significant part of the day, where considerable warming and cooling occur). They should not face windows and doors from which cold drafts or streams of warm air may blow on the instruments; and they should not be installed over or too near radiators. It will be understood that when a mercury barometer is subjected to marked changes in ambient temperature or strong fluxes of heat, there almost always result significant differences of temperature between the ambient air, the attached thermometer, the barometer scale, and the column of mercury. In addition, non-uniformity of temperature will develop in the various components of the barometer, as for example when radiation is incident upon an exposed element and is shielded from an interior element, or when a draft of cold air strikes one portion of the scale and not another. Since the temperature of the various components changes at different rates, the temperature of one component or segment of a component may lag behind that of another component or part. Under these conditions the indication of the attached thermometer will not be generally representative of the temperatures of the barometer scale and mercury column, respectively. However, the correction of the barometer for temperature is calculated on the basis of the assumption that the temperature of the instrument is represented by the indication of the attached thermometer, and it is assumed that all parts are in thermal equilibrium. When these assumptions are not fulfilled, the calculated correction for temperature corresponding to the attached thermometer reading is not applicable, and an error will result if it is used. One may render errors from such causes relatively small or practically eliminate them by the selection of a good site for the installation of the barometer, and by the employment of good observing practices. Additional information relevant to this subject will be found in sec. 2.2.1. When it is desired to establish quickly a fairly uniform temperature over the entire length of the barometer, as in the case where comparative readings are to be made for purposes of standardization and calibration, this may be done effectively by playing a fan on the instrument.

A–2.16.1.2 Choice of Installation Site, with a View to Avoiding Pollution Sources.—Barometers should be kept in a clean, dry place. They should be protected from accumulations of dust, soot, atmospheric pollution, moisture, spray from sea water, and any other substances or agents which may cause damage or deterioration. It will be noted that certain chemical substances in the atmosphere especially if polluted, and in sea water, tend to produce fouling of the mercury in barometer cisterns. As the mercury becomes impure, this often acts to impair the quality of the results yielded by the instrument (see secs. 2.7.1 and A–2.14). To protect it, the barometer case should be kept closed when the instrument is not in use. The barometer should be dusted carefully with a soft cloth from time to time. Polishing of the scales should not be undertaken in the field.

A–2.16.1.3 Precautions Necessary When Moving, Tilting, or Inverting Barometers.—There are certain precautions and principles which must be observed when barometers are to be moved, tilted, or inverted; and no one should carry out these actions except in accordance with the pertinent instructions, as in sec. 2.2.7.0–2.2.7.5. This matter is emphasized because the application of improper procedures with regard to handling of barometers may permit a bubble of air to rise into the vacuum space at the top of the glass tube of the mercurial instrument, or cause other damage to the equipment, thus impairing its function seriously (see sec. 2.7.3, A–2.17.2, and A–2.17.3). Experience has revealed that the leather bag in the cistern of the mercury barometer and the parts to which the bag is attached are very delicate. These components are easily damaged by improper handling, which can give rise to leakage of the mercury, putting the instrument out of commission. Another possible cause of serious damage to a mercury barometer becomes effective when the mercury is somehow permitted to impinge against the top of the glass tube at relatively high speed, as might be the case if the instrument were suddenly overturned, or if it were jarred suddenly in a vertical direction while the mercury is too near the top of the tube. Since the column of mercury is very massive, a quick blow of the head of the column upon the top of the glass tube can produce breakage of the latter. To avoid the ill effects described in the preceding sentences, anyone who is or will be required to move or handle barometers should become thoroughly familiar with the relevant instructions before undertaking the action, and should follow these instructions carefully.

A–2.16.1.4 Protection of Barometers Against Rough Handling and Shocks.—Barometers should always be given gentle and careful handling in order to preserve them and to maintain them in calibration. Serious damage may be done to a barometer if tampered with, treated roughly, or handled in a manner out of accord with instructions. Unauthorized persons should not be permitted to meddle with the equipment. It is essential to avoid, as much as possible, subjecting a barometer to bumps, jars, shocks, and strong accelerations or decelerations. These injunctions apply equally for situations where the barometer is merely hanging, is in use, is in process of being packed or unpacked, or is being transported.

The case of a mercury barometer installed on a vessel requires special attention. Figs. 2.6.1 and 2.6.2 illustrate the equipment under consideration. When the ship is armed and weapons are fired, as during target practice, the strong concussion may damage a hanging mercury barometer; hence, an instrument of this nature needs extra protection during such periods. Protection will be afforded to the Navy-type marine mercury barometer by the following actions: In accordance with the instructions in sec. 2.2.7.5, the jackscrew is turned up slowly until the head of the mercury column reaches the top of the glass tube; the barometer should then be removed from its gimbal and slowly tilted until it is horizontal; then the jackscrew should be turned back (slacked off) one full turn to allow for expansion of the mercury in case the temperature increases; and finally the barometer should be laid horizontally on a thick mattress, covered with heavy blankets to serve as a protective cushion, and secured in place to prevent its falling off. To reinstall the barometer after the period of strong concussion, the procedure outlined above should be carried out in reverse. The instructions in sec. 2.2.7 are to be applied in connection with the moving of barometers in all cases.

A–2.16.1.5 Limitations on Turning the Adjusting Screw or Jackscrew of a Barometer.—In order to safeguard the instrument, it is necessary to apply certain limits with regard to the turning of the adjusting screw of the Fortin-type barometer (see fig. 2.5.0) or the jackscrew of the Navy-type marine mercury barometer (see figs. 2.6.1 and 2.6.2). First of all, the turning of the screw should always be done slowly. Secondly, if the turning becomes hard, it is best to stop and study the situation, in order to determine the cause if possible and to avoid damage that might be produced by the application of excessive internal pressure on the cistern. Irreparable damage can result if the turning is continued beyond the point at which strong resistance is felt as the screw advances. This conclusion is obvious from the fact that forcing the screw too hard will cause the mercury to push against the top of the glass tube, while the intense hydrostatic pressure thus established will act to squeeze mercury through the joints of the cistern or through the pores of the leather bag, thereby giving rise to serious injury to the barometer. In this connection it is suggested that the reader refer to secs. 2.2.7.3 and 2.2.7.5, which give instructions for tilting or inverting Fortin- and Navy marine-type barometers. When performing the operations of tilting or inverting these instruments, it is important *not* to force the head of the mercury column all the way to the top of the glass tube by means of the screw, but rather it is necessary to leave a little space for a vacuum or a small air bubble at the top. The space serves to allow some room for expansion of the mercury in case its temperature increases; while the air bubble, if present, provides a buffer between the head of the mercury column and the top of the glass tube, which would tend to absorb the shock in the event the mercury were to strike the glass suddenly, due to a tilting, vertical acceleration, or jar of the barometer. After the small space is visible at the top of the glass tube, the tilting process, which must be done slowly, can begin; and this will permit bringing the mercury into contact with the top gradually, thus avoiding a strong impact.

A–2.16.1.6 Need for Applying Special Instructions in Packing and Shipping Barometers.—The packing and shipment of a barometer, or the carrying of one by hand, especially in the case of the mercury instrument, must be undertaken only in strict accordance with the pertinent instructions. See secs. 2.2.7 and A–2.20 regarding the appropriate instructions and information. Failure to observe the instructions carefully may result in damage to the barometer.

A–2.16.1.7 Need for Regular Inspection and Comparative Readings of Barometers.—From time to time a barometer should be inspected and checked by comparison against another barometer which serves as a standard, directly or indirectly. Chapter 6 presents the information and instructions relevant to checking and standardization of barometers. With regard to the matter of inspection, the adjusting screw below the cistern of the Fortin-type barometer should be examined for signs of mercury, which might indicate leakage from the cistern; while the ivory point, scales, vernier, etc., must be inspected to see that no parts have become loose. If the mercury and the glass cistern of a barometer exhibit an excessive amount of fouling and pollution, the instrument should be cleaned by an authorized person in accordance with pertinent instructions (see sec. A–2.17, and appropriate maintenance manuals of the military services). Comparisons of barometers against another instrument or set of barometers used for standardizing purposes must be made in accordance with the instructions pertaining to the case. As a rule, it is desirable to compare mercury barometers in this manner at least every year, preferably at regular six-month intervals, if possible. Aneroid instruments must be compared much more frequently (see secs. 6.7, 6.8, et seq.). In case any barometer comparison seems to indicate that a relatively large instrumental error has developed, careful consideration should be given to the possible causes and to the need for a replacement of the instrument. A few crucial points are deemed worthy of special mention here in this regard, taking account of the fact that oftentimes instruments of two or more different types are compared, e.g., mercury and aneroid barometers, microbarographs, and altimeter-setting indicators. Thus, if it appears that the instrument reads *too low* by a significant amount, one should examine the following possibilities: (a) in the case of a mercury barometer, a bubble of air or water vapor mixed with air may have risen to the vacuum space above the mercury column; and (b) in the case of an aneroid instrument, a leak may have developed in the capsule or evacuated metallic box with flexible membrane which actuates the needle of the instrument. In each of these cases, the error of the instrument has decreased algebraically (in other words, the necessary correction to overcome the error has increased algebraically); and with regard to the aneroid type, a leak in the capsule can be expected to progress, leading to the result that the error will usually get worse as time goes on (see sec. 2.10.6). Should such serious sources of error become effective quick remedial action is called for. Considering the particular case of a mercury barometer, it will be noted from the instructions that if the total instrumental error exceeds 0.020 inch of mercury (about 0.7 mb.) in absolute amount (regardless of sign), action is generally necessary to secure the replacement of the barometer by another instrument having significantly less error.

With regard to the subject of air in the glass tubes of mercury barometers and of possible methods of checking the vacuum, the attention of maintenance personnel and other interested readers is invited to the information in secs. 2.7.3, A–2.17.2 and A–2.17.3.

A–2.16.1.8 Special Comparisons Required When Barometer Is Moved, Jarred, Etc.—When a barometer is moved or if it is subjected to mechanical shocks and other treatment which may affect any of its operating characteristics adversely, special comparative readings are necessary. Thus, when a barometer is to be moved, comparative readings of the instrument against another barometer should be taken immediately before and after the operation. An additional set of such comparative readings is considered essential about four (4) hours after; and whenever practicable, another set about twenty-four (24) hours after would be desirable. Secs. 6.5 and 6.6 provide information and instructions pertinent to this matter. Similarly, when a barometer is to be tilted, inverted, cleaned, or disassembled, such comparative readings are required. If there are unusual circumstances such as the firing of missiles on board ship or the occurrence of an earthquake which can subject barometers to severe jarring motions and accelerations, comparative readings should be taken as soon as practicable after the event, and also at the subsequent times suggested above (4 and 24 hours intervals). Results obtained from the comparative readings before and after should be studied with a view to determining whether damage has occurred to the instrument and whether the instrumental correction should be revised (see sec. 4.4).

A–2.16.2 Installation, Handling, and Maintenance of Aneroid Indicating Instruments

A–2.16.2.0 Introduction.—The category of aneroid instruments will be understood to include all types of pressure-responsive measuring devices which function by means of an aneroid mechanism; hence the category embraces aneroid barometers, altimeter-setting indicators, altimeters, and the like (see figs. 2.8.0, 2.9.3, 2.9.6, 6.8.1, 6.8.2, 6.9.4, A–2.21.0, A–2.21.1, A–2.21.5, A–2.21.6, A–2.21.7, etc.).

In secs. A–2.16.2.1 through A–2.16.2.12, which follow, general information is presented regarding the handling and maintenance of aneroid instruments. Many of the instructions which apply to this class of instrument stem from the fact that aneroid pressure-responsive elements are not absolute measuring devices; rather they are relative, and therefore must be calibrated, generally by means of comparisons with a standard (or calibrated) mercury barometer. Still another important reason for the need to supply special instructions relating to aneroid instruments arises owing to the various manifestations of anelastic behavior, such as hysteresis, drift, etc., as discussed in secs. 2.9 and 2.10.

Sec. A–2.16.2.1 summarizes the main

points to be considered with regard to the selection of a site for installing aneroid indicating instruments, and the precautions to be taken with a view to protecting the instrument and obtaining good results from it. Position of the instruments should be governed by the information given in sec. A–2.16.2.2. Under climatic or operating conditions where strong relative winds will be experienced, it is desirable to vent the aneroid instruments to a static pressure head, as outlined in sec. A–2.16.2.3.

At the time of their procurement, aneroid instruments should be properly adjusted and calibrated in the laboratory under the general provisions of sec. A–2.16.2.4, with a view to reducing errors to a minimum or correcting for them so as to secure most accurate data. Each aneroid indicating instrument should be carefully and thoroughly put through a procedure at the field station for the purpose of standardizing it and of determining the appropriate correction as outlined in sec. A–2.16.2.5. Sec. A–2.16.2.6 specifies the limited amount of adjustment which is permitted at field stations in order to obtain a suitable correction for the instrument. A continuing program to maintain a quality control watch on the performance of the aneroid indicating instrument is required under the terms of the general directions given in sec. A–2.16.2.7. It is pointed out in sec. A–2.16.2.8 that each such instrument requires the appropriate, latest determined correction to be posted near the device. When aneroid instruments are employed in high-precision work, corrections for temperature of the instrument should be applied as suggested in sec. A–2.16.2.9.

The steps necessary to provide proper care and maintenance of aneroid indicating instruments are briefly presented in sec. A–2.16.2.10. Under circumstances where it is necessary to move such an instrument from one site to another the provisions of sec. A–2.16.2.11 will govern. Finally, the general instructions contained in sec. A–2.16.2.12 will be used as a guide in regard to the packing and shipping of aneroid indicating instruments.

A–2.16.2.1 Installation of Aneroid Indicating Instruments.—Owing to the fact that such instruments may not be perfectly compensated for effects of temperature, the place selected for mounting the device should be preferably one which has a fairly uniform temperature throughout the day. Therefore, it should be in a location where it is shielded from the direct rays of the sun, and from other sources, either of heat or cold, which can cause abrupt and marked changes in its temperature. Under the provisions of this limitation, places near radiators and windows or doors subject to currents of either warm or cold air are to be excluded for the site of the instrument. See sec. 2.2.1 for details and further suggestions.

One should choose a location where it will be also least likely to suffer damage from mechanical concussions, vibrations, or the tampering of persons with the apparatus.

The site selected should be dry and clean; also relatively free, insofar as practicable, of substances in the air which could cause corrosion, fouling of the mechanism, etc.

It is important to mount the instrument so that its face will be at a convenient height for reading at ordinary eye level under normal operating conditions, with a view to minimizing the effects of parallax (see fig. 2.10.2).

A secure method of mounting the instrument should be employed so that the device will not fall if it is accidentally pushed or if its support is subject to vibration. In cases where the supporting surface does undergo excessive vibration or mechanical concussion it is desirable to install the instrument on an anti-vibration or shock-insulating mount (see sec. A–2.21.0).

At land stations it is desirable to have the aneroid instrument installed in the vicinity of a mercury barometer which may be used to check and standardize the instrument (see secs. 6.7 and 6.8).

Provision should be made for venting the instrument to a static-pressure head if required under the conditions specified in sec. A–2.16.2.3.

A–2.16.2.2 Position of Aneroid Instruments.—It is desirable to mount aneroid instruments in the same position with respect to their mechanism as they were when originally calibrated; that is, if they were initially calibrated with their faces in a vertical plane, they should be installed in the same manner; and similarly with regard to the horizontal plane. Such a practice tends to make the calibration data more pertinent to and consistent with the actual readings of the instrument than if the plane of the instrument face were different at its final installation than at its original calibration.

A–2.16.2.3 Venting of Aneroid Indicating Instruments.—It is desirable to connect the pressure-responsive instrument to an outside static-pressure head (see fig. 2.11.0) under either of two conditions: (a) when the structure or vessel in which the instrument is installed will experience strong relative wind velocities; or (b) when the instrument is mounted at some height within a building whose inside temperature may differ markedly from that of the outside or when a high-velocity air conditioning system is employed, thus causing a marked differential of pressure. The justification for this is explained in secs. 2.11.1 and 2.11.2. The inside diameter of the tube used to connect the instrument to the static-pressure head should satisfy the criterion laid down in Appendix 2.11.1. In order to permit making such a connection the instrument must be provided with an air-tight case and a nipple by means of which the tube can be connected. Thus, if the pressure within the structure differs significantly from the ambient static pressure under any of the conditions described above, the function of the static-pressure head is to yield the value of ambient static pressure at its orifice in order to permit the instrument to indicate a representative value of the outside pressure.

A–2.16.2.4 Laboratory Adjustments and Calibration of Aneroid Indicating Instruments.—In modern, precision aneroid indicating instruments means are provided for making several necessary kinds of adjustments in regard to the calibration, re-calibration, or proper operation of the instruments. The adjustment screws or other devices used for such purposes should be accessible without the use of special tools; and moreover they must be so designed that they will not change their setting or become loose as a result of normal handling and use of the instrument. As a rule separate means of adjustment are required for the following: (a) adjustments for rate of movement and linearity of movement of the pointer for a given pressure change; (b) adjustments for the temperature compensation device; and (c) adjustments for zero or zero setting that may be necessary for any purpose, such as to calibrate, re-calibrate, or to reset the instrument when it has drifted from true pressure indications. In the special case of the altimeter-setting indicator the instrument is provided with a screw, usually located in the back of the apparatus, for setting the "elevation dial" which is visible on the front of the instrument (see figs. 6.8.1 and 6.8.2, also sec. 6.8.0).

As a general rule the specifications require that it shall not be necessary to remove any component part of the instrument in order to gain access to the adjusting screw or device. In regard to aneroid instruments used at land stations or on ships it is very desirable that the instrument case be substantially air-tight after zero adjustments are carried out (see the pertinent specifications indicated in Appendix 2.8.1). Under these conditions a tapped hole must be included in the instrument case to permit connecting a tube from the instrument to a static-pressure head (see secs. 2.11.1 and 2.11.2 for reasons which justify such provisions).

The manufacturer is called upon to make all of the necessary adjustments in order to meet the performance requirements as stated in the specifications of the instrument. These requirements generally call for a series of tests, calibrations, and certain guarantees as outlined in the following list: (1) positional tests; (2) scale accuracy at room temperature; (3) temperature compensation; (4) overpressure and underpressure test; (5) case tightness; (6) friction; and (7) aging drift guarantee.

Appendix 2.8.1 presents an example of the performance requirements for a station type, precision aneroid barometer. It briefly describes the tests referred to in the preceding paragraph. See also sec. 6.10.0.

A–2.16.2.5 Field Standardization of Aneroid Indicating Instruments.—In order to standardize an aneroid barometer it is necessary to make a series of comparative observations between the station pressure (P) determined with the aid of a standardized, properly corrected mercury barometer and the simultaneous reading (R_a) of the given aneroid instrument. For any single comparative observation the difference between these two data ($P - R_a$) constitutes, generally speaking, the correction (C_a) which if applied to the reading of the given instrument will yield the true, existing station pressure. When the average of a suitable number of such individual corrections is obtained, it is regarded as the so-called "mean correction," designated by C_{am}. As a rule, it is considered that ten (10) separate observations of C_a spaced over a suitable period of time are necessary as a basis for establishing the mean, C_{am}. An analogous plan is employed in connection with altimeter-setting indicators.

Procedures for the standardization of aneroid indicating instruments are fully described in Chapter 6; wherein sec. 6.7 is concerned with aneroid barometers at land stations, sec. 6.8 with altimeter-setting indicators at land stations, and sec. 6.9 with aneroid barometers on ships.

The reader is advised to consult first of all secs. 6.7.2.1 and 6.8.2.1, which present a summary and an outline of the plan of the program for standardization of aneroid indicating instruments at field stations. In the case of stations which have had such an instrument for a period of less than six (6) months, it is required that the full program as described in Chapter 6 be carried out at the station.

Briefly, the program may be summarized as follows: (1) The making of comparative observations twice daily, at a six-hour interval, for a period of not less than 36 days to determine C_a in each instance; (2) the preparation of a quality-control chart which is designed to give a graphic presentation of the performance of the instrument as indicated by the consistency or variability of the values of C_a plotted as a function of time; (3) the making of calculations to check whether or not there has been excessive drift between the mean of the first fourteen values of C_a and the last fourteen values in a series based on twice-daily comparative readings obtained over a 35 day period; (4) the determination of possible drift by noting the change in mean correction as read off at 29-day intervals from the curve of best fit constructed on the quality-control chart; (5) the checking of the so-called "tail-end drift" by observing whether the last several points on the quality-control chart are very nearly equal in value or whether they are showing a distinct tendency for the corrections to drift on a slope away from the normal horizontal distribution of C_a-points which is found in the typical case of a well aged instrument in first-class working order; (6) the checking of the plotted points of C_a versus time to determine whether there is much or little variability between them in relation to the curve of best-fit on the quality-control chart, considering that an instrument which shows little variability and performs well otherwise is more consistent and repeatable than one with a great deal of variability; (7) calculation of the "mean correction," C_{am}, based on the average of ten (10) values of C_a ascertained on five different days spaced at weekly intervals, where two values of C_a are determined on each of these days at six-hour intervals; and (8) posting the latest values of the "mean correction," C_{am}, near the instrument for use.

An exception to the program outlined in the previous paragraph will be permitted in the case of any aneroid indicating instrument that has been in continuous good working order at a field station for at least six (6) months and that has shown its average correction when checked on a weekly basis over this period to be consistent within a tolerance of 0.2 mb. Under these conditions, step (1) outlined in the previous paragraph may be dispensed with, provided that this is deemed desirable by the local meteorologist or officer in charge, in view of an existing heavy workload, and provided also that there is no reason to suspect any sudden malfunction of the instrument at this time.

When the exception to step (1) is decided upon under these conditions, step *(1) will* be replaced by the following general rule: Pertinent (consistent) values of the individual correction, C_a, will be determined twice daily at six-hour intervals for a period of five (5) consecutive days, and the mean correction, C_{am}, will at first be calculated on the basis of the average of these ten consistent individual values of C_a, provided that the criteria regarding drift and variability laid down in Chapter 6 appear to be reasonably well satisfied by the sample of data.* Under this condition, the mean correction, C_{am}, thus determined may be posted for a period of about one week in conformity with the instructions given in secs. 6.7.2.8 and 6.8.2.1; and the mean correction during this period may be used for correcting the readings of the instrument as shown in secs. 6.7.2.8 and 6.8.2.1. In addition, two determinations of C_a at six-hour intervals will be made at least one day per week for each succeeding week; and for each successive week the mean correction, C_{am}, will be based on the average obtained from the cumulative sum of the individual corrections, C_a, *until a period of five (5) weeks elapses.* Thereafter, the mean correction, C_{am}, will be calculated as illustrated in fig. 6.7.9 on the basis of the average of ten (10) individual values of C_a determined on the last series of five days *spaced at weekly intervals,* with two values being obtained on each of these days (for example, two determinations of C_a every *Sunday,* at the 0600 and 1200 GMT synoptic hours).

All of the foregoing rule is subject to the condition that the criteria regarding drift, variability, etc., specified in secs. 6.7 and 6.8 are satisfied during the given period of operation to the best judgment of responsible officials.

The foregoing rule will apply under the specified conditions in cases where the instrument is re-set by means of an appropriate adjusting screw (see sec. A–2.16.2.6).

It should be understood that the standardization program outlined above and further elaborated in Chapter 6 is a continuing program, intended to remain in effect during the entire life of the instrument at the field station.

A–2.16.2.6 Field Adjustment of Aneroid Indicating Instruments.—As a general rule it is considered desirable for the individual values of corrections C_a determined under the provisions of the instructions in Chapter 6 to be *all* positive and of relatively small magnitude. This is advantageous owing to the fact that there is less likelihood under these conditions of anyone making a mistake in obtaining the algebraic sum of the individual corrections for the purpose of calculating C_{am} as outlined under step (7) in sec. A–2.16.2.5 (see sec. 6.7.2.7 and also fig. 6.7.9 for an example). In addition, there is less chance of a mistake in application of the mean correction, C_{am}, if it is *always* positive, and not sometimes positive and sometimes negative.

It is a recommended practice that the mean correction, C_{am}, for aneroid indicating instruments be maintained within the range from *plus* 0.8 mb. to *plus* 3.0 mb (*plus* 0.024 to *plus* 0.089 inch of mercury). The meteorologist in charge, the officer in charge of the meteorological unit, or the chief observer, if duly authorized by one of the former, may re-set the proper adjustment screw by a slight amount in order to obtain a value of the mean correction, C_{am}, within convenient limits, preferably those specified in the preceding sentence. Careful note must be made of the fact that if any adjustment screw is re-set in order to produce a change in the mean correction, C_{am}, the pertinent instructions regarding procedures of field standardization outlined in sec. A–2.16.2.5 should remain in effect. Thus, when a change in the mean correction, C_{am}, is produced by re-setting of an appropriate adjustment screw, the fact should be indicated on the quality-control chart and on Form WBAN 54–6.6 by pertinent notations. Also, when the mean correction, C_{am}, is changed by such a re-setting, it is important to determine the new value of the mean, C_{am}, on the basis of the individual corrections, C_a, observed *after* the re-setting operation is performed (see next paragraph); and hence it is essential that values of C_a which were ascertained *before* the re-setting operation must *not* be included in the sum of values of the individual cor-

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* During this period of five days the instructions previously in effect may be continued in operation.

rections, C_a, used in calculating the new mean correction, C_{am}, which applies after the re-setting action.

If and when an aneroid indicating instrument is re-set so that the mean correction, C_{am}, will be different after the re-setting than it was before, the provisions of the general rule given in sec. A–2.16.2.5 regarding the determination of the mean correction, C_{am}, will be put into effect as soon as practicable *after* the adjustment is made. In conformity with the general rule, it will require a period of at least five (5) days with twice daily comparative readings at six-hour intervals for a total of ten individual values of C_a before a new value of the mean correction, C_{am}, can be established following the adjustment, provided that the other relevant conditions regarding drift, variability, and reliability are satisfied. However, if the specified conditions are not satisfied, it will be necessary to revert to the full program as stipulated in Chapter 6.

Field personnel should note that a difference exists between the proper methods of re-setting aneroid barometers and altimeter-setting indicators. Thus, with regard to the aneroid barometer, the instrument is re-set by means of the zero adjustment screw. However, with respect to the altimeter-setting indicator, the instrument is to be re-set in the field, if necessary, only by means of the adjustment screw which controls the indication of the "Elevation Scale" (in feet) visible on the face of the device. (The design shown in fig. 6.8.1 has the adjustment screw for the elevation scale in the back of the case; whereas the design presented in fig. 6.8.2 has the screw projecting from the lower portion of the face of the instrument.) When the adjustment screw is turned, it causes the entire interior mechanism of the instrument to rotate so that both the main needle and the "elevation scale" on the face of the apparatus will rotate about the central axis.

When it is desired to cause the instrument to yield a value of the mean correction, C_{am}, falling within the limits from plus 0.8 to plus 3.0 mb., this should be done by making use of the pertinent adjusting screw specified in the preceding paragraph. Thus, in the case of the altimeter-setting indicator, this signifies that the adjustment screw will be turned, as required, to secure the desired value of C_{am}; thereby also causing the indication on the "elevation scale" to change. It is permissible for the indication on this scale to differ from the actual elevation of the instrument by as much as 100 feet. If the difference exceeds this amount, the facts should be reported to the appropriate headquarters.

As soon as practicable after it is found that the indication of the "elevation scale" exceeds 100 feet, an effort should be made to take special comparative readings under pressure conditions which deviate widely on either side from the average at the station. By an investigation of the individual values of the correction, C_a, thus determined for both relatively high and low pressure conditions, it should be possible to ascertain whether the respective values of C_a under these extreme conditions depart significantly from the mean correction, C_{am}, and from each other. In cases where these departures are found to be significant, it is considered desirable to take the given altimeter-setting indicator out of service, and to replace it with an instrument that will provide satisfactory performance.

A–2.16.2.7 Quality Control of Aneroid Indicating Instruments.—The quality-control chart is designed to provide a graphic history of the behavior of the instruments as revealed by the variations of the individual corrections, C_a, with time. The relevant instructions in sec. 6.7.2.2 and 6.7.2.9.3 regarding preparation of this graph will be understood as indicating that the chart will be continued during the service life of the instrument at the station. By inspecting the data plotted on a quality-control chart one can tell at a glance a good deal regarding the quality of the performance of the instrument to which it refers. All field personnel concerned with the quality of the pressure data reported by the station should therefore keep the quality-control chart under scrutiny at least once each week or more often, if there are any indications of instrument malfunction. Details regarding the criteria by means of which one can judge the quality of the data as revealed on the chart are presented in secs. 6.7.2.2—6.7.2.6 and 6.7.2.9.4—6.7.2.9.8.

A–2.16.2.8 Posted Correction for Aneroid Indicating Instruments.—The mean correction, C_{am}, determined in accordance with the instructions in secs. 6.7.2.7 and 6.8.2.1, will be posted on a *current* basis in conformity with the provisions of secs. 6.7.2.8 and 6.8.2.1. Whenever any doubt arises concerning the validity of the mean correction, C_{am}, entered on "Posted Correction Card," an appropriate note should be written on the card. Measures to determine the cause of the trouble must be instituted as soon as practicable after the appearance of the first clear sign of excessive deviation of the instrument from good performance, judging by the criteria referred to in sec. A–2.16.2.7. Care must always be taken to indicate the proper algebraic sign of the mean correction, C_{am}, on the "Posted Correction Card," and on Form WBAN 54–6.6.

Examples of the application of the mean correction, C_{am}, are given in secs. 6.7.2.8 and 6.8.2.1.

A–2.16.2.9 Temperature Corrections for Aneroid Indicating Instruments.—In many instances the manufacturer calibrates the instrument at room temperature, often at about 75° F. The temperature compensation device referred to in Appendix 2.8.1 is usually adjusted so that the corrections necessary owing to departure of instrument temperature from 75° F. are relatively small within the normal operating range of pressure of the apparatus. Fig. A–2.21.8(b) illustrates a calibration curve for scale error of a precision aneroid barometer obtained at room temperature. At the bottom of fig. A–2.21.8(a) there is shown an example of the pertinent temperature correction curve for the same instrument. The ordinate of this curve represents a factor which when multiplied by (t° F. — 75° F.) yields the correction of the reading for departure of instrument temperature from 75° F. Fig. A–2.21.9 illustrates a similar type of curve for a different design of aneroid barometer. On the other hand, fig. 2.9.5 shows sets of scale calibration curves for an aneroid barometer obtained within a pressure chamber maintained at three different respective constant temperatures, namely at 80° F., 40° F., and 0° F. (t = aneroid temperature).

When aneroid indicating instruments are used for work of the highest precision such as in checking other barometers or in surveying, the appropriate correction for temperature of the instrument should be applied. (See sec. 2.9.3.2.6.)

A–2.16.2.10 Care and Maintenance of Aneroid Indicating Instruments.—Such instruments occasionally require to be cleaned on the outside with a soft, damp cloth, and then dried, in order to remove any dust or grime that may collect. *Under no circumstances should anyone, except possibly in a suitably equipped laboratory, endeavor to lubricate an aneroid indicating instrument.* Tampering with the instrument should never be permitted. In case an instrument malfunctions it should be taken out of service and relevant facts reported to headquarters.

When a static-pressure head is connected to the instrument, moisture may sometimes collect in the system. This liquid together with any associated solid suspended material must be drained out of the static pressure system by means of a plenum chamber provided at the lowest point of the connecting line (see sec. 2.11.1).

A–2.16.2.11 Moving of Aneroid Indicating Instruments.—When an aneroid indicating instrument used at a station is moved from one site to another by hand, two series of comparative readings should be made with reference to another barometer, preferably a standardized, properly corrected mercury barometer. One series is required shortly before the move is made, and the other series is required at the terminal point where the instrument is to be installed. The latter series should be begun only after the instrument has been in its new environment at the terminal point for a sufficient length of time to permit the instrument to come to temperature equilibrium with the surroundings. In general, five comparative observations should be made in each series, spaced generally at 15 or 30 minute intervals. (Note secs. 2.2.7.0, A–2.16.1.8, 6.5.2, 6.5.4, and 6.6.0; also Form WBAN 54–6.3 regarding "Comparative Barometer Readings."

Pertinent instructions are given on the reverse side of the form; see figs. 13.6.2 and 13.6.3.) If two different mercury barometers are used for comparative purposes at the two sites, their deviations should be taken into account.

Care must be taken during the move to avoid subjecting the instrument to jolts.

If the results of the comparisons obtained before and after the move reveal that the mean correction, C_{am}, has not been significantly altered by the move (within 0.1 or 0.2 mb.), the same mean correction as was in effect before the move may be reinstituted in use after the move. However, in every case the general procedures outlined in sec. A–2.16.2.5 with regard to the standardization of aneroid barometers and altimeter-setting indicators must be resumed in accordance with previously given instructions. In cases where there has been a marked change in the correction (greater than 0.2 mb.) as a result of the move, the instrument should be taken out of service, and the relevant procedures specified in Chapter 6 should be put into effect, as though the instrument were newly received at the terminal point (station at new location).

A–2.16.2.12 Packing and Shipping of Aneroid Indicating Instruments.—The relevant instructions contained in sec. A–2.21 will apply.

A–2.16.3 Installation, Maintenance and Operation of Barographs at Land Stations

A–2.16.3.0 Introduction.—The instructions published in Technical Manuals by the respective agencies or Services with regard to the maintenance of barographs should be followed. Manufacturers of barographs also prepare instruction books or pamphlets dealing with this subject which provide extremely valuable material. The information contained in these booklets consistent with the relevant instructions issued by the pertinent agency or Service can generally be considered as a useful guide to field personnel. Whenever the agency or Service directs that the instructions in these latter booklets be put into effect for the particular equipment, such directives should be followed in accordance with established policy.

Since equipment constructed by different manufacturers varies in regard to mechanical details, it is not possible to give here a complete set of instructions for the maintenance of barographs which will be equally suitable for all makes. However, it is possible to give certain general instructions which are likely to apply in most cases, as indicated in the following.

A–2.16.3.1 Protection Against Mechanical Damage and Extreme Temperature Variations.—In order to avoid injury to the delicate mechanism of barographs they should not be subjected to jars, jolts, or any mechanical shock. If necessary for the safeguarding of the instruments at installations of the type that may be subject to severe mechanical shock, it is recommended that the barograph be fastened securely on a shock-insulating mount (see sec. A–2.21.0).

Barographs are preferably installed at a location where a fairly uniform temperature is maintained. The site should not be subjected to extreme temperature variations such as might be due to direct exposure to sunshine, currents of warm air from ducts or radiators of heating systems, and drafts.

A–2.16.3.2 Cleanness and Dryness of Barograph.—Barographs must be kept clean and dry to assure proper operation. Therefore, the case of a barograph should be kept tightly locked except when necessary to have it open for some useful purpose, such as changing the chart, making adjustments, etc. In order to remove any dust that may accumulate within the instrument, and especially on the working parts, a clean, soft camel's-hair brush should be used with great care. As a rule it is desirable to employ the brush for such cleaning purposes at least every month. In regions where there is an abnormal amount of dust or atmospheric pollution, more frequent cleaning may be necessary.

It is essential to avoid exposure of barographs to excessive moisture since this may lead to condensation within the mechanism and possibly rusting of certain parts. These conditions are obviously undesirable owing to the fact that they may impair the equipment, cause increased friction in the clockwork, and perhaps eventually produce a stoppage.

A–2.16.3.3 Cleaning Pen.—Under normal operating conditions the pen should make a fine, clear line. If it does not do so, the pen ought to be cleaned, preferably at a time when the chart is to be replaced.

The following steps should be taken:

(1) A piece of cellophane or paper that does not yield lint (such as chart paper) may be drawn between the nibs of the pen in order to remove any solid deposits. While doing this one should be careful not to bend the nibs or to allow any particles of paper or other material to remain between them. Then the pen may be inked and tested to determine whether it performs satisfactorily.

(2) In case step (1) does not enable the pen to produce a fine, clear line, the pen should be removed from the pen arm and cleaned. When removing the pen, the pen arm is held with the right hand while the pen is pulled horizontally to the left with the left hand. In carrying out the various operations, great care must be exercised to assure that neither the pen nor the pen arm is bent, deformed, or otherwise damaged. Strain to the mechanism must be avoided at all costs. Any dried ink which is on the outside of the pen should be lightly scraped off. Under ordinary conditions of pen cleanliness, the pen should next be thoroughly washed in warm, soapy water, then rinsed in clean tap water. However, if the dried ink is heavily caked on the pen, especially within its barrel, the process of washing in warm water may not be sufficient to remove all of the dried ink. In that case it is advisable to wash the pen in denatured alcohol first, followed by a washing in a warm, soapy water and a rinse in clear tap water. Finally, the outside of the pen is dried with a clean cloth; and the inside of the pen is also dried by drawing a piece of clean, lint-free paper between the nibs. Washing and cleaning of the pen in the foregoing manner is generally recommended as a routine at intervals of about four months, unless experience at the station reveals that a shorter interval is desirable.

(3) The pen should be examined to check whether the writing points fit tightly together, as they ought to for good performance. If the points are excessively worn, it is desirable to substitute a new pen for the old one.

(4) In order to replace the clean pen on the pen arm, the pen arm is held with the right hand to protect the tilted axis from strain while the pen is installed on the pen arm and seated against the shoulder on the latter. While doing this operation the precautions mentioned under (2) must be taken.

(5) Finally, the pen should be inked in accordance with the instructions given under sec. 6.10.1.13, paragraph (10). A little test should be performed to check that it yields a fine, clear-line trace, in which event normal operation of the barograph should be resumed.

A–2.16.3.4 Care of Clock and Chart Cylinder Drive

(*A*) *General precautions*

(1) Clocks must be safeguarded against mechanical shocks either due to external forces or inertia. Extreme care must therefore be taken never to drop a clock as this may do irreparable injury to the clock movement.

(b) When the proper time arises for the clock to be wound (as at the moment of changing the chart under normal conditions), the observer should see to it that the winding of the mainspring reaches the point of completion; *but he should take care to stop winding just as soon as the resistance of the mainspring is felt to become hard.* If any effort is made to wind the mainspring beyond this point, damage to the clock is likely to result.

(3) No clock should be exposed to excessive moisture, dust, or pollution. These things can cause condensation and formation of rust within the mechanism, clogging of the delicate movement, and friction of such degree as may produce complete stoppage.

(4) It is undesirable to have any clock exposed to extremes of either high or low temperature, owing to the fact that such conditions have an adverse influence on the lubricants used, on the friction between

gears in the movement, and on its general operation.

(5) Only fully qualified watch repairmen are authorized to do the work of cleaning, oiling, adjusting, and repairing the clocks of delicate and important instruments like barographs. Station personnel should not attempt to perform any of these operations. (See Part (C), "Periodic Cleaning and Oiling of Clock," hereunder.)

(*B*) *Regulation of clock.*—If the clock runs significantly fast or slow, it is possible to regulate it at the station. The method of regulation depends upon the type of clock mounting, there being two different ones. In the first type the clock is mounted inside the cylinder; that is, the clock is housed in a fixed manner within the chart drum; hence this type will be designated by the term "integral clock." Fig. A–2.21.10 illustrates the older class of barograph which has this type of chart drum and clock assembly. However, in the newer class of barograph illustrated in fig. 2.9.1, a second different type of clock mounting may be used; namely, one in which the clock is installed directly on the base of the barograph, fastened by means of screws which engage on three ears that project from the foot of the clock housing. In the latter case, the chart drum rests on the clock housing and is caused to rotate by the action of the spindle (main shaft) which is turned by the clockwork. Therefore, we shall employ the term "separate clock" in referring to the type of clock which is mounted individually on the base in the category of barograph shown in fig. 2.9.1.

Observers are cautioned never to remove an "integral clock" from inside its chart drum. Neither should they endeavor to oil any type of clock movement, for this operation must be left to an expert watch repairman.

With special reference to the "integral clock," it may be pointed out that a stainless steel regulator arm for making an adjustment of the clock rate will be found beneath a little, round sliding window which is visible near the winding key on top of the clock housing within the chart drum.

However, with special reference to the "separate clock," it will be observed that the clock must be first removed from the base of the instrument after unscrewing the three screws which hold it in place, and then the regulator arm will be found within the threaded hole covered by the large, slotted screw plug on the bottom of the clock housing.

Since the arrangements for regulating the "integral clock" are different from those for regulating the "separate clock," two sets of instructions for on-station regulation are given below, under (I) and (II), one for each of these types of clocks, respectively.

(I) INSTRUCTIONS FOR REGULATION OF "INTEGRAL CLOCK"

In cases where the clock runs too fast or slow to a noticeable degree the following procedure will be used for regulating the rate of a clock mounted in a fixed manner within the chart drum:

(1) Open the little, opaque window on top of the clock housing. This is done by a sliding motion of the pin that projects from the window. After the window is slid open, the regulator arm will be visible within the round opening.

(2) While making an adjustment of the regulator arm with the aid of a suitable, fine implement, extreme care must be taken neither to let the implement slip in any manner nor to exert too much pressure, keeping in mind that a slip of the tool into the clock mechanism or an application of excessive force will do irreparable damage. By means of a long, fine implement such as a thin screwdriver, the regulator arm should be moved toward FAST if the clock has been running slow, or toward SLOW if it has been running fast. It may be kept in mind when making this adjustment that in many of the clocks a shift of the regulator arm by a single graduation will cause a change in rate of about 3 minutes per day.

(3) After the operation outlined in step (2) has been completed, the sliding window should be closed.

(4) Following the return of the barograph to normal operation, its rate should be checked over a period of weeks by comparison against an outside clock of known accuracy.

(II) INSTRUCTIONS FOR REGULATION OF "SEPARATE CLOCK"

With regard to cases where the clock runs too fast or slow to a noticeable degree the following procedure will be employed for regulating the rate of a clock mounted directly on the base of the barograph (category shown in fig. 2.9.1):

(1) Remove the chart drum in accordance with the instructions given in sec. A–2.16.4.6, paragraph (3).

(2) By means of a screwdriver, remove the three screws which hold clock movement as a whole on the base of the barograph.

(3) Remove the large, slotted screw plug from the bottom of the clock movement housing; and note the small, shiny regulator arm within the threaded hole from which the plug was unscrewed.

(4) If the clock rate has been too slow, carefully push the regulator arm toward the graduation marked F (or FAST); whereas, if the clock rate has been too fast, carefully push the regulator arm toward the graduation marked S (or SLOW). Use a fine implement, such as a small screwdriver to do this. In case the rate is tested and adjusted with the aid of an electronic timer such as that employed by expert watch repairmen, it is necessary to set the clock so that its operating rate on the timer is *fast* by the amount of 9 seconds per hour (45 beats per hour). The reason for doing this is explained following paragraph (8) below. When adjusting the regulator arm, care must be taken not to let the implement slip. The clock should be handled on a surface so that it will not drop.

(5) Replace the large, slotted screw plug by threading it into the appropriate hole in the bottom of the clock movement housing.

(6) Mount the clock movement on the base of the barograph, and fasten it in place by means of the three screws which had been removed in accordance with step (2).

(7) Replace the chart drum on the spindle of the barograph in accordance with the instructions given in sec. A–2.16.4.6, paragraph (9).

(8) Following the return of the barograph to normal operation, its rate should be checked over a period of weeks by comparison against an outside clock of known accuracy.

Sometimes there arise emergencies with regard to the functioning of the clock movement of the barograph, such that time is not available to get a replacement chart drum assembly from the depot or instrument laboratory, where it becomes essential to employ a local expert watch repairman to service the clock with a view to getting it back into operation quickly. In situations of this kind it is generally advisable for the watch repairman to clean, oil, repair, and regulate the clock insofar as practicable. As a rule the watch repairman will make use of an electronic timer for the purpose of regulating the clock; and when this is the case he should be informed of the following facts:

Information for Expert Watch Repairman.—When regulating the clock by means of an electronic timer, it should be timed 9 seconds fast per hour. The purpose of this is to permit the clock movement to yield the required rate after the chart drum assembly is in normal operation, since the effect of the gearing is to slow it down in comparison with the rate which it has when the chart drum is separate from the barograph. Accordingly, the escapement of the clock has been designed with a view to overcoming this effect as may be seen from the technical explanation given below:

The escapement regulates and times the rate of unwinding of the mainspring barrel through the train of gears. This escapement beats 45 beats faster per hour than the usual timepiece, which is timed to five beats per second. The standard rate is 18,000 beats per hour, as against 18,045 beats per hour for the special clock mechanism used on these instruments. This should be kept in mind when using a standard rate recorder, since the instrument chart will show an *apparent* gain of 1080 beats or 216 seconds per day. This slightly higher speed, however, is necessary to turn the cylinder at the required rate of rotation.

(*C*) *Periodic cleaning and oiling of clock.**—It is a recommended practice that

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* Observers should understand that they are not to take the clock out of the chart cylinder assembly. Therefore, when they have to ship one to an equipment depot or instrument laboratory for any maintenance work, it will be understood that they will forward the entire chart cylinder assembly containing the clock in its proper fixed position within the drum.

the barograph clock be sent about every 18 months, or more often if found necessary, to an appropriate equipment depot or regional headquarters for cleaning and oiling of the clock movement by qualified, expert watch repairmen. In an emergency this work might be done by a local, qualified, expert watch repairman. Personnel at stations are not authorized to undertake this type of maintenance, unless they are classified under the category of expert watch repairmen. Experience has revealed that the clocks which are periodically cleaned and oiled on a regular schedule as outlined above give better service and have a longer life than those not given such good maintenance care.

Before any instrument clock is shipped to an equipment depot or regional headquarters it is necessary to have a replacement on hand in order to assure continuous operation of the barograph. When an official wishes to request a replacement clock from such a source, he must take care to notify the depot or regional headquarters regarding the proper instrument designation, equipment model number, name and model number (or stock number) of component needed, and the purpose for which it is required. Depots and regional headquarters keep on hand a stock of spare chart cylinder assemblies (including clocks) in order to be able to fulfill such requests.

Various agencies provide Technical Manuals and/or Equipment Allowance Lists which give the appropriate nomenclature and stock item numbers pertinent to the components for the meteorological equipment under consideration. Information regarding the proper terminology, model numbers, stock item numbers, etc., for the components may be determined from such sources, if these facts are not known to the station personnel.

If a spare chart cylinder assembly including clock in good working order is available at the station, or if a replacement of this kind is received from the equipment depot or regional headquarters, the new chart cylinder assembly should be installed in the barograph at an appropriate time. Action should then be taken to have the original chart cylinder assembly, containing the clock that requires maintenance work, carefully packed and shipped to the pertinent depot or headquarters for cleaning, oiling, and repairs if necessary.

Station personnel should never attempt to repair a clock movement or to adjust it in any manner, except to regulate it for time rate as described above under paragraph (B), "Regulation of Clock." *A clock movement which is integral with the chart cylinder should never be removed from its cylinder at the station, since this is a matter which must be left to the skilled hands of an expert watch repairman.*

The type of clock oil to be used by the watch repairman for the appropriate lubrication of the clock movement should conform to Fed. Spec. Mil–O–11734 (Ord.).

(*D*) *Procedures for clock replacement.*—As previously explained, the clock in the land-station barograph is contained within the chart cylinder assembly and is not to be removed from the cylinder by station personnel. Therefore, so far as station personnel are concerned the main point under consideration here is the replacement of the old chart cylinder assembly with a new chart cylinder assembly whose clock is in good working order. Following this the old chart cylinder assembly is to be packed and shipped to an appropriate equipment depot, regional headquarters, or instrument laboratory for the required maintenance work. It may be noted that some agencies (for example, the U.S. Army Signal Corps) have in the past required that the original main shaft (spindle) together with its attached stationary gear be removed from the barograph in order to permit it to be shipped to the equipment depot with the chart cylinder assembly. Such action is not required by the U.S. Weather Bureau, although other agencies do so by specific directives. In cases where the main shaft is removed for such shipping purposes, the new chart cylinder assembly will be supplied with its own main shaft when delivered from the depot.

Apart from the matter of mere replacement as indicated above, attention must also be given to questions regarding the proper meshing of gears and the control of backlash. With reference to these points, the pinion which is mounted on the cylinder bottom plate must mesh properly with the stationary gear which is located at the foot of the spindle (fixed main arbor, or main shaft) that projects vertically up from the base of the barograph. If there is an excessive amount of backlash or friction owing to the fact that the pinion does not mesh properly with the stationary gear (for example, when the distance between centers of these two gears is too great or too little, respectively), it is necessary to make a careful adjustment of this distance. Before such an adjustment can be made, it is necessary to remove the spindle together with its stationary gear from the base of the instrument and to adjust the pinion with relation to the stationary gear while the chart cylinder assembly is separate from the barograph. See paragraphs (1) to (5) below for details.

The pertinent method for removing the spindle together with its stationary gear depends upon the design of the barograph. Thus, if the barograph is one of the older design illustrated in figs. 2.9.0 and A–2.21.10, first of all the base cover must be taken off by removal of the screws from underneath the base.† Then, the main arbor wingnut must be unscrewed from its place on the threaded portion of the spindle which projects down from underneath the base. Care must be taken to save all washers and replace them in proper positions when reassembling the equipment. On the other hand, if the barograph is one of the newer design illustrated in fig. 2.9.1, the wingnut may be unscrewed directly, since this design does not have a base cover underneath the bottom of the spindle.

When it is necessary to remove the spindle from the older design of barograph illustrated in figs. 2.9.0 and A–2.21.10, special precautions must be taken not to spill the fluid from the dashpots. Such spilling may be avoided if one person holds the instrument upright in an elevated position while another person removes the screws which hold the base cover underneath the main body of the barograph. Care should be taken not to tilt the instrument at an angle of more than 45° since this might permit the fluid to spill out of the dashpots. These precautionary measures must be observed both when removing the base cover and spindle; and also when re-installing these components.

Details regarding the procedures for replacing the chart cylinder assembly are stated in the following steps:

(1) Move the shifting lever to hold the pen away from the chart.

(2) Lift the old chart cylinder assembly vertically up from the spindle.

(3) Replace the old one with a new chart cylinder assembly whose clock movement has been cleaned and oiled, or is entirely new. In doing this, the new cylinder is lowered on the spindle and it is necessary to exercise care to have the pinion on the chart cylinder bottom mesh with the stationary gear on the base.

(4) Check the backlash and the friction between the pinion and the stationary gear. One method of performing this check is to rotate the cylinder to some extent in either direction, say first clockwise and then counterclockwise; thus determining whether the mesh is too loose, too tight, or tolerable. It is necessary to allow a little backlash, usually the equivalent to 5–15 minutes of chart time, in order to avoid excessive friction or tightness between the gears. Thus, backlash of this order is tolerable, but much more than the equivalent of 15 minutes is regarded as too much. At the same time the gears must mesh in a normal manner without their being squeezed so tightly together at any point that a clock-stoppage could be caused by the friction. If either the backlash or the friction is unsatisfactory, an adjustment of the pinion position to rectify this matter must be undertaken in accordance with the instructions given in the following steps:

(5) In case the backlash or the friction between the gears is excessive, steps (a)–(h) given below will be pursued:

(a) Lift the chart cylinder assembly up from the spindle.

(b) If the barograph has a base cover underneath the spindle, remove the base cover by taking out the screws beneath

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† With regard to some makes of barograph it should be noted that the screws which hold the base cover fastened to the bottom of the instrument are located within rubber feet on the four corners.

the base, then unscrew the wingnut from the bottom of the spindle, and lift the spindle with its attached stationary gear from the base, taking care to save all washers including one large and one small relating to the spindle. But, if the barograph is of the newer design without a base cover underneath the spindle, the wingnut which holds the spindle in place is to be immediately unscrewed, and the spindle lifted up as indicated before.

(c) Reassemble the washers and the wingnut on the bottom of the spindle. Insert the spindle in the cylinder from the bottom of the latter until the pinion meshes with the stationary gear.

(d) While holding the spindle and cylinder in this manner, bottom end up, over a table, just barely loosen the three screws found on the bottom of the cylinder *but be careful not to remove them completely.*

(e) By using the thumb and forefinger push the pinion *gently* together with the stationary gear in order to engage them at the proper relative distance between centers; then tighten the three screws. When this step is properly done, the gears will mesh in the correct relationship, there will be very little backlash, and the friction between the gears should be appropriate for normal operation, without likelihood of the clock being stopped owing to an undue amount of pressure between them at any position.

(f) Remove the spindle together with its stationary gear from the cylinder, unscrew the wingnut from the thread on the bottom of the spindle, and install the spindle in its proper place on the base of the barograph. When performing this latter step, the large washer must be put into position centered over the hole in the base and the stationary gear must rest on this washer when the spindle is properly seated. Finally, the small washer must be put over the threaded end of the spindle ahead of the wingnut when the latter is screwed up tight underneath the base to hold the spindle mounted in its normal, proper position.

(g) If the barograph is of the type equipped with a base cover to go below the bottom of the spindle underneath the base, fasten this base cover back into place by means of the screws and washers originally removed.

(h) Perform steps (3) and (4) as indicated above, in order to re-install the new chart cylinder assembly and to check its operation.

(*E*) *Special gears to change rate of cylinder rotation.*—Certain special projects require the use of speeded-up rates for the rotation of the cylinder, instead of the conventional rate of 4 days per revolution which is generally employed at regular synoptic stations. For example, it is sometimes necessary for special projects to use rates of 12 hours or 24 hours per revolution. When this is the case, the normal operating procedure is to have the appropriate instrument laboratory provide a complete chart cylinder assembly already equipped with the proper pinion and stationary gear which will yield the required rate of rotation of the chart drum; and at the same time a supply of suitable barograms is issued pertinent to the specified rate (see sec. A–2.16.3.9).

However, there may sometimes be circumstances under which the normal operating procedure is not carried out, where it will be necessary for personnel at the station to change the pinion and stationary gear locally in order to obtain the required rate of cylinder rotation pertinent to the given special project. The following steps may be employed by field personnel when and if they are called upon to change the pinion and gear for the reasons outlined above:

(1) Move the shifting lever to hold the pen away from the chart.

(2) Lift the available chart cylinder assembly vertically up from the spindle, and turn it bottom end up in order to perform the succeeding steps.

(3) By means of a pair of pliers very carefully remove the fine wire at the top of the 108 hour pinion.

(4) Remove the upper washer.

(5) Remove the 108 hour pinion, but in doing so one should bear in mind that it may require a slight twisting motion and at the same time a pulling away of the pinion from the shaft until it slides free.

(6) Install the new pinion appropriate to the required rate, doing this in the reverse order to which the old, 108 hour pinion was removed. This new pinion is to be placed on the so-called "daily shaft," making sure that it is sufficiently tight on the shaft to drive the clock. In this connection one should note that the pinion is slotted; hence if it is not tight enough on the shaft, one may cause it to increase its tightness by producing a slight squeeze at the base of the pinion with the aid of a pair of smooth pliers.

(7) Remove the old stationary gear from the spindle, and replace it with the new stationary gear which if appropriate must have stamped on it the same identification number and letter as was stamped on the new pinion (for example, 12E or 24E, depending upon the number of hours per revolution of the cylinder produced by the use of the given combination of pinion and gear).

(8) Adjust the relationship between the new pinion and stationary gear in order to secure a proper mesh between them, if there is either excessive backlash or friction, as indicated under the provisions of paragraphs (4) and (5) of subsection (*D*).

After the foregoing operations have been properly performed, the chart cylinder assembly and the spindle together with its pertinent stationary gear should be ready to place back in the barograph in accordance with the relevant instructions previously given for such installations (see subsection *D* above, which deals with "Procedures for Clock Replacement").

A–2.16.3.5 Lubrication.—The clock movement is to be cleaned and oiled by an expert watch repairman at certain regular intervals as recommended in the foregoing discussion under the caption "Periodic Cleaning and Oiling of Clock." *However, the remainder of the barograph should never be oiled,* for the special pivots and bearings of the instrument mechanism are designed to operate without lubrication. The use of oil in this mechanism has to be avoided owing to the fact that oil tends to cause the collection of dust and other pollution from the environment, which act to produce an increase of friction between moving parts, thereby reducing the sensitivity of the barograph. In order to avoid these and other harmful effects, station personnel are cautioned *not* to apply any oil to the equipment.

A–2.16.3.6 Dashpots and Damper.—The older types of 2.5–1 barograph illustrated in figs. 2.9.0 and A–2.21.10 are equipped with dashpots which require the use of a special, suitable fluid. For purposes of good operation it is desirable to keep the level of the fluid about 3/8 inch below the top of the dashpot. An eyedropper may be used to add fluid when necessary to maintain this level, or to remove any excess. It is desirable that the fluid *not* be of a type which absorbs water vapor, since fluids which have an affinity for moisture tend to become diluted and thereby lose much of their effectiveness. The special fluid must be characterized by a suitable degree of viscosity over the entire range of temperature and humidity to which it might be exposed.

When initially filling the dashpots with the special fluid, the dashpot covers must be first lifted up and then slipped over the lever arms to hold them temporarily. After adding fluid until the level is about 3/8 inch below the top of the dashpot, it is necessary to move the dashers up and down slowly until all air is excluded. Then, the dashpot covers should be replaced. It is essential for the dashers to be completely covered with the special fluid at all times. If the dashpots are properly maintained in accordance with the foregoing instructions, they function in such a manner as to damp out effects of vibrations and of minor fluctuations of pressure such as those caused by slamming of a door, gusts of wind, etc.

The newer type of 2.5–1 barograph illustrated in fig. 2.9.1 is not equipped with dashpots, but rather it is provided with a damper. This mechanism has a hollow cylinder, mounted on the shaft, which rotates about another cylinder as the shaft turns. A small amount of high viscosity silicone fluid is employed within the space between the two cylindrical surfaces, and the effect of this fluid is to yield the desired damping action. It is expected that under normal operating conditions it will rarely if ever be necessary to replenish the silicone fluid in the damper during the lifetime of the instrument in the field. Whenever it is found essential to change the damping, use must be made of the relevant information on the subject given by the manufacturer of the barograph in a pamphlet entitled "Instructions for Installation, Operation, and Maintenance of Microbarograph," a copy of which is supplied to stations with each instrument. For further information regarding regulation of the damper see sec. A–2.16.4.10.

It is conceivable that under persistent conditions of severe atmospheric pollution, dust, and sand that an excessive degree of friction will develop due to dirt which has collected in the damper mechanism. If the marked friction is traced positively to this source, it is recommended that the barograph be sent to the appropriate instrument depot or laboratory for overhaul, after a replacement barograph is at hand to permit the obtainment of continuous pressure records at the station. At the instrument depot or instrument laboratory a skilled mechanic will be able to clean the damper and refill it properly with high viscosity silicone fluid.

A–2.16.3.7 Protection Against Moisture and Fungi.—Barographs should be operated under reasonably dry conditions such as those which prevail in ordinary meteorological offices. If the instruments are given a prolonged exposure to high temperatures and humidities (for example, under tropical or sub-tropical conditions), they are likely to suffer from ill effects due to the excessive moisture and the action of fungi. Therefore, such exposures should be avoided.

A–2.16.3.8 Laboratory Adjustment and Recalibration of Barographs.—Whenever it is found at a field station that the barograph is not giving good performance (see sec. 6.10.0), action should be taken to secure a replacement from an appropriate instrument laboratory or depot, and then to ship the impaired barograph to the pertinent laboratory or depot for overhaul.

The following brief list indicates the kind of steps taken at the instrument laboratory or depot to bring the barograph into good working order:

(a) Replace all damaged or worn-out parts.

(b) Replace the clock-movement, if necessary.

(c) Clean and oil the equipment in accordance with good instrument practice.

(d) Make a preliminary calibration of the barograph in a pressure chamber and adjust its mechanism so that it will yield practically a linear performance (see sec. 6.10.0).

(e) Test the barograph in a chamber whose temperature can be varied under controlled pressure conditions, and adjust properly the temperature compensation device of the instrument so that its indications will not be unduly affected by temperature variations.

(f) Calibrate the barograph in a pressure chamber, taking great care to adjust the mechanism precisely in order that it will give a linear performance. Check the overall operation of the apparatus.

(g) Re-paint and refurbish the equipment wherever necessary.

A–2.16.3.9 Selection of Barograph Charts.—Charts for 2.5–1 barographs are printed to cover a range of 2.5 inches of mercury or 85 mb.

As a general rule, barograms should be selected on the basis of the principle that the pressure value pertaining to the point midway on the printed vertical scale of the chart should be most nearly equal to the normal (or mean) annual pressure at the location of the barograph. By referring to Table 3.3.3, the observer or meteorologist in charge will find data which will permit him to estimate the normal, annual station pressure at various localities. If the foregoing principle is properly used as a guide in choosing barograms, it will assure that when the existing station pressure is equal to the normal annual value pertinent to the given location, the trace will run about midway on the vertical scale of the chart; while the available pressure range on the barogram will allow for a deviation of approximately 1.25 inches of mercury from the normal, annual value.

The following table indicates the form numbers and descriptions pertaining to the various barograms:

Form numbers and descriptions of various barograms

Form No.	Time covered by one rotation	Pressure indication			Use
		At top of chart	Midway of chart	At bottom of chart	
		Value (mb.) or decimal (in. Hg)			
WBAN 54-2.9.1	4 days	1050 mb.	1005 mb.	965 mb.	Ship
WBAN 54-2.9.2	4 days	0.50 in. Hg	0.25 in. Hg	0.00 in. Hg	Land
WBAN 54-2.9.3	4 days	0.00 in. Hg	0.75 in. Hg	0.50 in. Hg	Land
WBAN 54-2.9.4	12 hours	0.50 in. Hg	0.25 in. Hg	0.00 in. Hg	Land
WBAN 54-2.9.5	12 hours	0.00 in. Hg	0.75 in. Hg	0.50 in. Hg	Land
WBAN 54-2.9.6	4 days	50 mb.	7.5 mb.	65 mb.	Land

Pressure values omitted from the printed scale on the barogram will be filled in by the observer as may be appropriate to the given station. All entries should be in ink; for example, enter 30, 29, etc., preceding printed 0.00 in. Hg, at suitable points on the scale, as illustrated in fig. 6.10.0.

The system of form numbers employed in this Manual of Barometry with reference to barograms differs from that previously used; hence, to assist in correlating the same forms under the new and old Weather Bureau designations, the following list is provided: (1) WBAN 54–2.9.1 = WB Form 455–12; (2) WBAN 54–2.9.2 = WB Form 1068C; (3) WBAN 54–2.9.3 = WB Form 1068D or WB Form 455–17; (4) WBAN 54–2.9.4 = WB Form 1068E or WB Form 455–18; and (5) WBAN 54–2.9.6 = WB Form 1068G.

Information which supplements that given above with reference to the selection of barograms will be found in the WBAN Manual of Surface Observations, Circular N, Chapter 7, on "Pressure."

The following specific instructions apply to the various services with regard to the selection of barograms:

WEATHER BUREAU STATIONS: Use the foregoing principle as a guide in choosing the appropriate barogram, taking account of the information given in the table and in Chapter 7 of Circular N.

AIR FORCE STATIONS: Use Chart ML–236, unless specifically requested to use Form WBAN 54–2.9.4 (that is, WB Form 1068E) for 12-hour records on the barograph.

NAVAL STATIONS: Use Chart Stock No. R 7640–324–1687–HO35.

A–2.16.3.10 Disposition of Barograms.—Completed barograms should be forwarded monthly in accordance with the relevant instructions on the subject given in the latest edition of WBAN Manual of Surface Observations, Circular N.

A–2.16.3.11 Application of Barograph Correction.—In harmony with the definition of the barograph correction given in sec. 6.10.1.1, the latest pertinent barograph correction is to be applied *algebraically* to the current barograph reading in order to obtain the current value of the station pressure. That is, if C = barograph correction, R = reading of barograph, and P = station pressure, then

$$P = R + C.$$

It is essential to take into account the proper algebraic sign of the correction.

EXAMPLES

No. 1	No. 2	No. 3	No. 4
$R =$ 29.875 in. Hg	$R =$ 30.120 in. Hg	$R =$ 1007.6 mb.	$R =$ 985.8 mb.
$C =$ +0.015 in. Hg	$C =$ −0.025 in. Hg	$C =$ +0.2 mb.	$C =$ −0.6 mb.
$P =$ 29.890 in. Hg	$P =$ 30.095 in. Hg	$P =$ 1007.8 mb.	$P =$ 985.2 mb.

A–2.16.4 Installation, Maintenance, and Operation of Marine Barographs

A–2.16.4.0 General Information Regarding Marine Barographs.—The marine barograph, illustrated in fig. 2.9.1, is equipped with a damper whose purpose is to damp out the effects of small or insignificant pressure fluctuations such as those due to gusts, and to diminish oscillations of the pen or other moving parts of the barograph set up by vibrational or accelerated motions of the ship. Consequently the damper permits the pen to make a relatively fine line despite ordinary vibrations, and prevents the trace from becoming excessively wide even when the vessel is making headway in a heavy sea or is exposed to strong, gusty winds. In the damper assembly, installed at one end of the shaft about whose axis the pen rotates, there is a hollow cylinder or cup which rotates about an internal solid cylinder as the shaft turns. Use is made of a high viscosity silicone fluid in the space between the cup and the internal cylinder, for the purpose of producing a viscous drag between them as the shaft undergoes rotary motion. A damping action is exerted in this manner, depending upon the viscosity of the fluid and the area of overlap between the cup and the internal cylinder where the fluid exercises its drag effect. Therefore, it is possible to control the degree of damping by varying this area of overlap.

By virtue of the fact that modern marine barographs have to be operated in many instances within ships which are more or less airtight, they are designed to have an airtight case with provisions for connecting a hose at either end of the base in order to vent the interior of the barograph case to a static pressure head (see sec. 2.11.1 and fig. 2.11.0). The procedure for removing the airtight case of this type of barograph and for replacing it is described in sec. A–2.16.4.1; while information pertaining to the proper exposure and installation of marine barographs is presented in sec. A–2.16.4.2.

As a general rule, the problems of installation and maintenance of marine barographs should be left to the responsibility of the Port Meteorological Officer or some other officer or official designated by the agency concerned to perform these functions, as indicated in secs. A–2.16.4.2, A–2.16.4.9, and A–2.16.4.11. If the barograph trace obtained while at sea is too broad, action can be taken to adjust the damper in accordance with the instructions given under sec. A–2.16.4.10.

Since the chart drum makes one revolution in 96 hours (4 days), designated personnel on board the ship will be responsible for carrying out the following tasks pertinent to the continuous operation of the barograph: (a) winding the clock; (b) inking the pen; (c) setting the pressure and time indications of the barograph correctly whenever the chart is changed; (d) changing the chart at the end of each revolution of the instrument drum; (e) making the proper entries of data on the chart both before it is placed on the drum and after it is removed, in order to complete the required record. Instructions relating to these activities are given in secs. A–2.16.4.3—A–2.16.4.7. Completed barograph charts, together with other marine meteorological records, are to be forwarded to certain headquarters in accordance with the existing instructions to meteorological observers on board ships (see sec. A–2.16.4.8 for further information). The meteorological work conducted on board vessels is subject to review by pertinent Port Meteorological Officers or other designated officials (see sec. A–2.16.4.11).

A–2.16.4.1 Removing and Replacing Case of Marine Barograph.—Marine barographs are equipped with an airtight case which is *not* hinged but is so arranged that it may be lifted vertically off the base of the instrument when the catches at the end are released.

With regard to the model of the marine barograph illustrated in fig. 2.9.1, the case is removed by rotating the catch wings counterclockwise as far as they will turn, then swinging the catch away from the case, and finally lifting the case *straight up* very carefully in such a manner that its flange will not catch the pen.

In order to replace the case of the barograph referred to above, it is first lowered *straight down* very carefully in such a manner that no part of the case strikes the pen mechanism. The case must then be centered on the flange and the latches swung into position so that the dogs on the latches engage the ear rods on the case. Finally, the latch wings must be rotated clockwise until tight, thus compressing the case gasket against the base.

A–2.16.4.2 Exposure and Installation of Marine Barograph.—A barograph will generally be installed on a stout shelf or platform reasonably free from excessive vibration, where it will not be directly exposed to sunshine or to strong sources of heat or cold, such as hot pipes, currents from radiators, drafts from open portholes, etc. It should be in a position where it is convenient to read, service, and use the instrument for meteorological observations. The room or space in which the barograph is located should be suitable for such purposes, with practicable arrangements which will enable one to run a hose or tube from the nipple on either end of the base of the instrument to a static pressure head (see figs. 2.9.1 and 2.11.0). As a rule the hose or tube should be of at least 1/2 inch inside diameter, and not be more than 50 feet in length. Longer lengths are permissible with commensurately greater inside diameters.

The barograph shown in fig. 2.9.1 is provided with a threaded boss together with a bushing or a nipple at each end of the base. With each instrument there is furnished a plug and a hose connection, in order to permit plugging the bushing at one end while the hose connection is installed at the other end, whichever is more convenient. After the hose is connected to the static pressure head and the barograph case is replaced in the manner described in sec. A–2.16.4.1, the instrument case is sealed airtight and the barograph should be capable of indicating the true static pressure if properly set.

In order to enable the barograph to be mounted securely on a shelf the base of the instrument is provided with two tapped holes which accept screws of a certain size and pitch to a specified depth (for example, 1/4–20 screws to a depth of 7/16 inch). The screws should be of such length that the threaded portion does not extend more than 3/8 inch above the support top.

If it should happen that the only available site for the location of the barograph is subject to extreme or severe vibration, consideration should be given to the use of a shock-insulating mount for the equipment (see sec. A–2.21.0).

Whenever the room, space, or ship in which the barograph has been installed is essentially airtight, it is very important to vent the instrument to a static-pressure head, for without such a connection the effects of marked pressure differentials between the inside and the outside of the ship introduce significant errors, as might be the case if the vessel is subjected to strong relative wind velocities (see sec. 2.11.1). However, when there are considerable air leaks between the inside and the outside, the differences of pressure under consideration are generally less and the resultant errors less significant. When and if the latter is found to be the case, it is felt by some persons that the connection to the static-pressure head is not essential; but such an assumption is not always warranted. In other words, it is a recommended practice that the static-pressure head be used whenever practicable.

A–2.16.4.3 Winding of Clock of Marine Barograph.—Before it is possible to undertake winding of the clock, it is necessary to remove the thumb-nut from the center of the inside of the chart drum, and to lift the chart drum vertically from its spindle, taking care to avoid hitting of the pen by any part of the cylinder. The clock-winding lever can be seen by looking down on the clock housing which is mounted on the base of the barograph. This device serves as a reciprocating lever for the operation of a ratchet wheel connected to the mainspring.

In order to wind the clock, the lever should be operated back and forth until the mainspring is completely wound; *but it is very important to stop winding just as soon as the resistance of the mainspring is felt to become hard.* Any attempt to continue winding beyond this point may cause damage.

Following the completion of the winding operation, the free end of the lever should be pushed back toward the center spindle as far as it will go. This action is intended to lock the lever in a position that will prevent it from interfering with the rotation of the chart drum.

Complete winding of the clock in accordance with the foregoing instructions should be performed every time that the chart is normally changed (usually at intervals of 96 hours).

A–2.16.4.4 Inking of Pen on Marine Barograph.—A bottle of special slow-drying ink is supplied with the instrument, and its stopper carries an applicator designed to trap a drop of ink as it is removed from the bottle. In order to obtain the proper amount of ink the applicator should be removed from the bottle with a quick motion. Care should be exercised *not* to draw out the applicator too slowly, since this will enable much of the ink to drain back from the applicator into the bottle, leaving an amount which will not be sufficient to fill the pen.

To complete the inking task, the end of the applicator should be inserted in the barrel of the pen and the barrel should then be given a charge of ink to nearly three quarters (3/4) of its capacity, but not more. When handling the applicator and ink supply, great care must be taken to avoid contact of the ink with the exterior surfaces of the pen and to prevent spilling any ink on parts of the barograph or other areas. These precautions are emphasized since the special slow-drying ink is very difficult to remove from painted surfaces.

In case the pen is dry or clean (as when new), it requires some special effort to get the pen started after it is filled. To do this, a piece of hard paper free of lint (for example, a piece of the chart paper) is drawn through the nibs of the pen, thereby causing a film of ink to be drawn out of the pen barrel into the space between the nibs of the pen.

A–2.16.4.5 Setting for Correct Pressure and Time on Marine Barograph.—Whenever the chart on a marine barograph is changed, the pen of the instrument should be set to indicate both the correct pressure and the correct time.

Unless other instructions are issued to the contrary, the correct pressure will be understood as the *existing sea-level pressure* at the point of observation. As a rule the pressure datum required for this purpose will be obtained on board ship from the properly corrected reading of a precision aneroid barometer, making due allowance for the reduction of pressure from the actual barometer to mean sea level, depending upon the average height of the instrument above the water line. The pen will be set to the proper pressure as specified above by turning the knurled knob at the top of the housing which contains the pressure-sensitive bellows element. It is essential for the observer to tap the housing lightly while making adjustments of this knob, in order to overcome effects of friction.

In order to set the barograph so that it will indicate the correct time, the pen must be raised slightly from the chart by means of the shifting lever and either of the following steps may be taken in making the adjustment: (a) turn the barograph cylinder counterclockwise until all slack motion is removed and continue turning in this direction until the pen point indicates the correct time according to the scale provided by the curved vertical time lines on the chart; or (b) turn the cylinder clockwise to a point where the time indication is, say, 1 to 2 hours ahead of the correct time, then finally turn the cylinder counterclockwise until the pen indicates the correct time. At the last stage the pen point should make contact with the chart; and both the pressure and time readings should be checked.

For further information see secs. 6.10.1.10 and 6.10.1.11.

A–2.16.4.6 Changing Chart on Marine Barograph.—The following instructions will govern the replacement of charts on marine barographs:

(1) Remove the barograph case in accordance with the provisions of sec. A–2.16.4.1.

(2) Push the shifting lever to hold the pen away from the cylinder (chart drum).

(3) Unscrew and remove the thumbnut in the center of the cylinder; then lift the cylinder vertically up, taking care not to hit the pen or pen arm.

(4) Remove the metal chart retainer (chart clip) which holds the old chart in place by pulling it vertically up from the slot in the chart drum flange and the top notch in the drum. Carefully remove the old chart already in the cylinder and lay it in a safe place, using care to avoid smearing the ink.

(5) Take a clean, new chart and enter the required beginning data, which include the name of the ship, its route (from ----, to ----), and the current date and time (GMT), in accordance with instructions given in sec. 6.10.2.2.

(6) Install the new chart on the cylinder. When doing this, wrap the chart around the drum in such a manner that time indication increases from left to right; fit the chart smoothly and tightly on the cylinder with the bottom edge of the chart resting squarely and uniformly in contact with the flange at the bottom of the cylinder; and line up the beginning of the chart with the right-hand sides of the bottom slot and top notch of the drum. In this manner the chart is wrapped around so that its end portion laps over its left-hand margin and comes very nearly up to the line of the actual beginning of the trace area as determined by the right-hand sides of the bottom slot and top notch of the drum.

(7) While holding the chart firmly and snugly in the position described under step (6), slide the chart clip into the slot in the flange of the chart drum and into the notch (recess) in the upper rim of the drum. When doing this operation, the chart clip (metal chart retainer) is held so that the outside of the curve in the clip is toward the chart; the straight end of the clip is inserted into the slot in the flange; the clip is laid flat against the lapped portions of the chart; and the hooked top of the clip is pushed down to engage the notch in the rim of the cylinder. Check to see that the lower edge of the chart is snug against the bottom flange of the drum, that the chart fits smoothly and tightly, and that the ends of the pressure lines on the chart appear to match or be at the same level above the flange.

(8) Wind the clock in accordance with the instructions of sec. A–2.16.4.3.

(9) Replace the cylinder on the barograph by sliding it down over the spindle or tubular carrier until the driving slots in the drum tube engage the pin (carrier dog) which projects horizontally from the spindle; and replace the thumbnut so that the drum will remain on the spindle regardless of pitching of the ship.

(10) Fill the pen with ink about 3/4 full in accordance with the instructions given in sec. A–2.16.4.4.

(11) Determine the correct, current sea-level pressure from the properly corrected reading of a precision aneroid barometer (or better pressure measuring instrument, if available); and also determine the correct time (GMT).

(12) Adjust the pen of the barograph so that it indicates the correct, current sea-level pressure and set the chart drum so that the pen indicates the correct time, in accordance with the instructions given in sec. A–2.16.4.5. Check the settings; also be sure that the pen point is lowered by means of the shifting lever so that it maintains contact with the chart and yields a trace.

(13) Replace the case of the barograph in accordance with the instructions given in sec. A–2.16.4.1, thus rendering it air-tight.

A–2.16.4.7 Data Entries on Charts of Marine Barograph.—After a chart containing a trace is removed from the cylinder, it should be completed by making the required entries in accordance with the provisions of sec. 6.10.2.2.

On this basis, the date and time at which the chart was removed are to be entered at the side of the chart. Also, the date, latitude, and longitude pertaining to the position of the ship at 1200 GMT must be entered at the top of the curved lines corresponding to this time *for each day* covered by the trace on the chart.

All dates and times will be given in terms of Greenwich Civil Time (GMT or GCT).

A–2.16.4.8 Disposition of Charts of Marine Barograph.—Action should be taken to render promptly completed copies of charts obtained from the barographs, together with completed copies of other relevant forms such as "Ship's Weather Observations," obtained during the previous voyage or normal period of operations (such as one month).

Each agency will issue specific instructions to personnel on the ships regarding the transmission of these records to appropriate centers or headquarters. (See the latest edition of the WBAN Manual of Surface Observations, Circular N. As a general rule, completed forms are mailed to the National Weather Records Center, Asheville, North Carolina).

A–2.16.4.9 Regulation of Clock of Marine Barograph.—In cases where a clock runs too fast or slow to a noticeable degree, action should be taken to regulate it so that the correct rate will be obtained.

The procedure for doing this is as follows:

(1) Remove the chart drum in accordance with the instructions given in sec. A–2.16.4.6, par. (3).

(2) By means of a screwdriver, remove the three screws which hold clock movement as a whole on the base of the barograph.

(3) Remove the large, slotted screw plug from the bottom of the clock movement housing; and note the small, shiny regulator arm within the threaded hole from which the plug was unscrewed.

(4) If the clock rate has been too slow, carefully push the regulator arm toward the graduation marked F (or FAST); whereas, if the clock rate has been too fast, carefully push the regulator arm toward the graduation marked S (or SLOW). Use a fine implement, such as a small screwdriver to do this. In case the rate is tested and adjusted with the aid of an electronic timer such as that employed by expert watch repairmen, it is necessary to set the clock so that its operating rate on the timer is *fast* by the amount of 9 seconds per hour (45 beats per hour). The reason for doing this is explained in sec. A–2.16.3.4, Part (B). When adjusting the regulator arm, care must be taken not to let the implement slip. The clock should be handled on a surface so that it will not drop.

(5) Replace the large, slotted screw plug by threading it into the appropriate hole in the bottom of the clock movement housing.

(6) Mount the clock movement on the base of the barograph, and fasten it in place by means of the three screws which had been removed in accordance with step (2).

(7) Replace the chart drum on the spindle of the barograph in accordance with the instructions given in sec. A–2.16.4.6, par. (9).

A–2.16.4.10 Regulation of Damper of Marine Barograph.—As explained in sec. A–2.16.4.0, the purpose of the damper is to reduce vibration of the pen and to damp out effects of small scale pressure variations, such as those due to wind gusts. Fig. 6.10.1 illustrates the type of fine trace which is generally obtained when the damper is properly set under normal operating conditions.

If the trace yielded by any given barograph is too broad, as a rule, while the ship is making headway in a heavy sea, it is considered desirable to adjust the damper in order to secure a finer trace.

The damper is constructed of a hollow cylinder or cup, mounted on the shaft that carries the pen arm, arranged so that the hollow cup partially covers (overlaps) a solid cylinder which is rigidly fastened to a vertical post fixed on the base of the barograph. When the pressure varies, the shaft is caused to turn about its axis and therefore the hollow cup rotates similarly about the solid cylinder. A high viscosity silicone fluid is employed in the thin space between the surfaces of the hollow cup and solid cylinder which face each other. This produces a drag between the inner wall of the hollow cup and the outside surface of the solid cylinder and thereby yields a damping action. It may be visualized from the foregoing description that the degree of damping will be increased if the area of overlap between the two cylindrical surfaces is increased; whereas the degree of damping will be decreased if the area of overlap is decreased. (Note: The tube which projects over the hollow cup merely serves to shield the damper from dust and does not have any mechanical function.)

The hollow cup is held in position on the shaft by means of a set screw. *In order to* change the area of overlap previously described, it is necessary to loosen the set screw and to slide the cup *slowly* along the shaft.

Accordingly, use is made of the following procedure when it is necessary to change the degree of damping:

(1) Loosen the set screw on the shaft.

(2) If it is desired to increase the damping, slide the hollow cup very slowly along the shaft a small distance toward the solid cylinder mounted on the post; but if it is desired to decrease the damping, slide the cup very slowly along the shaft a small distance away from the solid cylinder. Only a small amount of change of damping should be tried at one time. (Note: Do not slide the hollow cup too fast along the shaft since this may cause air to become entrapped between the cup and the inside solid cylinder. Such entrapping of air within this space is harmful and should be avoided, owing to the fact that it will impair the effectiveness of the damper. In performing step number (2) it is important to avoid sliding the hollow cup all the way as far as it will go into the damping mechanism, since this would cause excessive friction at the bearing surfaces between the end of the hollow cup and the post against which the cup is forced. Such friction is objectionable because it would prevent the barograph from operating freely, and render the damper useless.)

(3) Be sure to tighten the set screw, doing so in such a manner that it acts on the flat area existing on the shaft at about the original orientation of the cup. (Note: Any failure to tighten the set screw will prevent the cup from rotating with the pen shaft, and hence will cause the damping action to stop. Also, the precaution of tightening the set screw on the flat area of the shaft is essential to avoid marring of shaft; for, if the shaft is marred, it may become impossible to slide the cup along the shaft to control the degree of damping.)

In order to determine whether the degree of damping obtained under the foregoing procedure is correct, it is necessary to observe whether the barograph traces secured with the given setting of the damper are of satisfactory character. This should be done under various conditions of wind and sea.

A–2.16.4.11 Maintenance and Port Control of Marine Barographs.—The Port Meteorological Officer or other designated officer or official, depending upon the agency immediately concerned, is responsible for maintenance work connected with the meteorological equipment on board ships in port.

With reference to the marine barograph installed on any ship which may properly come under consideration, the designated officer will perform the following functions:

(1) Inspect the barograph and the available completed chart traces in order to ascertain whether the instrument appears to have been properly functioning during recent weeks and months. Make inquiries of the personnel on board the ship who have had opportunities to observe the performance of the barograph, and endeavor to learn whether it has been giving good service or has shown signs of malfunctioning. Determine whether it has been necessary to make significant changes in either the pressure or the time adjustment of the instrument at every replacement of the chart. Inspect the completed charts to see whether the instrument has yielded satisfactory, fine trace lines or unsatisfactory, excessively wide trace lines due to pen arm oscillations.

(2) If the latter is the case, adjust the damper as appears to be necessary. (See sec. A–2.16.4.10.)

(3) If the clock movement has not been cleaned and oiled for 18 months or more, replace the clock with one which is either new or has been recently cleaned and oiled; also send the old clock movement to the appropriate instrument laboratory or headquarters for action to have it cleaned, oiled, and repaired if necessary. If the clock rate has been either too fast or slow, regulate the rate of the clock movement in accordance with instructions given in sec. A–2.16.4.9.

(4) In case it is found that unusually large adjustments have been required in the pressure setting of the pen practically every time that the chart was replaced, or if there is other evidence of malfunctioning of the barograph, consideration should be given

to replacing the barograph with another one in good operating condition. Before final decision is reached to do this, the performance of the precision aneroid barometer used on board ship as the standard for the barograph should be checked by the methods described in sec. 6.9. If the precision aneroid barometer is found to give satisfactory performance, judging by the calibarometer and other tests, it may be concluded that the old barograph was at fault and action should be taken to have it replaced with a new or reconditioned barograph.

(5) The pen on the old barograph should be cleaned in accordance with the instructions given in sec. A–2.16.3.3.

(6) A camel's-hair brush should be used for the purpose of removing dust or salt deposits from the barograph proper, and a soft cloth should be employed to dry it as well as to eliminate any oil or grime which may have collected on exposed parts. In performing these operations care must be taken not to strike or disturb the pen arm and the remaining parts of the sensitive mechanism.

(7) The portions of the mechanism visible to the eye without disassembling the instrument should be examined to determine whether they appear in good working order.

(8) Finally, the barograph case should be checked in order to ascertain the condition of the gasket, the catches on the ends of the case, the glass windows, and the overall assembly, which should be capable of providing an air-tight cover for the instrument proper. If anything is out of order, action should be taken to rectify the deficiency.

(9) Should the barograph be equipped with a static-pressure head, steps should be taken to clean it, to see that its orifices are open, and to investigate the condition of the tube or pipe which is used to connect the static-pressure head to the barograph. If there is any water, oil, salt deposit or other foreign matter in the pipe, or plenum chamber it should be drained off and removed. (See sec. 2.11.1.)

(10) The entries and data on completed charts should be compared with the pertinent records contained on forms for the same periods, e.g., Ship's Weather Observations. An effort should be made to determine whether the data are consistent and the settings of the pen in harmony with the correct sea-level pressures at various times. The procedures employed by the ship's observers should be checked in regard to the reading of the aneroid barometer, the application of the proper correction to obtain the sea-level pressure, and the setting of the pen to indicate the latter pressure at the time that a new chart is placed on the barograph cylinder. Entries required on the chart under the provisions of sec. 6.10.2.2 should be checked for completeness and accuracy, insofar as practicable. Observers on board ship should be given instructions regarding proper procedures if necessary.

A–2.17 CLEANING OF FORTIN BAROMETERS, AIR IN BAROMETER TUBES, AND THE "METALLIC CLICK"

A–2.17.0 Introduction

This section is concerned with the technique of cleaning Fortin barometers in the field where limited facilities exist for the purpose, and with the problem of removing small bubbles of air from barometer tubes. Both of these matters require special knowledge and the exercise of great caution in the handling of the instrument so that it will not be damaged or impaired. Therefore, only persons with adequate experience or those acting under the immediate direction of skilled technicians themselves having considerable knowledge and practice in the art should undertake the task of cleaning barometers and removing air bubbles.

Section A–2.17.1 deals with cleaning of the instrument. Before the cleaning is begun, and after the cleaning is completed, not less than five comparative barometer readings must be taken with reference to another barometer which is used as a standard. The relationship between the results of the comparisons before and after the cleaning serves as a guide in assessing the degree of success achieved in the process or in determining whether the instrument has been impaired, as may be the case sometimes when a leak develops in the cistern or a large bubble of air inadvertently reaches the vacuum space at the top of the tube.

Section A–2.17.2 is concerned with a practice sometimes used to remove small bubbles of air from barometer tubes. Sec. A–2.17.3 gives two methods which may be used to estimate the quality of the vacuum. The first of these methods involves judging the sound known as the "metallic click" which is produced by the impact of the mercury with the top of the tube, while the second method involves measuring the size of the bubble at the top of the tube while it is in a horizontal position.

It is difficult, if not practically impossible, to completely remove all bubbles of air adhering to the inside wall of a barometer tube by the methods described in sec. A–2.17.2; while in the second method described, there is the hazard that moisture as well as additional air may get into the tube, thereby increasing the likelihood that eventually the vacuum will become impaired. Once the vacuum has deteriorated to a serious degree owing to the inclusion of a significant quantity of air or water vapor in the space near the top of the tube, it requires a laboratory technique to remove the foreign gaseous substances from within the tube and to produce a high degree of vacuum (see sec. A–2.15). In view of these considerations, it is obvious that the attempt to remove air from barometer tubes should not be entered into lightly, and that it is not a task for a novice. Thus, the best general plan is to use such criteria as may be available to estimate the quality of the vacuum before and after cleaning the barometer, considering especially visual evidence based on the possible observation of bubbles adhering to the inside wall of the tube, aural evidence from the character of the "metallic click," and experimental evidence from the results of the barometer comparisons. With respect to the latter, it should be borne in mind that the presence of air or water vapor in the vacuum space tends to make the given barometer read too low relative to the absolute standard barometer. If the totality of evidence indicates that the vacuum is seriously impaired, it is considered best to report the facts to appropriate headquarters and to recommend replacement of the barometer. However, if the vacuum appears to be still of reasonably good quality, but there are small visible bubbles of air adhering to the inside wall of the tube, these facts should also be reported to headquarters. In this event, the results of the barometer comparisons of the given instrument must be watched with especial care over a period of time, so that if the data indicate the barometer to read more or less progressively lower and lower over this period, it may be inferred that the bubbles are gradually ascending to the vacuum space. Then, if the discrepancy of the given barometer relative to the standard becomes excessive, a replacement of the instrument should be suggested. See sec. 2.7.3, A–2.15, and 4.4 regarding causes of excessive discrepancies. With the introduction of a system involving the use of "residual corrections" as outlined in sec. 4.4, much of the error arising from the presence of a small quantity of air in the vacuum space may be overcome.

A–2.17.1 Cleaning of Fortin Barometers[46]

After continued use the mercury in the cistern of a barometer loses its brilliant surface and becomes coated with a slight film of oxide or other impurities (see sec. A–2.14). This does not impair the barometer to any serious extent, and very accurate readings can yet be made. It is a bad practice to clean the mercury in barometers as soon as it becomes slightly dull and tarnished. Leaks are apt to be started in the joints of the cistern, and slight changes in the position of the ivory point give rise to new and unknown corrections for instrumental error. The mercury itself is apt to become contaminated with impurities and afterwards will remain bright only a very short time.

For the reasons given above the cleaning of mercury in barometer cisterns is usually done, when necessary, by authorized, experienced personnel, such as inspectors or field aides. Unless special authorization has been granted, the cleaning of mercury contained in barometer cisterns should not be undertaken by regular meteorological station personnel. Unauthorized tampering with

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[46] Most of the information contained in secs. A–2.17.1, A–2.17.2, and A–2.17.3 was extracted from the booklet by C. F. Marvin, "Barometers and the Measurement of Atmospheric Pressure," Weather Bureau Circular F, U.S. Government Printing Office, Washington, D.C. (1941). (Out of Print.)

the barometer may cause serious damage and may greatly reduce the accuracy of the instrument. Minor repairs may be made only after authorization by the appropriate headquarters, except in an emergency. In the latter situation, the circumstances should be reported in detail to the appropriate headquarters as soon as practicable.

In cases where significant amounts of air or moisture collect in the barometer tube, routine cleaning is insufficient and special steps are necessary by the methods given in secs. A–2.15 or A–2.17.2.

INSTRUCTIONS

Only personnel specially trained in regard to the cleaning of barometers are granted authority to perform this function; and as a rule, the cleaning is necessary only when the instrument is so very dirty that accurate readings cannot be made. The following instructions will then guide in the proper performance of the work:

Take a series of five comparative readings before the work is begun.

Provide one or more very clean, *dry* porcelain or glass cups or saucers. Avoid the use of damp, unclean, or metal vessels. Cleanse the vessels by thorough washing with a detergent or soap and water and wipe dry with a clean towel, finally polishing the vessel with tissue or similar soft, lint-free paper. Provide, also, some pieces of clean cloth and sheets of tissue paper for cleansing the glass parts of the cistern, also a few small sheets of clean, lint-free white paper about 4 by 6 inches for use in filtering the mercury. Calendered letter paper is not so good as the ordinary so-called book paper. A most convenient position for cleaning a barometer is to be seated in front of a desk with a drawer at the top and side partly opened. This affords convenient corners in which the barometer can be rested in upright positions during the process.

The barometer will be removed from its box or support and inverted, in accordance with instructions in sec. 2.2.7.3.

After the barometer has been slowly inverted to a vertical position with the cistern end up, it should be secured carefully in place as a step in preparation for disassembly. If the hanger end of the barometer is resting on the floor or other hard surface, place a thick piece of soft material, such as sponge rubber, between the hanger and the hard surface. Very great care must be exercised in bringing the barometer to rest on the surface since a sudden jar can cause some mercury to be ejected from the open end of the barometer tube with the possibility of air entering the end of the tube. This is particularly true when the cistern has been disassembled and the open end of the tube is no longer covered with mercury.

In the following instructions we make use of the parts of the barometer listed in fig. 2.5.0, referring to the parts by number.

When disassembling the cistern while the barometer is in the inverted position, the procedure to be pursued depends upon the conditions and the design of the instrument, as follows: (1) case where mercury has leaked from the cistern; (2) case where the cistern has a vent; (3) case where portions of the cistern consist of tapped and threaded bakelite parts; and (4) case where the cistern does *not* have a vent and the parts "13" and "16" are constructed of wood. We shall consider each of these cases in turn.

(1) Case where mercury has leaked from the cistern.—This condition will generally be indicated by the presence of minute globules of mercury adhering to the threads of screw "21"; hence the first thing one must do after the barometer is inverted is to examine carefully the lower portion of the cistern and the screw thread with a view to discovering traces of mercury which may have leaked out. If the evidence points to such leakage, the screw cap (part "20") at the extreme bottom of the cistern should be unscrewed. Since the escaped mercury has been in contact with the metal parts of the cistern, it must be regarded as contaminated with dissolved metallic impurities and therefore must be considered unfit for use in the barometer. Consequently, the mercury thus characterized must not be mixed with the mercury afterwards taken from the leather bag and it should not be employed for refilling the instrument unless it is subjected to the complete process of purification described in sec. A–2.14. If, by inadvertence, the mercury that has been in contact with the cistern metal is mixed with the mercury taken from the leather bag, the entire quantity of mercury must be regarded as impure and unfit for use in filling the barometer. A supply of pure, dry mercury will then be required.

In order to empty the impure mercury which has escaped into the metallic part of the cistern, the finger should be used to force the leather bag up into the cistern while the barometer is inclined and the impure mercury poured out. During this process care should be taken to move the instrument slowly, particularly while the barometer is held inclined most nearly in a vertical position and while the barometer is being later re-inverted until the "metallic click" is heard in case a vacuum space has been formed. These precautions are necessary since the hydrostatic pressure is greatest upon the leather bag when the instrument is vertical and since the impact of mercury with the top of the glass tube may cause breakage if the motion is too rapid.

After the contaminated mercury has been poured out of the cistern housing (part "19") and the barometer re-inverted, it is necessary to unscrew that part and to examine carefully the remaining visible parts of the cistern, especially parts "13," "14," "15," "16," "17," and "18," with a view to discovering, if possible, the cause of the mercury leakage. When such a cause is found, this will usually suggest an appropriate method for rectifying the fault. If no damage to parts is discovered, one may proceed with the disassembly in accordance with instructions under the relevant caption below. Fig. A–2.17.0 illustrates the appearance of the parts "13"—"18" after part "19" has been removed.

(2) Case where the cistern has a vent.—Before the cistern is disassembled a small quantity of mercury can be removed from barometers having cistern vents. This mercury may be removed by a suitable suction apparatus while the barometer is still upright or with the barometer inverted it may be allowed to drain slowly through the vent into a clean, dry container that is inert to mercury. Any apparatus that comes into contact with the mercury when it is being removed from the cistern must be constructed of materials that will not contaminate the mercury and the apparatus must be clean and dry. For example: stainless steel, glass and porcelain are satisfactory. Rubber is not satisfactory unless it is sulphur free. After about two (2) tablespoonfuls of mercury have been removed in this manner, the vent cap should be screwed back tightly to close off the flow. The advantage of this procedure is that it will aid later to avoid spillage when the cistern is disassembled, but is not an essential step if great care is exercised in disassembling the cistern. One should then proceed with the disassembly in accordance with instructions under Case (3) or (4), whichever is appropriate.

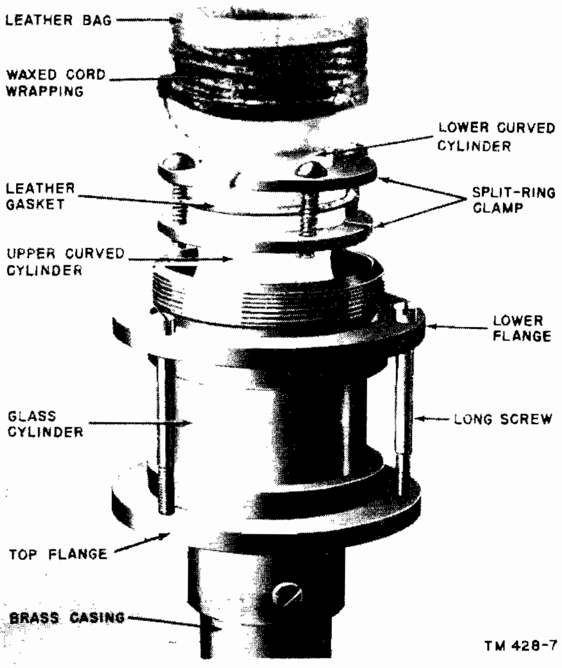

FIGURE A–2.17.0. Cistern of a Fortin-type barometer, shown inverted with outer shell removed (U.S. Army photograph).

(3) Case where portions of the cistern consist of tapped and threaded bakelite parts.—Some barometers have tapped and threaded bakelite parts of the cistern instead of the wooden parts ("13" and "16"). The parts under consideration will be revealed after the cistern shell, part "19," is removed. Before doing this, one should back off several turns on the cistern adjusting screw, part "21." Then, one should grasp the cistern shell, "19," with one hand and the narrow lower flange, part "12," with the other. In this manner one should unscrew part "19," but no screws should be loosened as yet. As will be obvious from fig. 2.5.0, the adjusting screw assembly (parts "20" and "21") will remain attached to the cistern shell when part "19" is removed.

In regard to the case where the bakelite parts are present in the cistern, each of the two parts (corresponding to "13" and "16" in regard to function) will be grasped separately and the uppermost part (analogous to "16") should be unscrewed by turning it in a counterclockwise direction with respect to the lowermost part (analogous to part "13"). After this step is completed, the uppermost part to which the leather bag is attached should be carefully lifted off, taking precautions to avoid spilling mercury from the lowermost portion. The leather bag and the part to which it is attached are to be cleaned and all particles of remaining mercury removed therefrom in accordance with instructions regarding this matter given below under case (4). Since the cleaning procedure from this stage onward is essentially the same regardless of whether the specified parts are made of bakelite or wood, we shall refer the reader to the instructions given below under case (4) relative to the matter of cleaning the parts and filtering the mercury.

It will be obvious how the assembly of the cistern parts constructed of bakelite differs from that pertaining to cistern parts constructed of wood, the latter of which is fully covered under case (4).

(4) Case where the cistern does not have a vent, and the parts "13" and "16" are constructed of wood.—Following the procedure outlined in the first paragraph under case (3), the cistern shell, part "19," should be unscrewed with respect to the narrow lower flange, part "12," after backing off several turns on the cistern adjusting screw, part "21."

The next step is to separate the two wooden portions of the cistern, parts "13" and "16." Before doing this, one should mark the adjacent flanges of these parts with a pencil or by some other means in order to insure that the two parts can be reassembled in exactly the same position as they were originally, giving consideration to the fact that many of the cistern parts are paired and will fit properly only in one position. Similarly, the metal flange "12" should be marked in relation to metal flange "4" so that they may be reassembled with the same orientation as previously. This precaution of marking adjacent parts should be taken in all appropriate cases. Now, in order to separate the wooden parts "13" and "16" one should loosen the four screws uniting the upper and lower portions of the split-ring clamp, part "14," but when doing this it is important that each screw be loosened a little in turn. Otherwise, an uneven strain will be thrown upon some portion of the fragile wooden flanges of parts "13" and "16," possibly causing a piece to be chipped out. After loosening each of the screws holding the split-ring clamp, "14," one of the screws may be taken out entirely, and the whole system of split rings still interlocked by the screws will generally unfold from around the cistern. Sometimes another screw must be taken out.

If the rings are separated, they should afterwards be united again precisely in the original relation. When removing the wooden piece "16" to which the leather bag is attached, lift it cautiously directly up from the part "13" so as not to spill the mercury, which is thereby exposed and should just about fill "13." Hold a clean, dry vessel which is inert to mercury close under the flange of "13" and pour the mercury steadily from the cistern until the barometer is about horizontal. The mercury will not leave the open end of the barometer tube so long as the latter is not raised above a horizontal position, unless the opening is large and the tube shaken or jerked a little. Care must be taken to prevent the mercury from passing out of the tube. To insure this, press the gloved finger or a small piece of clean, lint-free cloth against the tube opening. The rest of the mercury may *then* be poured with safety by raising the hanger end of the barometer above the horizontal until all mercury has left the cistern. The barometer is then returned to its inverted position, taking care not to set the hanger end against the floor too suddenly as the shock will eject mercury from the now exposed open end of the tube. The remaining parts of the cistern may now be removed by loosening the screws "10." Mark part "12" in relation to "4" so the same screw holes are opposite when the unit is reassembled. This prevents the cistern housing from changing position and causing the barometer serial number to be oriented to the side or back, instead of in front. Loosen each screw a little in turn to avoid chipping or cracking the glass cylinder. If a small globule of mercury remains in the glass cistern, allow the latter to rest in its position, while the screws "10," the metal flange "12," and the marked boxwood piece "13," are removed. Then holding the glass cylinder in position with the fingers, empty what remains of the mercury in the cistern. In handling the little leather washers taken from the parts of the cistern, avoid wrinkling or creasing them or otherwise changing their form, as any injury of this kind will probably result in leaks that cannot be prevented except by new washers. If new washers are available, they should be used in preference to the old ones.

The barometer tube and attached piece "5" (wood or gray iron), as shown in fig. 2.5.0, may be next withdrawn from the metal sheath, if this can be accomplished without undue risk of damage to the tube, and the parts thoroughly cleaned. In those cases where there is no reason to suspect the presence of air bubbles or an impaired vacuum, the barometer tube need not be removed from the metal sheath and the work may be terminated with cleaning of the cistern. Before removing the tube notice exactly the position of the ivory point in reference to the outside sheath and make a pencil mark on the sheath at this orientation so that the point may be returned to this position; otherwise a significant change may be introduced in the correction for instrumental error. The ivory point is normally oriented on the right side (as the observer faces the barometer) between 45° and 90° from the line of sight when looking at the center line of the barometer through the vernier slot.

In all probability, small quantities of mercury will be spilled into or remain in various little cracks and crevices while the cistern is being emptied. These, by all means, should be thoroughly dislodged, especially from about the metal parts. With the glass tube removed, the sheath should be tapped and shaken smartly to remove all small globules of mercury. It may then be wiped and cleaned thoroughly with cloths or chamois skin.

In case the scale is somewhat dull and tarnished, it may be brightened by suitable polishing, but this is a delicate operation and should be avoided rather than otherwise. The danger lies in shifting the position of the scale; and if polishing is absolutely necessary, it should, therefore, be done with very great care. When new, the scales are usually protected from tarnishing by a thin coating of clear lacquer.

The upper portion of the glass tube should also be cleaned on the outside with the aid of a damp cloth if necessary to improve visibility through the glass.

If observable evidence indicates the presence of one or more air bubbles, either captured at the top of the barometer tube or adhering to the walls of the tube, consideration should be given to the question of the advisability of removing the air. To this end, the reader is referred to sec. A–2.17.2 for a discussion on the subject of "Air in Barometer Tubes" and the methods which may be used to remove the air. See also sec. A–2.17.3.

Sometimes the bubbles consist of moisture or of moist air. If the amount of moisture is significant, it is necessary to do a complete job of cleaning, drying, and refilling the entire barometer, as it is virtually impossible to remove the moisture without such a thorough undertaking. For information in regard to drying and filling mercury barometers, see sec. A–2.15. The best method of drying and filling is considered to be the vacuum pump method where use is made of a hygroscopic absorption train containing a first-class drying agent such as phosphorous pentoxide, while the mercury is heated to 300° C. Operations of this scope are only conducted in the laboratory by specially trained personnel. (Note: The boiling point of mercury at normal atmospheric pressure is 356.9° C.)

One of the most difficult and delicate parts of the process of cleaning is that about the piece "5" and the ivory point "7." The deep and narrow annular space between the glass tube and the flanged cylinder "5" is generally covered with oxide of mercury and/or other foreign material, which should be thoroughly removed by repeated wiping with clean cloths applied upon the ends of slender sticks or by similar means. Tufts of raw cotton will adhere firmly to, and are readily wrapped about, rough sticks and may serve with advantage in wiping out the narrow spaces. Sometimes, however, the space is so small it cannot be properly cleaned. Care must be observed not only here but in subsequent operations to blow away or otherwise remove every vestige of lint, dust, shreds of cotton, etc.; since such things, if allowed to remain about the parts of the cistern, will quickly find their way to the surface of the mercury, upon which they will float about, to the detriment of accurate adjustments.

It is obvious that the delicate ivory point should be handled with great care.

The glass cylinder of the cistern should be washed with a detergent or soap and water and thoroughly rinsed in copious applications of fresh water (preferably water which is not hard and does not contain significant amounts of mineral substances or other impurities). After this, the cylinder should not be touched with unprotected hands, especially upon the inside. Wipe it thoroughly dry with a clean, dry towel or handkerchief, and polish it with clean tissue paper. The remaining wooden portions of the cistern should also be wiped thoroughly clean and dry without touching the inside with the bare fingers. Shake out of the bag as far as possible every little particle of mercury that tends to remain in hidden corners and crevices. These little particles are very apt to be dirty, and should, therefore, be removed.

An additional technique which has been found useful to achieve a better degree of cleansing of the leather bag ("18") involves the employment of the clean mercury as a rinsing substance to aid in carrying off the residual particles and impurities. In this method the mercury which has been removed from the cistern and has since been cleaned is divided into two equal portions. One of these portions is poured into the leather bag and the opening of the bag is covered with a gloved finger or held closed while covered with a clean piece of lint-free paper such as that found suitable for filtering. The bag with its contents of mercury is shaken rather violently and the contents poured into a clean glass container for re-use. Next, the other portion of the mercury is poured into the bag and the rinsing process repeated, saving the contents as in the previous case. Usually, this technique is fairly effective for the removal of the last traces of particles from the bag. Finally, the mercury thus fouled must be filtered a few times in order to clean it again.

The several parts of the barometer should be replaced in the following order:

First, return the glass tube to its sheath, being careful to place the ivory point in the position in relation to the scale, or front of the barometer, formerly occupied. In performing this operation, one should be careful to avoid handling with the bare fingers the end portion of the barometer tube where it dips into the cistern, as a slight film of oil may be communicated to the mercury of the cistern by this means.

The glass cylinder, with its leather washers, one at each end, is next placed in position, followed by the wooden piece "13" and the lower flange "12." Make sure that the lower flange "12" is oriented so that each screw hole is opposite the same screw hole in top flange "4" as before disassembly; otherwise it will be necessary to attach temporarily cistern housing "19" to part "12" in order to find the proper orientation. The three long screws "10" are next to be inserted and partially screwed up. While these various pieces are still loosely held by the screws, it is well to move the parts about a little until the glass cylinder is well seated against the gaskets "6" and "11" located between the glass cylinder and parts "5" and "13." In other words, one should try to bring the surfaces in the several joints nicely and uniformly into contact with each other, and adjust the ring "12" so that the screws are not perceptibly askew, but when properly drawn up, produce a direct, uniformly distributed pressure. Similarly, one should make sure that the lower flange "12" is pressing evenly against the upper curved wooden cylinder "13." When the parts are thus adjusted, the screws "10" are to be tightened little by little, each one a little in turn after the others, until all are drawn down together equally tight. The observer must judge this partly by the amount he has turned each screw and partly by the resistance it offers to further turning. It is not necessary that the screws be extremely tight. The best procedure is to tighten the screws, wait several minutes, then tighten again. This is particularly helpful when new gaskets are installed, as the waiting period gives the gaskets a chance to become compressed and serves to keep the joints from becoming too loose later, with danger of possible leakage. Excessive tightening, particularly if unevenly distributed, can result in damage to the parts involved. It is essential that one pay careful heed to the foregoing instructions and observe meticulously all of the precautions indicated with a view to securing perfect joints in the cistern. Failure to do this may give rise to leaky joints and the production of unequal pressures on various parts of the cistern, which are apt to cause breakage of the fragile boxwood flanges or cracking of the glass.

Continuing with the process of restoring the barometer, the next step is to filter the mercury and fill the cistern. Dry mercury of a high degree of purity should be used in filling the barometer. The reader should refer to sec. A–2.14 for detailed information in regard to methods of cleaning mercury and testing it for purity.

For the benefit of those who will be enabled only to employ the filtering method for cleaning the mercury which was removed from the cistern and who do not have at their disposal the means required for using the highly technical and refined methods described in sec. A–2.14, we shall recapitulate the essential points concerning the filtering method at this place. In this technique, a sharp cone made of clean paper of suitable kind is employed. Either the cone is formed by rolling up a small sheet of such paper with a very minute hole left at the apex, or the cone is obtained ready-made or prepared in such a manner that it is necessary to make a minute pinhole in the apex. By looking toward a light source through the hole one can check to see that its size is suitably small for the filtering purpose. The cone should then be partially filled with the mercury while it is held with apex down over a clean vessel made of glass, porcelain, or other suitable substance.

By twisting the folds of the cone in a manner that the person performing the work must learn by trial, the opening at the point may be regulated to any size desired, even while the cone contains mercury. Thus, the mercury will flow slowly through the pinhole, leaving behind the bulk of the film of impurities which had appeared on the surface of the liquid, and also permitting the removal of some of the oxides of base metals, such as lead, tin, and zinc, which are sometimes present. During the process of filtration, the cone should be kept well filled with mercury until all has been added, but it is important that the very last portion should not be allowed to pass through the filter since this contains most of the impurities in the form of a dross.

If one has only the supply of pure mercury taken from the barometer, economy must be exercised, but there is no difficulty whatever in being able to filter and utilize the entire quantity of mercury originally in the barometer, and this is sufficient. The purity of some of the filtered mercury may be tested as described in sec. A–2.14. Another indication of the purity of the mercury is the character of the mark left on the paper cone after filtering. To be able to judge this, one must filter both pure and impure mercury and compare the marks.

The mercury for the cistern, having been filtered at least once, may next be filtered into the cistern, directing the little stream away from the open end of the barometer tube to avoid inclosing small air bubbles just inside the tube. The open end of the tube should, in the meantime, be completely filled, taking care to avoid trapping air bubbles in the tube. One of the best ways of accomplishing these objectives is to employ a method whereby the mercury will be heaped into a little dome-shaped protuberance on the tip end of the open tube, as by increasing the volume of the mercury or adding a suitable quantity, in accordance with one of the procedures outlined below:

(1) Move the barometer into a warmer room or heat the room by several degrees. (2) Warm the tube by placing it near a warm radiator, a 100-watt light bulb or an infrared heat lamp, using care not to overheat the tube. (3) Add mercury with a hypodermic syringe equipped with a steel needle. Care must be exercised to make sure that the needle is not composed of a metal or alloy which will contaminate mercury. (4) Draw a piece of 1/4-inch glass tubing to a fine capillary at one end and add mercury to form a column about two inches high, hold a finger over the upper end of the tube to control the flow of mercury as it is being added to the open end of the barometer tube. The dome-shaped protuberance of mercury referred to above will unite with the mercury of the cistern as it arises around the tube, and the chances of inclosing air in the tip end of the tube are thus greatly lessened.

In general, the cistern should be filled to the brim of the upper curved wooden cylinder, part "13"; however, in the case of barometers equipped with cistern vents, a small quantity of mercury may be withheld and later introduced through the vent by means of a capillary glass tube or a hypodermic syringe after the barometer is mounted in its normal upright position and the mercury has been lowered to the usual reading level.

The leather bag, part "18," with its attached lower curved wooden cylinder, part "16," should be re-examined with a view to determining whether it is clean. If not, all dust, shreads, particles of leather, mercury, etc., should be removed from its interior, being careful not to touch the inside with the finger since this may introduce grease or soil. A clean stick, possibly covered with lint-free cloth, may be used to assist in performing this cleaning operation. The method of rinsing the interior of the bag with mercury, previously described, may also be employed.

Part "16" should next be fitted carefully over part "13" making sure that the marks made at the time of disassembly match exactly. Fasten these two parts in place with the split-ring clamp, part "14." In fastening this clamp, the screws should be tightened a little at a time, and the precautions cited above observed to insure a closely fitting and uniformly tight joint.

Next, it is essential to test the barometer for leaks. To accomplish this, one first places a finger on the "button" (wooden bearing, part "17") at the bottom of the chamois bag and forces the bag firmly into the cistern piece (part "16") to which it is attached. Then, the barometer is slowly erected to its normal vertical position, while enough pressure is being exerted on the "button" ("17") to keep the barometer tube almost filled with mercury. This operation should be performed over a sheet of white paper on which one might catch and detect any droplets of mercury that might leak out. At this stage it is necessary to examine carefully the chamois bag, together with all joints and other places where mercury might possibly leak out. (Note: Two persons should perform the operations when a large bore barometer is being handled, since these instruments are relatively heavy and since it is absolutely essential that one person hold the chamois bag in its cistern piece ("16") as the barometer is being turned to render it erect and all the time it is held in the normal vertical position.)

The barometer should now be slowly returned to the inverted position with the cistern end up, while the "button" ("17") of the chamois bag is steadily kept depressed into the cistern piece ("16") and held in a well centered position. If no leak of mercury has been detected and the parts appear to be in proper working order, the assembly of the barometer may be completed. To this end, the cistern shell (part "19"), together with its attached cistern adjusting-screw assembly (parts "20" and "21") should be replaced by screwing it into position on to part "12."

Finally, the assembled barometer should be slowly brought upright into its normal vertical position by following the relevant instructions already prescribed for this operation in sec. 2.2.7.3. This will require that the cistern adjusting screw be tightened gradually, but not excessively, while the barometer is still inverted, thus causing the slack to be taken from the bag. In the process of bringing the barometer to the upright position the instrument is slowly inclined, first to a horizontal position, at which stage the adjusting screw should have been backed off sufficiently to cause a bubble of air about the size of a dime to be present in the cistern and visible to the eye. The process of slowly inclining the barometer to the erect position is continued while the adjusting screw is further backed off until a thin layer of air appears between the top of the cistern and the surface of the mercury within it. Now the barometer should be hung securely from its support and the vent cap, if any, carefully loosened (see instructions in sec. 2.2.4.1). Lastly, the barometer must be rendered vertical in accordance with instructions given in sec. 2.2.4.2.

In some cases it may be observed that after the barometer has been brought upright to the normal vertical position the mercury column will remain firmly adhering to the very top of the glass tube, without the appearance of a vacuum space. The reader is referred to sec. A–2.19 for information concerning this phenomenon. With a view to restoring the barometer to normal operating condition, when the mercury has not broken away from the top of the tube, the instrument should be moved up and down a few inches, slowly at first, or jarred lightly, until a vacuum is formed above the top of the mercury column. Generally, this problem will arise when the instrument is being tested for leaks, before the cistern shell ("19") has been screwed in place. Under those circumstances, the "button" (part "17") will be held by a finger to keep the chamois bag (part "18") up in the wooden piece (part "16"); and, therefore, when the mercury breaks away from the top of the glass tube a sudden increase of hydrostatic pressure will be felt by the finger.

Comparative readings of the barometer with its companion or standard instrument are required, following the process of cleaning described above. Instructions relevant to this purpose are presented in secs. 6.5–6.6 (see for example, sec. 6.6.3 pertaining to the case of station barometers). At least five comparative readings are necessary. Not less than two hours should elapse from the time the barometer was reassembled after cleaning until the time the comparative readings are begun. As a rule, the results of the comparative readings will be more reliable if the elapsed time is 12-24 hours, and the latter interval is recommended if practicable under the circumstances.

A–2.17.2 Air in Barometer Tubes

This section is devoted to a consideration of steps which may be undertaken in cases where a small but detectable amount of dry air is contained in the barometer tube. However, if there is a relatively large amount of air or moisture in the tube, the methods described in sec. A–2.15 should be used to refill the tube after it has been emptied in the laboratory. Only technicians who are experienced and skilled in the arts of filling mercurial barometers and of removing air from the tubes are permitted to perform these operations, which are outlined in sec. A–2.15 and in the following text, respectively.

How air can gain entrance to the vacuum of a barometer otherwise in good condition, which is supposed to have been hanging quietly and undisturbed upon its supports, is a matter that is very difficult both to imagine and to explain (see sec. 2.7.3).

In situations where barometers are frequently handled by laboratory personnel with long experience in this field, very rarely does one find a case in which a significant quantity of air reaches the space above the meniscus in the barometer tube. Hence, when such a defect is discovered in an instrument in use at a station, the observer investigating the cause should make sure that the barometer has not been tampered with or roughly handled by unauthorized persons; for if the instrument is undamaged in other respects, it may be considered that misusage is the most probable explanation of the defect.

If an appreciable quantity of air is in the tube at the time of cleaning, it can be seen more or less conspicuously in the shape of a small bubble or bubbles adhering closely to the walls of the tube. If these bubbles appear no larger than good-sized pinheads, and especially if they are not more than halfway up the tube, then it is certain that the condition of the vacuum is more likely to be greatly impaired than improved by attempts to remove them.

Sometimes the barometers that personnel may be called upon to inspect or repair, seem to have numerous rather flat-shaped air bubbles firmly lodged against the sides of the tube. Generally these are not air bubbles at all, but are particles of moisture, the presence of which is due to carelessness in the original preparation and filling of the tube. The edges of an air bubble are sharp and the mercury generally remains bright and makes well-defined contact at a steep angle with the glass. If some moisture is present, either alone or with the air, the edges are less clearly defined, the mercury is oxidized, and the angle of contact is less steep, the bubble itself being very flat.

It is impossible, without entire cleansing, drying, and refilling, to do anything with a barometer that contains moisture.

If a bubble or so of air is present in a tube, remove the tube from the sheath in accordance with previously given instructions in this section. The procedure that should be first tried for removing such bubbles of air from the tube is as follows:

First method.—Incline the tube 45° or thereabouts, with the open end up, and tap it gently in the vicinity of the bubble, revolving the tube a little at the same time so as to encourage the bubble to creep along the inclined surface of the glass. If the inclination is too great the bubble will be greatly compressed by the weight of mercury above it; if too small, the bubble will not tend to move.

If the treatment is successful and the bubble is removed, the result will probably be beneficial; but at best the operation is generally very tedious, and often the bubble seems to grow smaller and finally disappears, being separated into almost imperceptible portions which remain distributed along the walls of the tube.

Second method.—The following plan is more frequently applied, especially when the quantity of air already in the tube is considerable, is lodged at the top, and must be partially removed at least:

Empty an inch or two of mercury from the tube. Close the open end tightly with the gloved finger and cause a large bubble of air to glide slowly and regularly along the tube until it unites with all the portions of air it is desired to remove. The large bubble is then as slowly and gradually worked to the open end of the tube again, using every possible precaution to prevent small portions of the bubble from separating and remaining behind. Such a bubble of air may sometimes be successfully passed once into and out of the tube, but even at the best the vacuum in a barometer that has been treated in this manner is very apt to be greatly impaired and cannot be restored. The reason for this is that the glass walls of the tube have very strong hygroscopic properties, and while the air bubble is passing along the tube considerable portions of both moisture and air are invisibly retained upon the walls of the tube. While, therefore, a bubble of air may be successfully passed once into and out of the tube, a repetition will be attended with less good effect, as in the meantime the moisture and gases of the bubble will have acted upon the mercury to produce oxidized films that will probably adhere to the walls of the tube, so that when bubbles are again passed there will presently be a marked tendency to cling to the tube and leave small detached bubbles imprisoned against the walls. When, afterwards, the barometer is set up, the walls in the upper portion and near the vacuum, being no longer subjected to the full air pressure as they were while the bubble was passing along the tube, now readily give off both air and moisture, and in many cases numerous little bubbles form against the walls even below the top of the column and probably later work their way into the vacuum. This second method is most successful when accomplished under conditions of low humidity such as a dry heated room in the winter season.

The removal of air from a barometer tube, therefore, cannot be perfectly effected in any such way, and should not be undertaken unless the defect is a very serious one. If the comparative readings taken before cleaning a barometer do not show serious errors, any air the tube may be thought to contain had best be allowed to remain.

A–2.17.3 The "Metallic Click"

As a rule the criterion applied in connection with the "metallic click" is that if the sound yielded at the top of the tube by the impact of the mercury with the glass is sharp and metallic, the vacuum is judged to be of satisfactory quality; whereas, if the sound is characterized as soft, dull, or leaden, it is generally inferred that the vacuum is impaired in quality relative to the desired standard. The difference in sound in the latter case is considered to arise from the fact that a bubble of air would act as a buffer between the mercury and the glass at the top of the tube.

The so-called "metallic click" is best produced while the barometer is inclined about 45°, or possibly still more nearly horizontal at high-level stations. The cistern must not be screwed up too much. The "click" occurs just as the mercury moving up the tube reaches the top and completely fills it. If the barometer is quickly inclined, the violent shock of the mercury against the top of the tube is sometimes sufficient to crack the tube. Hence sudden movements of this sort are always attended with danger to the barometer.

The following information is provided for those authorized to clean and test barometers:

Many think they can judge the excellence of the vacuum in a barometer by the character of the "metallic click." It is exceedingly deceptive, however, and even experts are able to draw only approximately correct conclusions from its character. The greatest caution should be exercised in producing the click, as, if the vacuum is first class, it tends to injure the barometer. A good plan is to incline the barometer, as described above, until the mercury almost reaches the top of the tube; then, holding it in this position, move it somewhat quickly, but very slightly and regularly, back and forth three or four times exactly in the direction of its length, and, if necessary, changing the angle of inclination and increasing, very cautiously, the intensity of the shaking motion until two or three gentle clicks may be heard. Too great care cannot be exercised in this respect, and only the most gentle clicks should be produced. Even then, with very perfect vacua, the internal stress is very great, and barometer tubes that have been subjected to boiling in the process of filling and are not thoroughly annealed are sometimes in such a state of internal stress as to be very easily cracked and injured.

In addition to the technique of using the "metallic click" to judge the quality of the vacuum, there is an alternative method which is often valuable in the hands of persons experienced with the characteristics of mercury barometers of a given type, and this method involves the measurement of the size of the air bubble at the top of the tube while the instrument is lying in a horizontal position. The instructions in sec. 2.2.7.3 should be followed during the process of placing the barometer in this position, and the barometer should be laid carefully on a table or other flat surface. Next the hanger ring cover cap should be removed from the top of the instrument. If there are inserts above the top of the tube, they should be removed and kept in a safe place until they are needed for re-insertion when the barometer is later reassembled. An inspection should be made of the upper portion (closed end) of the tube to determine whether an "air bubble" is visible. If no bubble is visible, the barometer should be erected to its normal vertical position, then it should be tapped gently, and finally it should be again inclined and brought to a horizontal position, following carefully the instructions in sec. 2.2.7.3 when performing these operations.

At this stage the closed end of the tube should be re-examined with a view to determining the size of the "air bubble," if any. In case a bubble is observed, an effort must be made to measure it. To accomplish this, the bubble should be illuminated with a small light source such as a flashlight, and a narrow scale should be introduced into the barometer shell to permit the measurements to be made. If necessary, a scale suitable for this purpose may be prepared by using a narrow strip of paper or cardboard and marking small graduations at equal millimeter intervals on the narrow end.

The diameter of the bubble should be measured with the aid of the scale, employing a magnifying glass when making the observation. An indication regarding the maximum size of the bubble which can be tolerated has been given by F. A. Gould in Vol. III of "A Dictionary of Applied Physics," edited by Sir Richard Glazebrook, London, (1923), page 157. According to Gould, a bubble not exceeding 1.3 mm. in diameter may be tolerated for a tube having a bore of 1/4 inch; while in the case of a tube having a bore of 1/2 inch, a bubble whose diameter exceeds 2 mm. would be considered excessive. (These values of the bubble size are given for guidance only, and they must be regarded as approximate.) After measuring the bubble, it is necessary to replace the hanger ring cover cap while the barometer is still in a horizontal position.

If an excessive amount of air appears to be present in the tube of a barometer located at a field station, the fact should be reported to headquarters (see sec. A–2.17.0). When there is a small amount of air in the tube, the procedures outlined in sec. A–2.17.2 may be applied by experienced, authorized personnel in an effort to remove the bubble.

A–2.18 HAZARDS OF MERCURY; AND CONTROL OF ITS VAPOR CONCENTRATION

In laboratories and shops where mercury is extensively used and handled, persons exposed to it may be subject to certain hazards since this substance is toxic[47]. Mercury can enter the human body through any exposed area of the skin or tissues, even though intact. Most commonly, mercury is absorbed through the respiratory tract when air contaminated by its vapor is inhaled. There are numerous cases where mercury droplets have fallen onto clothing, equipment, floors, and work benches, producing sources of the vapor and mercury-containing dust which may remain for long periods of time. Cigarettes tapped on such benches will be generally contaminated with mercury, so that smoking of them will lead to inhalation of the mercury vapor.

Mercury spilled on an ordinary work bench or floor will tend to disperse in the form of minute droplets within cracks and even under baseboards, therefore being extremely difficult to clean up. A little calculation shows that the total surface area presented by say several ounces of mercury in the form of such very small droplets is quite considerable, enhancing the ability of the liquid to yield a copious supply of its fumes, whose vapor pressure rises rapidly with temperature (see sec. 2.4). It has been observed that in a room thus contaminated with mercury the effect of a person walking across the floor is to raise the concentration of the mercury vapor very considerably[48].

Investigations of the concentration of mercury vapor in scientific laboratories have shown that the concentration tends to be highest in unventilated rooms where there has been mercury spilled on benches, equipment, floors, etc., without adequate cleanup. The concentration is raised if equipment operating at relatively high temperatures has been contaminated. Experience indicates that it is very difficult, if not impossible, to remove completely all traces of mercury

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[47] Goldwater, L. J., "The Toxicology of Inorganic Mercury," Annals of the New York Academy of Sciences, vol. 65, pp. 498–503, (April 11, 1957).

[48] Shepherd, M., Schumann, S., et al., "Hazard of Mercury Vapor in Scientific Laboratories," Jour. of Research of the National Bureau of Standards, vol. 26, pp. 357–375, (1941).

from equipment, floors, workbenches, and the like, with which it has come into contact[48].

Clinical medical studies suggest that persons exposed over a period of time to concentrations of more than 0.1 milligram of mercury vapor per cubic meter of air are likely to suffer from a chronic illness, termed "mercurialism," whose effects are well known from experience in the felt-hat industry.[47–50] It may be noted in passing that the most frequent manifestations of chronic mercury poisoning are quoted by Goldwater[47] to be: "(1) gingivitis and stomatitis, often associated with loss of teeth; (2) tremor, involving the hands and later other parts of the body; (3) personality change known as erethism. This condition is characterized by irritability, bursts of temper, and excitability, sometimes alternating with depression. There are numerous other signs and symptoms, including salivation, loss of appetite, weight loss, weakness, and disturbances of urinary and gastrointestinal function." Sometimes the symptoms include loss of memory, difficulty in concentrating on study, colicky pain, and pain in the back, the latter two possibly bearing no relation to the nature or to the time of meals.[51] Occasionally, mercury may cause injury to the kidneys.

As in the case of other toxic and irritant substances, the effects of mercury vary with different individuals, depending upon the personal susceptibility or hypersensitivity; hence some may be much more affected than others for the same exposure to the vapor or intake of mercury.

Control.—Prevention of the hazards due to mercury depends upon the measures taken to control the concentration of its vapor in the air of the work spaces and the exposure of individuals to this toxic substance or to dust containing it. The following control measures have been suggested:[47 48]

(A) Mercury not in use should be kept in sealed bottles.

(B) All containers of mercury having the substance directly exposed to the air and all processes involving the use of mercury should be in enclosed and segregated spaces, whenever possible.

(C) General ventilation providing for an adequate number of changes of air per minute is essential in spaces where mercury is used with free surfaces; and local ventilation such as by means of exhaust hoods is necessary for special equipment and processes involving the actual use of liquid mercury or the volatilization of the substance, such that there is a possibility that the mercury vapor may escape into the room. For example, vessels containing exposed mercury should be kept in a well ventilated hood exhausted to the outside; and the exhaust of mercury diffusion pumps should be piped to an out-of-doors location so that there is no chance for the exhaust materials to enter the intake of the ventilation system. A threshold limit to the concentration of mercury vapor regarded as permissible in work spaces for human beings is 0.1 milligram per cubic meter of air; this value serving as a guide for the control of the ventilation.

(D) The atmosphere in work spaces should be tested periodically to determine that on the average the concentration of mercury vapor is well below the threshold limit and that the concentration never exceeds the threshold limit. Devices are available on the market to measure the mercury-vapor concentration on the basis of the scattering by the vapor of ultraviolet light at a wavelength of 0.2537 micron, as determined by means of a photoelectric tube.[47 48] In order to check the concentration of mercury-containing dust in the air one must use a dust-sampling device; for example, an apparatus in which the air containing the dust is forced to impinge on a surface capable of holding the pollution so that it can be measured.[52]

(E) All mercury which has been spilled must be cleaned up promptly; and in laboratories or shops where much mercury is handled special provisions are essential to catch such mercury and to prevent the collection of mercury in unwanted places.

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[49] Neal, P. A.; Jones, R. R.; et al., "A Study of Chronic Mercurialism in the Hatters' Fur-Cutting Industry," U.S. Public Health Service Bulletin No. 234.

[50] Neal, P. A.; Elinn, R. H.; Edwards, T. I.; et al., "Mecurialism and Its Control in the Felt-Hat Industry," U.S. Public Health Service Bulletin No. 263.

[51] Goldwater, L. J.; Kleinfeld, M.; and Berger, A. R.; "Mercury Exposure in a University Laboratory," A.M.A. Archives of Industrial Health, vol. 13, pp. 245–249, (1956).

[52] Barnes, E. C., "Determining the concentration of mercury in air," Am. Ind. Hyg. Assoc. Quart., vol. 7, p. 26, (1946).

With regard to the need for "scrupulous attention to 'housekeeping'" to which Goldwater[47] refers in this connection, he adds the following remarks: "The last of these requirements may call for the installation of impervious flooring slanted to a water-trapped catch basin and special covering of all floor-to-wall and floor-to-machinery joints. Spilled mercury that does not run to the catch basin should be picked up immediately with a vacuum line connected to an inertia water trap. Periodic sweeping with flowers of sulfur, calcium polysulfide, or a thiosulfate-type reagent is often desirable. Workbenches on which mercury is handled should have built-up edges to prevent spillage to the floor and should be slanted to a water-sealed collecting vessel."

In well planned laboratories where the relevant safety problems have been given careful consideration, specially designed workbenches are provided, equipped with an exhaust system for removing mercury vapors from the working area. These tables not only have built-up edges to prevent spillage of mercury but also are designed to collect mercury vapor from the table and to prevent its dispersal. The built-up edges of the table contain stainless steel tubing, leading to a manifold, through which vapors are exhausted to the outside by means of an exhaust fan. The entire working area and exhaust system are constructed of stainless steel. The manifold contains a trap from which spilled mercury can be removed.

It is possible to reduce the concentration of mercury vapor in a room by circulating the air over iodized charcoal,[48] or through a chemical cartridge respirator,[47] which should be changed after use for 2 or 3 days. Respirators should also be used to protect personnel from mercury-containing dust, whenever its concentration exceeds a safe threshold.

With regard to other preventive measures, Goldwater[47] presents the following remarks: "Work uniforms that are changed and laundered frequently, separate lockers for work and street clothing, adequate washing facilities and wash-up time, a suitable eating place free of mercury contamination, all are among the provisions that the employer must make available." These matters are important to those working in industrial or laboratory environments where relatively high concentrations of mercury vapor and mercury-containing dust may be present.

Further details of value regarding this subject may be quoted from authorities:[53]

"Housekeeping is probably the most important factor in protecting employees against mercury toxicity. Any spillage should be picked up immediately, and every precaution taken to avoid large evaporating surfaces of mercury in the atmosphere of the room. If the spillage occurs in an area where no cracks or crevices in the flooring may entrap mercury, it is sufficient to pick up the mercury and then spread 'flowers of sulfur' on the floor. If cracks or crevices are present, it may be necessary to use a water-soluble vapor retarder, such as calcium polysulfide. The picking up of spillage should be accomplished with a vacuum line and water trap. Vacuum cleaners are generally unsatisfactory. While such cleaners pick up mercury and while the Rex Air uses a water trap, it has been shown that the fittings, hoses, etc., of these cleaners become contaminated with mercury and blow mercury vapor into the room.

"If all other precautions, such as the above, are observed, it is desirable to wash down the room once a week or once a month (walls and floor) with a preparation of the thiosulfate type. An alternative for floor treatment is to use 'flowers of sulfur' as a sweeping compound. This latter material may be used, however, only where the flooring is reasonably crack- and crevice-free."

A–2.19 FLAT MENISCUS OF MERCURY UNDER CERTAIN CONDITIONS

Sometime during the latter part of the 18th century, a Supplement of the famous French "Dictionnaire encyclopédique" was published by Dom Casbois, a Benedictine, principal of the College of Metz, describing a method for filling barometers which would yield a flat meniscus in the tube of the in-

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[53] Kramer, I. R.; and Goldwater, L. J.; "Investment Casting by the Frozen-Mercury Process," A.M.A. Archives of Industrial Health, vol. 13, pp. 29–33, (1956).

strument. This matter was studied by the well-known chemist A. L. Lavoisier (1743-1794), who outlined the results of his investigations in a memoir (see: "Extraits des Mémoires de Lavoisier concernant la Météorologie et l'Aéronautique" publiés par les soins de l'Office National Météorologique de France, E. Chiron, Editor, Paris, 1926, pages 127–132).

In the method of Dom Casbois the basic barometer system was made entirely of glass, consisting of a bulb blown at the closed end of the tube and another near the open end, with the tube bent back in a U-shape a few inches from the latter bulb so that the second bulb with its opening pointed upward could serve as the barometer cistern. As preliminary steps, the pure mercury available was boiled and the glass sytem was heated until it was red, after which the glass was allowed to cool. Then, the system was filled with the warm mercury while the tube was nearly horizontal but inclined, with the open end elevated slightly in comparison with the bulb at the closed end. While in this inclined position, the system was heated over charcoal and the mercury was brought to a boil, so that air and water vapor trapped in the system or mercury was expelled and at the same time no air from outside could enter.

After some moments of thorough boiling of the mercury in this position of the instrument, the barometer was placed in a vertical situation, cistern end down. Lavoisier observed that if the meniscus at the upper end of the barometer was flat after cooling of the mercury it would remain in that condition indefinitely. If it were not flat on the first trial, repetitions one or two times of the boiling process as previously described would finally bring the meniscus to a flat state. Lavoisier experimented in order to determine how he could cause the meniscus in the tube to change from a flat to a convex form, and the only technique he found successful for this purpose was the introduction of a small bubble of air into the vacuum space. Also, the meniscus in the cistern was seen to be flat, but he observed that it gradually transformed from a plane to a convex shape over a period of several days immediately following the boiling procedure.

The capillary effect is, of course, not present in a perfectly plane meniscus; and Lavoisier endeavored to demonstrate this by means of a glass siphon consisting of two tubes, one about 33.8 mm. inside diameter and the other about 0.56 mm. inside diameter. Before heating the mercury, the level of the meniscus in the smaller tube was depressed relative to that in the tube of larger diameter owing to capillary action. However, after successive boilings of the mercury to expel air and water vapor from the siphon, he observed that the levels of the two menisci progressively approached one another, but he was not able to bring them to exactly the same level. Lavoisier reached the conclusion that the kind of repulsion which glass appears to exert on mercury in capillary tubes is not due really to the glass itself, but that it is due either to a thin film of water which covers over the glass or to particles of water contained and combined in the mercury. He did not mention any effect of a thin film of air, which might have been added.

In 1939, A. E. Bate[54] of London reported that a well-known instrument firm had provided him with double distilled mercury in a clean glass tube, such that at each point of contact of the mercury with the glass the angle of contact was 90°. The mercury had been boiled in the partly filled tube which afterwards was evacuated and sealed. When the axis of the tube was vertical, the surface of the mercury was found to be plane. The internal diameter of the tube was 0.9 cm. By measurements and calculations Bate determined that the surface tension of the mercury in vacuo was 490 dynes per cm. at 20° C, under the stated conditions, the angle of contact being 90°. Finally he studied the effect of exposing the mercury to air, and in connection with this matter he stated the following: "When the tube was cut and the air entered, the mercury meniscus became slightly convex the contact angle being about 100°; two days later this had increased to about 135°, with a marked tendency to adhere to the tube. This tendency diminished after a period of two days."

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[54] Bate, A. E., "The Surface-Tension and Angle of Contact of Mercury in Vacuo," Phil. Mag., Ser. 7, vol. 28, pp. 252–255, (1939).

W. E. K. Middleton,[55] in his book "Meteorological Instruments," Second Edition, University of Toronto Press, Toronto, 1947, indicated that on two occasions, barometers which were filled by the so-called "boiling method" (see sec. A–2.15) have had almost exactly flat menisci, and he conjectured that the possible cause of this phenomenon might be that the barometers in question were outgassed more drastically than usual.

It has been observed by Wichers[56] and colleagues of the National Bureau of Standards[57] that when a clean evacuated ampule was partially filled with pure dry mercury, the resulting meniscus was *flat*, indicating that there existed an equilibrium between the two interfacial tensions S_{sg} and S_{sl} acting vertically along the glass wall at the line of contact of the meniscus (see sec. 2.7.1). As reported by Briggs,[58] after such a result was obtained, *dry* air was admitted over the meniscus, but this did *not* lead to any perceptible change in its form, the meniscus remaining flat. Sealed tubes of mercury produced in this manner have been kept for over a dozen years without apparent change in the flat form of the meniscus, or reversion to the characteristic convex shape.

Briggs,[58] also of the National Bureau of Standards, has investigated this peculiar behavior of mercury, and he found that the phenomenon could be repeated at will, even with ampules of Pyrex glass having an internal diameter of 1 cm., under certain conditions.

He has described his experiment in the following words: "The tubes were evacuated with a diffusion pump, degassed at about 500° C., partially filled with mercury by distillation and sealed off. One tube was then opened to the air of the laboratory, when the meniscus assumed the characteristic convex form. The meniscus in the other evacuated tube was *flat*, out to the very wall of the tube. In fact, an examination of the edge of the meniscus under a magnifying glass gives the impression that the mercury is trying to climb the wall."

The foregoing experiment suggested to Briggs that under suitable conditions mercury might withstand a considerable negative pressure. The first experiment to demonstrate the validity of this idea was performed with manometers, as that author has explained: "A U–tube manometer of Pyrex glass with one leg sealed off was evacuated and degassed at about 500° C. with a mercury-vapor pump. With the pump still operating it was then filled with mercury by distillation. The length of the mercury column from the sealed end to the meniscus in the open leg was 52 cm. The bore of the tube was 5 mm.

"After filling, this manometer was mounted vertically and the open leg was evacuated. But nothing happened. The mercury column remained hanging from the top of the closed leg. This was so startling that I mistrusted the pump until it had been tested against another manometer.

"This experiment demonstrated conclusively that the negative pressure which mercury in glass was capable of sustaining exceeded two-thirds of an atmosphere. Only by vertical jarring was the column finally released, when the mercury assumed the same level in both legs of the tube."

In other words, when a clean glass tube is outgassed to an adequate degree by heating it to a suitable high temperature under vacuum and pure dry mercury is admitted to the tube so as partially to fill it, followed by further evacuation of the space above the mercury and finally sealing of the tube, a flat meniscus is present on the liquid, showing that under these conditions the opposing vertical interfacial tensions S_{sg} and S_{sl} balance along the glass as implied by the theory given in sec. 2.7.1, and that the mercury can therefore manifest the phenomenon termed "negative pressure." The outgassing under vacuum at first removes most of the gases adsorbed on the glass surface, and the heating at the maximum temperature the glass can withstand before it becomes softened removes the final monomolecular film of water and adsorbed gases.[59]

In order to determine the limiting nega-

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[55] See also W. E. K. Middleton and A. F. Spilhaus, "Meteorological Instruments," Third Edition, University of Toronto Press, Toronto, 1953, p. 39.

[56] Wichers, E., "Pure Mercury," Rev. Sci. Inst. vol. 13, pp. 502–503, (1942).

[57] Private Communication.

[58] Briggs, L. J., "The Limiting Negative Pressure of Mercury in Pyrex Glass," J. Appl. Phys., vol. 24, pp. 488–490, (1953).

[59] Strong, J., et al., "Procedures in Experimental Physics," Prentice-Hall, Inc., New York, 1939.

tive pressure which mercury could withstand, Briggs employed a centrifugal method. In this method the mercury is held in a capillary tube mounted on a horizontal spinner attached to the vertical axis of a variable-speed motor. The capillary tube is mounted in such a manner that the midpoint of the mercury column is intersected by the spin axis. One half of the liquid column thus pulls against the other half, owing to the centrifugal force acting in opposite directions upon the fluid material located in the two arms of the tube. By increasing in steps the angular speed of rotation of the tube about the vertical axis, Briggs was able to ascertain the negative pressure at the time the column of mercury broke near its center, under the existing centrifugal force.

It is known that the degree of degassing of a capillary tube subjected to a given vacuum pressure is dependent upon the temperature to which the tube is heated at the time of evacuation. The results given by Briggs show that when the tube was heated with a torch or in an electric furnace at various temperatures, the limiting negative pressure which the column of mercury would sustain increased roughly with the temperature, hence with the degree of degassing, as illustrated by the data in the following table:

TABLE

Limiting negative pressure of mercury (P_n) in Pyrex glass

Tube No.	P_n	Treatment
	bars	
9	46	Torched.
10	10	Not torched.
11	7	Not torched.
12	47	Furnace, 200° C.
	57	Furnace, 200° C.
13	277	Furnace, 450°–500° C.
	323	Furnace, 450°–500° C.
14	338	Furnace, 450°–500° C.
15	425	Furnace, yield point.
16	383	Furnace, yield point.

Briggs gave the following comments regarding the data presented in the table: "Comparison of tube 9 with 10 and 11 shows the importance of heating the tube during evacuation, even if the capillaries are freshly drawn. The remaining tubes were accordingly heated in a tubular electric furnace during evacuation.

"It will be noted that two values are given for tubes 12 and 13. In each case, as the speed of the motor was increased, a short segment first tore off from the outer end of the column and moved to the sealed-off end of the capillary. This gave the first value. The shortened column was then remeasured and the speed increased in successive steps until the mercury column broke at its intersection with the spin axis, which lead to the second higher value."

In the case of tubes 15 and 16, the temperature of the furnace was raised beyond that existing in the cases of tubes 13 and 14 to the point where the vertical capillary distorted slightly under the existing asymmetric load, showing that the glass had reached its yield point. One end of tube 16 broke off under the great stress due to the high centrifugal force used at the end of the experiment.

Referring to the data for tube 15, it may be pointed out that the maximum limiting negative pressure sustained by mercury in a fine capillary tube of Pyrex glass was about 425 bars (where 1 bar = 1,000 millibars = 0.986 atmosphere), under experimental conditions when the temperature was 27° C. In this case the stress was increased in 16 steps, commencing with a negative pressure of 120 bars. The bore of the capillary tube was about 0.14 mm.

The conclusion to be reached from the experiments described by Briggs is that when a Pyrex glass tube is evacuated and thoroughly degassed at a high temperature before it is filled with pure dry mercury, the liquid will have a relatively flat meniscus and can support a strong negative pressure, which could be manifested if the mercury were forced to the top of the glass tube. A perfectly flat meniscus does not involve a capillary force acting perpendicular to the surface, hence the technique presents a possibility of eliminating the capillary correction pertaining to the meniscus in the glass tube of a barometer, if desired for special purposes (see Appendix 1.4.2, and secs. 2.7.1 and A–2.5).

It has been shown experimentally by Schumacher[60] and Manley[61] that by subjecting the glass and mercury to certain treatments it is possible to obtain flat mercury menisci with considerable regularity. By means of certain procedures it is even possible to obtain concave-upward menisci, which yield a capillary rise, indicating that the mercury "wets" the glass in this case. The extreme angle of contact obtainable with a mercury meniscus is strongly influenced by the cleanness and chemical composition of the glass. This was indicated by the experiments of Schumacher,[60] who observed that fairly good wetting can generally be obtained on quartz, while on Pyrex and soda-lime glass it is obtained only occasionally. The flat meniscus is produced more frequently with Pyrex than with soda-lime glass, the latter of which has a higher alkaline content than the former.

A–2.20 PACKING, TRANSPORTING, AND SHIPPING MERCURY BAROMETERS

A–2.20.0 Introduction

Since mercury barometers are delicate instruments, easily susceptible to breakage, they must be packed, transported, and shipped with particular care and in a special manner. The reasons underlying these requirements are indicated partially in sec. A–2.16. Whenever a mercury barometer is to be moved or shipped any great distance, the instrument must be maintained in a certain position during the transit to its destination. Therefore, in sec. 2.2.7.0 information and instructions have been provided concerning the appropriate position for transporting and shipping each type of mercury barometer. Secs. 2.2.7.1-2.2.7.4 describe the proper methods for tilting and inverting certain types of barometers, such as the Fortin and the Navy marine-type mercury barometers. Everyone who is called upon to pack, transport, or ship barometers should become thoroughly familiar with the instructions given in those sections before endeavoring to undertake such actions, and should follow the instructions carefully. Caution must be exercised when handling barometers never to drop or jolt them. It is necessary to avoid subjecting these instruments to abrupt, rapid movements and accelerations or decelerations, owing to the fact that such violent changes of motion produce relative forces between different parts, thereby causing strains and possibly serious damage to the equipment. (See sec. A–2.16.)

A–2.20.1 Packing and Shipping Mercury Barometers

Before any personnel take action to pack or ship any type of mercury barometer they should read the relevant lettered paragraphs, (a)–(i), in this section, below. Paragraph (a) under sec. A–2.20.1.0 provides general information pertaining to the shipping of Fortin-type barometers; while paragraph (b) is of special concern to military personnel and paragraph (c) to Weather Bureau personnel. Paragraph (d) should be consulted whenever a regular packing case is unavailable, and it becomes necessary to improvise one. Paragraph (e) gives information in regard to elastic packing materials employed for safeguarding barometers during shipment; while paragraph (f) covers the matter of saving packing cases and materials for future use. Paragraph (g) indicates the action that must be taken when a barometer becomes defective. The application of carrying cases for transportation by hand of Fortin barometers when speed is essential is covered in paragraph (h). Readers concerned with finding the proper specific instructions on packing various types of barometers for shipment should consult the directory contained in paragraph (i), which refers to the pertinent sections A–2.20.1.1 to A–2.20.2 where detailed information is provided.

A–2.20.1.0 General Information on Packing Procedures

Most available mercury barometers are shipped in an inclined or in an inverted position with the cistern higher than the glass tube, as described in secs. 2.2.7.0-2.2.7.5; but there are certain exceptions regarding this

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[60] Schumaker, E. E., "The Wetting of Glasses by Mercury," Jour. Amer. Chem. Soc., vol. 45, pp. 2255–2261, (1923).

[61] Manley, J. J., "On the Capillary Action of Mercury in the Absence of Gas-Grown Skins," Phil. Mag., 7th ser., vol. 5, pp. 958–962, (1928).

matter as explained under sec. 2.2.7.0, paragraph (3) and sec. 2.2.7.2, paragraph (3).

The Instrument Laboratories, Supply Depots, Regional Headquarters, etc., of the various agencies may employ slightly different methods of packing barometers; and personnel in the field can learn the latest approved methods by observing the manner of packing instruments used by their Laboratories and Depots.

In this section some general information is given regarding procedures which have been found to work satisfactorily for packing and shipping barometers. Since the Fortin barometer is the type most commonly used in the United States, information relative to the packing of that variety will be presented first.

(a) **General Facts Relating to Fortin-Type Barometer Shipments.**—The Fortin barometer is generally shipped in an inclined position with its cistern end elevated a few inches above the tube end of the instrument. A sturdy wooden packing box is required for housing the barometer and keeping it surrounded with elastic packing material so that it will be protected against damage during shipment. It is the practice to construct this box with pointed or rounded ends so that it will not be possible for the box to stand on end. Such pointed or rounded ends are used in order to prevent shipment of the barometer in an erect position, since transportation of the instrument in that position would cause damage to it under the usual circumstances. Therefore, when a shipping box contains a Fortin barometer, personnel should never carry the box in such a manner that the instrument is held in its normal erect position; but rather the reverse is necessary, that is, the tube end must be down. That is, the box with the barometer should be carried and shipped in such a manner that the cistern end is always raised at least a few inches above the end of the glass tube containing the column of mercury. With regard to the thickness of the elastic packing material layer, it is suggested as a general rule that the layer never be less than two (2) inches thick between the instrument and the next adjacent solid surface (such as the interior of the packing case), while in some instances specific instructions are given to use an even greater thickness (such as four inches).

(b) **Special Packing Cases for Fortin-Type Barometers Used by Military Agencies.**—The military agencies employ special packing cases for shipping Fortin-type barometers. Such packing cases are of two designs, depending upon the bore of the barometer tube and the size of the instrument. Sec. A–2.20.1.2 describes the special packing case used for the small-bore Fortin-type barometer; while sec. A–2.20.1.3 presents an indication relating to the carrying case applicable to the large-bore Fortin barometer. Should a situation ever arise where a packing case is needed and the pertinent standard packing case is not available, the directions contained in sec. A–2.20.1.4 can be followed with a view to improvising a suitable packing case. Appropriate instructions for packing the barometers of the two sizes in the respective special packing cases are given in the sections specified above.

(c) **Shipping Cases for Fortin-Type Barometers Used by the Weather Bureau.**—The Weather Bureau employs certain packing cases for shipment of the instruments, but these are different in design from those referred to in the previous paragraph. For use within the continental limits of the United States where shipment of the barometers by Railway Express is carried out with special care, the Weather Bureau packing case generally has inside dimensions of about 8 in. x 8 in. x 48 in., applicable to Fortin-type instruments of 1/4-inch bore. Here it is assumed that careful handling will be given during transit. However, for use when the barometers are to be shipped overseas or when the quality of the handling which the shipment might receive is less certain, a heavier box of larger inside dimensions is required. This is true also for shipping barometers whose bore is larger than 1/4 inch.

At this stage additional information is given concerning the packing box used by the Weather Bureau for shipping Fortin barometers which have a 1/4-inch bore. Fig. A–2.20.0 illustrates the box. This variety

FIGURE A–2.20.0. Standard packing box used by the U.S. Weather Bureau for express shipment of Fortin barometers within continental United States. Barometer is wrapped in tissue paper, 2-inch layer of elastic packing material, single-faced corrugated cardboard, and kraft paper. In the packing box the instrument thus wrapped is surrounded on all sides by 2 to 4 inches of elastic packing material. Packing box is carried inclined, with cistern end up.

can be constructed of 1-inch wood by any carpenter. Its smaller inside cross-section, 8 in. x 8 in., is just large enough to hold the barometer with an adequate amount of elastic packing material around it to yield protection to the instrument under routine shipping conditions, and its length of about 48 inches leaves room for roughly 4 inches of such material on each end beyond the barometer to absorb shocks. The cover of the barometer box must be designed so that it will be screwed on, *never nailed,* since hammering on the box after it contains the delicate instrument would cause serious damage to the latter. Provision is made on the cover for a handle, usually made of heavy rope, and this handle is placed slightly toward the cistern end, a little off from the center of gravity, when the barometer is packed in the box. The purpose of this displacement is to cause the barometer to be inclined at a small angle such that the cistern end remains elevated about 4 inches above the tube end of the instrument when the box containing the device is carried by the handle. Pointed pieces of wood are nailed to the outside ends of the box before the barometer is enclosed. To illustrate a convenient way of making these, two pieces are cut in the form of an equilateral triangle, 8 inches on a side; and one of these pieces is bisected by sawing along a perpendicular to the middle of any side. The latter sawing operation yields two smaller pieces which are next arranged crosswise of the other larger equilateral piece and these all are nailed together; then the assembly is fastened by nails to the ends of the box for the purpose explained above, under (a).

(d) General Facts Relating to Improvised Packing Case.—Mention is now made regarding the packing box of larger inside dimensions used by the Weather Bureau for shipping Fortin-type barometers overseas or where the handling may not be as good as desired. The inside dimensions required for this box are generally about 16 inches depth, 12 inches width, and 51 inches length. A box of this size should be constructed from 1-inch wood when needed; and if it is necessary to improvise a packing box in the field in cases where a standard packing box is unavailable, the specifications given in sec. A–2.20.1.4 should be followed upon undertaking the construction. The improvised packing box may be prepared and used by representatives of any Service when a standard packing case is not at hand. It must have pointed protuberances on the ends; and the cover must be fastened in place by means of screws. Details regarding the method for packing a barometer in such a box are given in sec. A–2.20.1.4; but here the salient features worthy of special mention are stated, namely, that the cistern end of the instrument should be elevated about 4 inches above the tube end and that the elastic packing material should be at least 4 inches thick at all points around the inner package. This package containing the barometer should be wrapped in a manner at least as secure as that recommended for Weather Bureau Fortin barometers (see sec. A–2.20.1.1).

(e) Elastic Packing Materials and Wrapping Materials Needed for Shipping Barometers.—When a barometer is packed for shipment, it is first wrapped up in a suitable manner to be explained later, thus providing an inner package for the box where it must be completely enveloped by elastic packing material while it lies inclined at a proper angle. In what follows the term "*elastic packing material*" will be understood to refer to packing materials which, although sufficiently soft to prevent abrasion to equipment, are very resilient. Elastic packing material is essential for the surroundings of the inner package in which the barometer is carefully wrapped for protective purposes. The elastic packing material has several functions; it serves to cushion the instrument against shocks and jolts which could cause damage; it provides a medium which will resist deformation of the barometer by inertial forces; and it affords a safeguard against breakage by acting as a buffer which tends to hamper movement of the barometer relative to the walls of the box, when the latter is subjected to accelerations.

Various kinds of elastic packing materials are in use, but the variety considered best for barometer shipments is called "*bound cushioning material, firm.*" This cushioning material may be procured under Federal Supply Service Stock No. 8135-291-8619, in the form of 1/2-inch thick sheets, having dimensions 72 in. x 42 in. It is composed of natural or synthetic fiber bound with suitable elastic material, such as rubber; and an example of it which has been widely used for packing barometers is "*rubberized pig hair.*" One may readily combine the sheets of bound cushioning material into thicker layers, and the sheets may be cut into various forms for convenience if required.

Another kind of elastic packing material good for cushioning purposes is called "*plain cellulose wadding for packaging,*" stocked under Federal Supply Service Stock No. 8135-664-6958. This is without paper backing, is chemically neutral, and has little tendency to absorb water. Medium sheets 1 inch thick and 20 inches wide may be procured from Federal Supply Service in the form of a roll 60 feet long.

Excelsior or cotton batting may also be used as an elastic packing material when the kinds mentioned above are not at hand.

If no standard elastic packing materials are available, one may prepare an expedient by making wads of paper rolled into balls of suitable size and degree of compactness to secure the desired resiliency.

Apart from the materials mentioned above, certain wrappings are required for the inner package; and these always include tissue paper sheets, but in some cases, as explained later, they may also include corrugated cardboard (sometimes single-faced and sometimes double-faced), and finally kraft paper.

Personnel who carry out the shipping duties will be required to requisition the materials found to be necessary, according to the instructions.

(f) Saving the Packing Cases and Packing Materials for Future Use.—Whenever a barometer is received from any Headquarters, Depot, or Instrument Laboratory, the packing box or case in which it was shipped should be preserved for possible future use. All wrappings and elastic packing materials that were employed for protecting the barometer during transit are to be put back into the packing case. The cover of the box should be fastened on by means of screws. The packing case should be kept in a dry, clean place where it will be secure. A note should be entered in the Station Log book indicating the location of the place where the packing case is stored.

(g) What To Do About Defective Barometers.—When a barometer becomes defective, the facts should be reported to appropriate headquarters in accordance with instructions given in sec. A–2.20.1.8 and A–2.20.1.9. The latter section indicates what procedure is to be followed in case the mercury has leaked from the barometer.

(h) Use of Carrying Cases to Transport Fortin Barometers by Hand.—Where rapid mobility is essential and personal attention can be given to the handling of the instrument, advantage may be taken of the portability of the Fortin barometer by employing a suitable carrying case in accordance with the instructions given in sec. A–2.20.2. Portable cases used for military Fortin barometers are also described in secs. A–2.20.1.2 and A–2.20.1.3.

(i) Finding the Proper Specific Instructions for Packing Various Types of Barometers for Shipment.—In order to aid the reader to find the instructions for packing pertinent to the respective types of *mercury barometers*, a list of the subsections dealing with this subject is given below, and these can be found in the text which follows:

Section	Title
A–2.20.1.1	Instructions for Packing Barometers in an Inclined Position (Weather Bureau)
A–2.20.1.2	Packing Small-Bore Fortin Barometers in an Inclined Position (Military)
A–2.20.1.3	Packing Large-Bore Fortin Barometers in an Inclined Position (Military)
A–2.20.1.4	Improvising Packing Box and Packing Material
A–2.20.1.5	Shipment of Special Barometers in Erect Position
A–2.20.1.6	Shipment of U. S. Navy Type, Marine Barometers in Inverted Position
A–2.20.1.7	Shipment of Barometers of Unusual Type or of Kew Pattern
A–2.20.1.8	Reporting of Defective Barometers
A–2.20.1.9	Shipment of Defective Barometers, Emptied of Mercury
A–2.20.2	Transporting Mercury Barometers in Carrying Cases

A–2.20.1.1 Instruction for Packing Barometers in an Inclined Position (Weather Bureau)

When a 1/4-inch bore Fortin-type barometer is to be shipped within the continental limits of the United States, where careful handling of the packing case and its contents may be safely assumed, the packing box may have inside dimensions of about 8 in. x 8 in. x 48 in. The open box is placed with its long axis horizontal and a bed of elastic packing material having a suitable thickness is distributed within it. By following carefully the relevant instructions in sec. 2.2.7.3, the barometer is inclined and lowered to a horizontal position.

Personnel should carry out the operations specified below:

(1) Wrap the instrument in tissue paper.

(2) Surround this with a layer of elastic packing material about two inches thick.

(3) Make a snug wrapping of single-faced corrugated cardboard around the elastic packing material covering the barometer, as described in step (2) above.

(4) Finally, wrap kraft paper around the result obtained after performing step (3) above, and seal all openings with gummed tape to keep out dust, mois-

ture, etc. Completion of this operation yields what has been called "the inner package."

(5) Place the "inner package" containing the barometer about in the center of the box, and arrange the elastic packing material so that the cistern end will be maintained approximately one to one and one-half inches (1 to 1-1/2 in.) higher than the tube end of the barometer.

(6) Fill up all remaining space in the box with additional elastic packing material, particularly around the "inner package," so that the package will be protected from shocks and will not move about inside if the box is subjected to accelerations or jolts. The thickness of the elastic packing material around the "inner package" should be at least 2 to 3 inches, preferably 4 inches when possible.

(7) Fasten the cover on the box by means of screws. (*Never use nails for the purpose and do not hammer on the box.*)

(8) Check to see that when the box is held by the handle, the box will tilt with the cistern end up.

(9) Paint or stencil appropriate labels on the box, using letters not less than 1/2 inch high, indicating the need for careful handling, etc., for example, "Glass," "Fragile-Handle With Care," "DO NOT DROP OR STAND ON END, THIS BOX CONTAINS A GLASS TUBE FILLED WITH MERCURY."

In case a packing box with inside dimensions 8 in. x 8 in. x 48 in. is unavailable, or if the barometer must be shipped by some means where careful handling cannot be assumed, a larger packing box of the size described in sec. A–2.20.1.4 is recommended for use. Such a box may be improvised if necessary.

A–2.20.1.2 Packing Small-Bore Fortin Barometers in an Inclined Position (Military)

Small-bore barometers are classed as those with a glass tube whose internal diameter is about 1/4 inch. In this category are barometers ML–2 and ML–512 having adjustable cisterns used at meteorological stations of the U. S. Air Force and the U. S. Army (see figs. 2.2.2 and 2.5.0). These instruments are identified by Federal Stock Number (FSN) 6685-224-6350 and are described in the following terms:

Barometers ML–2() and ML–512 are Fortin-type mercurial barometers intended for permanent indoor installation. The range is 22 to 32 inches. They are graduated in inches and millibars. The attached thermometer is graduated in degrees Fahrenheit and Celsius (°C.). A case ML–48–() is provided for wall mounting.

Case CY–1320/UM is issued as a standard packing case for shipping barometers of the category listed above; and it is illustrated in figs. A–2.20.1 and A–2.20.2. With each case of this kind there are provided thick wedges of rubberized curled pig hair or similar elastic packing material. These wedges are arranged in an alternating manner in the packing case so that they will hold the barometer in position as shown in fig. A–2.20.2, maintaining it at an angle of inclination so that the cistern end is elevated at a level about 4 inches higher than that of the other end. When the case is carried by means of the handle, a nearly equal angle is obtained. The approximate dimensions and weight of Case CY–1320/UM are as follows: Length 55 inches overall; width 21 inches; height 18 inches; and weight of the case containing a barometer of the ML–2 and ML–512 series 42 pounds. The case has a rounded end near the place where the cistern fits into position, so that it cannot be stood on end. Six loose pieces of the rubberized pig hair as shown in fig. A–2.20.2 come with Case CY–1320/UM, but the remaining pieces of pig hair are cemented to the inside of the case and are not removable.

The first step before packing the barometer is to incline the instrument to a horizontal position, following carefully the directions given in sec. 2.2.7.3 (see also secs. 2.2.7.0 and 2.2.7.1). Next, the barometer is wrapped in tissue paper. It is then set in the rubberized pig hair in packing case CY–1320/UM. The wedge-shaped pieces of rubberized pig hair are placed in the case in such a manner as to prevent the barometer from moving in any direction and to keep

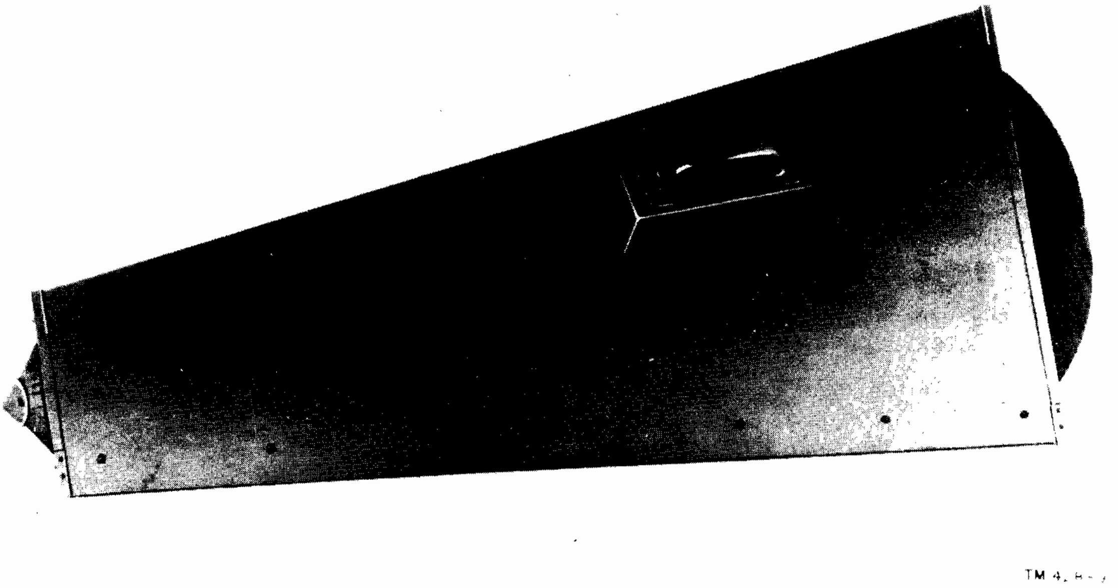

FIGURE A-2.20.1. Packing case CY-1320/UM used by U.S. Army and U.S. Air Force for shipping Fortin barometers of type ML-2 (), showing cover screwed in place and handle nearer cistern end of barometer which is carried inclined up (U.S. Army photograph).

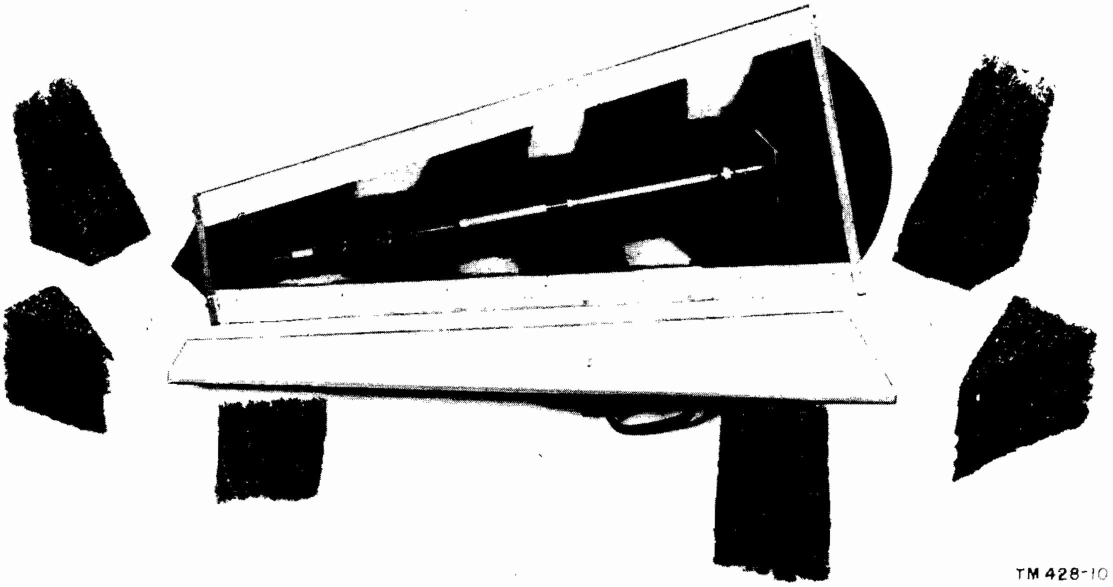

FIGURE A-2.20.2. Interior view of packing case CY-1320/UM used for shipping Fortin barometers of type ML-2 (), showing separate cover and wedges of elastic rubberized packing material employed to hold barometer in place and to help protect it against shocks (U.S. Army photograph).

the cistern end of the barometer raised up several inches above the other end. (See fig. A–2.20.2 to gain an idea of the arrangement when the barometer is first set into position.) The cover of the case is fastened by means of screws, as indicated in fig. A–2.20.1.

After receipt of the case with its contents at the destination, the barometer is to be raised to a normal, erect position in accordance with directions given in sec. 2.2.7.3, and installed in Case ML–48 (see figs. 2.2.2 and 2.2.3). Instructions for the installation are given in secs. 2.2.4.0-2.2.4.4. The tissue paper and the removable pieces of rubberized pig hair must be replaced in Case CY–1320/UM, and the cover of the case must be screwed on. It is essential for the case to be kept securely where it will remain dry and clean, so that it will be available for use when it may be necessary to reship the barometer at a later date.

A–2.20.1.3 Packing Large-Bore Fortin Barometers in an Inclined Position (Military)

Large-bore barometers are classed as those with a glass tube whose internal diameter is about 0.5 to 0.6 inch, or larger. This group of instruments includes barometer ML–330/FM, which is a Fortin-type mercury barometer larger in size than barometer ML–2 or ML–512. Barometer ML–330/FM is of the kind installed in each of the Regional Maintenance Shops of the U. S. Air Force, Air Weather Service (see figs. 2.2.5 and A–2.20.3). It serves as a substandard instrument for the region. It is identified by Federal Stock Number (FSN) 6685-244-1775 and is described as follows:

Barometer ML–330( )/FM is a mercurial barometer of laboratory precision which has been calibrated against the U. S. Army secondary standard at Signal R&D Laboratory, Fort Monmouth, N. J. It is larger and more accurate than the ML–2 and ML–512 above, but otherwise almost identical. It is provided in two scales ranges: 23.7 to 31.3 inches and 21.5 to 31.3 inches. It is graduated in inches and millibars.

In view of its use as a substandard, barometer ML–330/FM is generally transported by hand in a carrying case, illustrated in fig. A–2.20.3.

The carrying case is constructed of a sturdy plywood box, rectangular in shape, painted olive drab outside and varnished inside. The case opens longitudinally and is 51 inches long by 8 inches square. It has metal corners and is fastened with three trunk catches. The lid is one and one-half (1 and 1/2) inches deep and is attached by two piano hinges. A handle is provided for transporting the case by hand. Rounded pieces of wood are attached to one end of the carrying case in such a manner that the case cannot be stood on this end. When the barometer is packed in the carrying case, the cistern is placed toward the end to which these rounded pieces are attached (see fig. A–2.20.3). This arrangement is used so that during transit the cistern of the barometer will be higher than the end of the glass barometer tube as illustrated by the figure. To help protect the instrument during transit, the barometer is first wrapped in tissue paper and then packed in rubberized curled pig hair to prevent it from displacement within the box and to safeguard it from shocks.

If a packing case is needed and the standard carrying case shown in fig. A–2.20.3 cannot be found, a suitable packing box can be improvised in accordance with instructions given in sec. A–2.20.1.4.

Following receipt of the carrying case with its contents at the destination, a suitable site for installation of the barometer must be found and the barometer installed in accordance with instructions in secs. 2.2.4.0–2.2.4.4. The mounting case for barometer ML–330/FM is illustrated in figs. 2.2.4 and 2.2.5. The directions given in sec. 2.2.7.3 must be observed when raising the instrument to the normal, erect position. All wrapping and elastic packing materials taken from the carrying case must be replaced; and the carrying case, properly closed, must be safeguarded in a clean, dry location for future need.

A–2.20.1.4 Improvising Packing Box and Packing Material

Situations may arise where a standard packing case is not available, and it is nec-

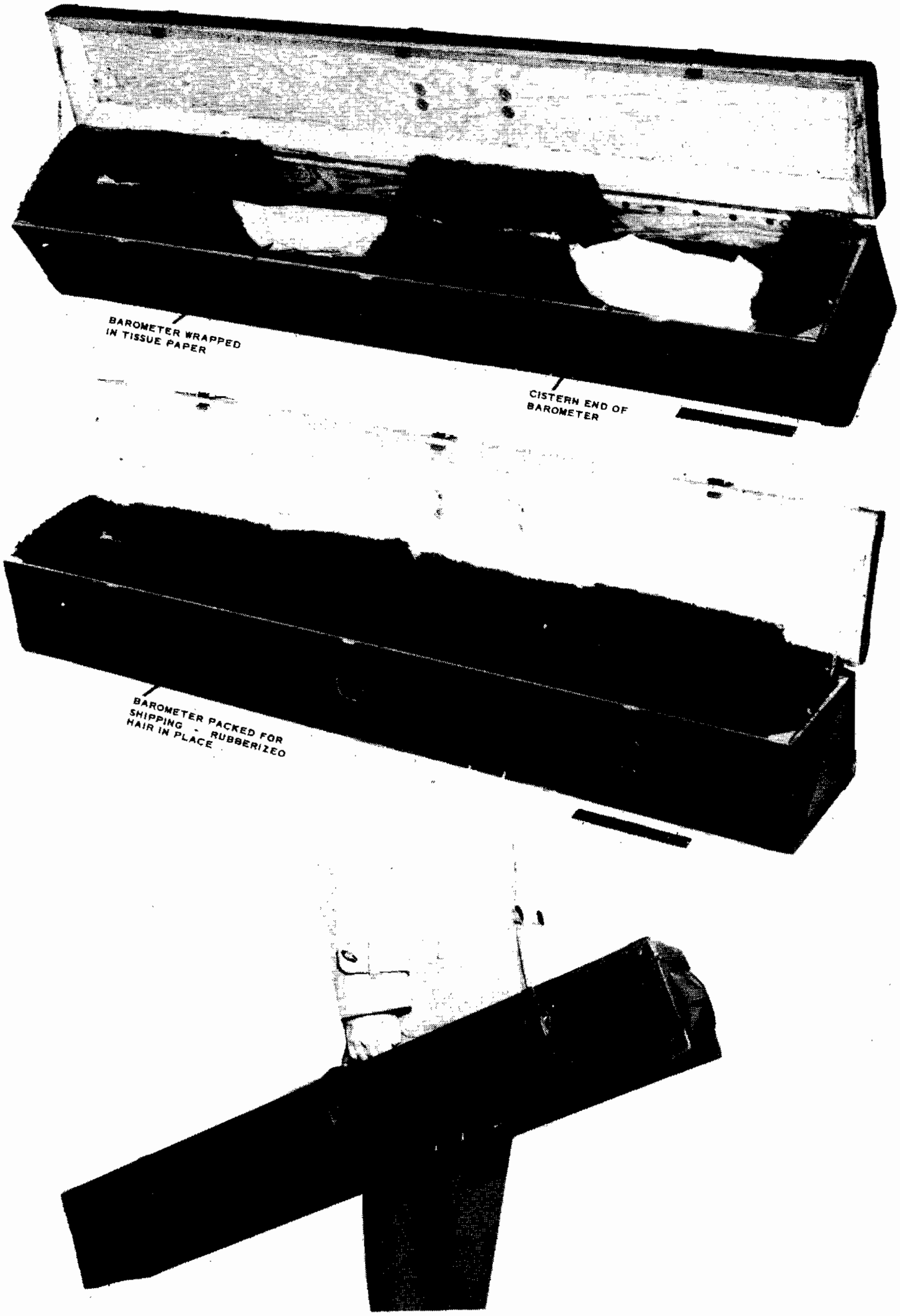

FIGURE A–2.20.3. Carrying case used by the U.S. Air Force for transporting type ML–330/FM large bore Fortin barometers (U.S. Army photograph).

essary to ship or transport a barometer. Under such circumstances, a suitable packing case should be improvised, keeping in mind the requirements described in sec. A–2.20.1.0. At this point an indication will be presented concerning some general specifications for such a box. These specifications are so written that they will apply for the shipment of a Fortin-type barometer in an *inclined position* over rough terrain or over long distances, for example, overseas.

First,several considerations which govern the design of the packing box will be outlined. The barometer is to be wrapped in a manner similar to that described in sec. A–2.20.1.1, and the completion of the wrapping process will yield the so-called "inner package" containing the instrument. Elastic packing material is to be employed as a bedding and protective surrounding for the "inner package" while it is in the packing case with a slightly sloping axis. The cistern end of the barometer must be elevated about 4 inches above the glass-tube end as the instrument within the "inner package" lies on the bedding mentioned above. In addition, elastic packing material should be placed in the packing case so that there will be at least 4 inches of the material between each point of the "inner package" and the nearest surface of the inside of the box. When all these allowances are made, it turns out that generally the inside dimensions of the packing case should be about 16 inches deep, 12 inches wide, and 51 inches long. Protuberances of a pointed or rounded nature are to be constructed for mounting on the ends of the box so that it cannot be stood on end. The cover is to be fastened into place by means of screws; and a strong handle for the box should be so located on the cover that the cistern end will tilt up when the packing case (containing the barometer) is carried by hand.

As a rule, it is desirable to use 1-inch lumber for the construction of the improvised packing box. Pointed protuberances can be readily prepared for the ends by cutting two pieces of wood in the form of equal-sided triangles and bisecting one of these (see sec. A–2.20.1.0). The two smaller pieces thus made by sawing the larger one in half are arranged at right angles to the bigger piece like a cross from the end-on view, and then the assembly is nailed into place on the ends of the box *before* the barometer is packed.

Elastic packing materials of the kinds described in sec. A–2.20.1.0 should be used. If the best, preferred types are not available, suitable materials can be improvised; for example, wads of paper may be rolled up in the form of a ball several inches in diameter having a suitable degree of compactness and resiliency. By distributing a number of these in the packing case, they may provide an adequate expedient in place of the rubberized pig hair which is generally preferable as the elastic packing material for shipping delicate instruments.

The instructions for packing the barometer in the improvised box are essentially the same as those given in sec. A–2.20.1.1, except that the cistern end of the barometer should be elevated about 4 inches above the other end of the instrument when the "inner package" containing the barometer is resting on the bed of elastic packing material in the lower part of the box with its long axis horizontal; and that at least 4 inches of elastic packing material should occupy the space between the "inner package" and the nearest surface of the inside of the box. Enough material must be used in packing the barometer to prevent the instrument from shifting around within the box during transit and to protect it from jolts.

After the barometer has been placed in the box and the packing has been completed, the cover must be screwed in position (*not nailed*), since hammering may then cause damage. Pertinent labels should be painted on the box with regard to handling instructions; thus: "Glass," "Fragile-Handle With Care," "Delicate Instrument," "Do Not Drop or Jolt," "Do Not Stand on End." The top of the box should bear the inscription: "This Side Up"; and the addresses of the points of destination and origin should be indicated.

A–2.20.1.5 Shipment of Special Barometers in Erect Position

Consideration is now given to the special problem of shipping certain types of barometers while in the normal, erect position. The instruments for which this method of shipment is necessary are indicated in sec. 2.2.7.0, paragraph (3), and sec. 2.2.7.2, paragraph (3). Included among these instruments are *certain* designs of fixed-cistern barometers. The best technique for shipping a barometer of the kind described in the paragraphs referred to above is to construct a sturdy case of wood to be shipped with its longitudinal axis in a vertical position while the barometer is hung suspended from a swivel ring at the top of the box by means of a strong spring. Rubberized curled pig hair is then packed around and under the cistern to absorb shocks and to damp vibrations or oscillations of the instrument. The cover of the box is secured in place by means of screws. In order to assure that the box is always maintained vertical with the barometer in the erect position, it is necessary to fasten pieces of wood which project horizontally from each corner at the lower end of the box (see fig. A–2.20.6). These pieces serve somewhat like feet and give the box greater stability when standing vertically, while the barometer is suspended inside with the cistern end down. On the outside of the box, near the top where the suspension hook is mounted, appropriate notations should be painted, with the object of having the case with its delicate contents properly handled; for example, "This Side Up," "Glass," "Handle With Care," "Do Not Drop or Jolt," "Delicate Scientific Instrument." Two strong strips of smooth wood should be screwed to the box to serve as handles for carrying by two persons. These strips should be fastened to opposite faces of the box and should be horizontal and parallel to each other when the box is setting upright on the feet mentioned above. The handles should extend beyond the edges of the box in both directions about the same distance as the feet and should be located at a convenient height for carrying.

When shipping a fixed-cistern barometer in the normal, erect position as outlined in the preceding paragraph, it is necessary to place a small rubber hose on the nozzle of the cistern and to clamp off this hose during transit. If a vacuum pump is available, the cistern should be evacuated of air prior to clamping off the hose so that the cistern will be completely filled with mercury while the instrument is undergoing transportation. This procedure causes the level of the mercury to be low in the barometer tube and lessens the chance that the very dense liquid will produce damage to the barometer by oscillating. If a vacuum pump is not available, it is still desirable to keep the hose clamped off during the transit period, as the motions of the mercury are thereby reduced.

Note: Kew-pattern fixed-cistern barometers are *not* in that category of barometer which can be safely shipped while in a normal, erect position. For further details, see sec. A–2.20.1.7. In the case of the Kew-pattern barometer, it is found that the best arrangements for shipping the device are those in which the cistern end is maintained at a higher level than the tube end of the instrument.

A–2.20.1.6 Shipment of U. S. Navy Type, Marine Barometers in Inverted Position

Figs. 2.6.1 and 2.6.2 illustrate the marine-type, mercury barometers of the design which has been used by the U. S. Navy, and to which the instructions in this section apply. This barometer is identified by Federal Stock Number (FSN) R6685–145–0579–HO35, and is described by the following nomenclature: Barometer, Mercurial type Aero–1927–USN, model 751–B, graduated in inches and millibars, complete with mounting case. Before taking action to ship a barometer of this type, the responsible personnel should become familiar with the information given in secs. 2.2.7.5 and A–2.16 relative to the moving of such instruments and the handling of barometers, both of this and other designs.

In brief, the barometer while still in its instrument case is to be inverted following a procedure to be described (see also sec. 2.2.7.5), and after certain wrapping operations the instrument case with its *included*

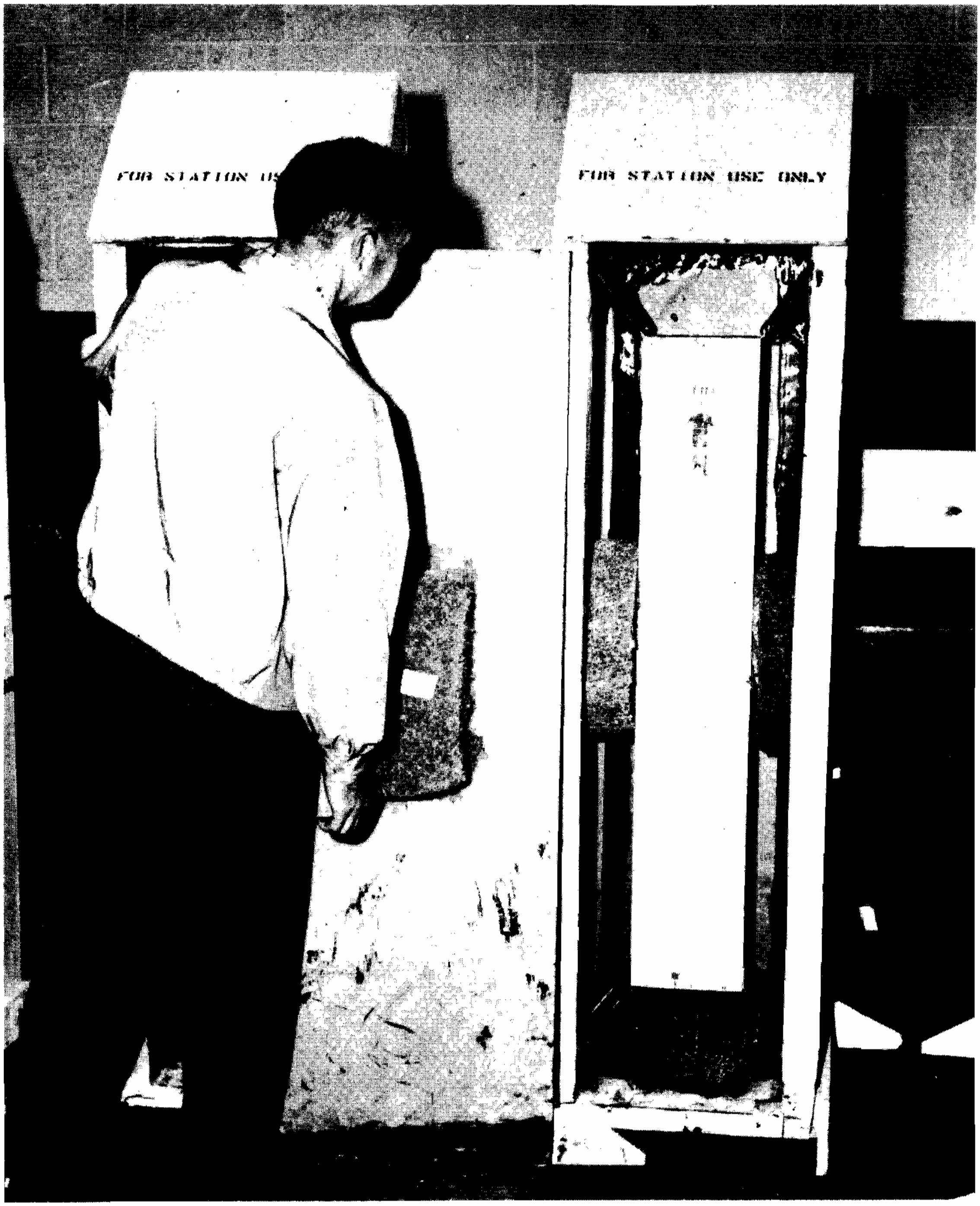

FIGURE A-2.20.4. Shipping boxes used by U.S. Navy for transportation of marine-type mercury barometers (see figs. 2.6.1, 2.6.2). Barometer is enclosed, cistern end up, in inner box which is suspended by springs and protected by wads of elastic rubberized packing material (U.S. Navy photograph).

FIGURE A–2.20.5. Close-up view of springs which suspend inner barometer box shown in fig. A–2.20.4 (U.S. Navy photograph).

barometer is to be mounted in a plywood box so that the cistern end is up. The plywood box is suspended by means of stout springs within a larger box as illustrated in fig. A–2.20.4. A close-up view of the upper four suspension springs is revealed in fig. A–2.20.5. Finally, fig. A–2.20.6 shows a view of the larger box in which the plywood box containing the inverted barometer is shipped.

With a view to maintenance of the box in the required plumb position, the larger outside shipping box has feet projecting from the four lower corners to facilitate keeping the box with its long axis vertical so that the barometer will remain inverted during transit. Fig. A–2.20.4 presents an exhibit of how the plywood box is protected from jolts by means of the springs attached at each corner (eight in all), both upper and lower, while pads of rubberized pig hair or similar material are placed on the bottom and all four vertical sides of the plywood container to safeguard against shocks, and to hamper vibration of the contents. It has been shown, by using a vibration table, that if the pads were not used, then at times the vibrations of a moving vehicle will match the vibration frequency or rate of the suspension springs. This causes extreme movement of the inner package in relation to the shipping container and serious damage to the instrument can result. Consequently, the pads of elastic packing material are required as indicated above to obviate the development of such excessive vibrations.

Navy Depots will ship barometric equipment in the type of packaging described above. When the equipment is received at station and the barometer with its case has been removed from the shipping boxes, all of the packing materials and the boxes

FIGURE A–2.20.6. Outer shipping boxes used by U.S. Navy for shipment of marine mercury barometers (U.S. Navy photograph). (See also figs. A–2.20.4, A–2.20.5.)

should be put away for safekeeping until needed at a later time.

INSTRUCTIONS FOR SHIPPING BAROMETERS

In accordance with the directions given in sec. 2.2.7.5, the following procedure is employed with regard to marine barometers of the U. S. Navy type: (1) Remove the jackscrew cover. (2) Raise the level of the mercury slowly by means of the jackscrew, and stop turning the screw when the head of the column reaches the top of the glass tube, using care not to force it too hard. (3) Secure the barometer in the clamps in the instrument case. (4) Remove the case with its enclosed barometer from the bulkhead on which it was mounted. (5) Invert the entire assembly slowly and carefully, until finally the cistern end is uppermost. (6) Slack off immediately on the cistern adjustment knob about one full turn to allow for expansion. (7) Replace the jackscrew cover over the knob at the bottom of the cistern. (8) Surround the barometer with tissue paper, and then pack the remaining space within the barometer case with elastic packing material so that the instrument will not break loose during transit. (9) Close and secure the cover of the case. (10) Mount the case in the special plywood box illustrated in fig. A–2.20.6, keeping the cistern end uppermost, pack the vacant space left in the box with elastic packing material, and fasten on the cover of the plywood box by means of screws, hammering not being permitted. (11) Suspend the plywood box vertically with the aid of eight steel springs in the center of the outside packing case as shown in fig. A–2.20.4. (12) Employ thick layers of elastic packing material underneath and around all sides of the plywood box to absorb shocks and to hamper oscillations of that box, as illustrated in the figure. (13) Close and fasten the cover of the outside packing box by means of screws as indicated in fig. A–2.20.6. (14) Add any painted labels on the packing box, if necessary, to secure safe handling and maintenance of the barometer with its cistern end up during the transportation.

Note: The elastic packing material, the steel springs, the plywood box, and the outside packing box should be saved for possible future use after the shipment is received at a station. Keep these things in a dry, secure place. When returning the barometer to its normal, erect position after receipt in an inverted position, follow the directions given in sec. 2.2.7.5. Fig. 2.6.1 illustrates the manner in which the Navy-type marine barometer is mounted; and secs. 2.2.4.0-2.2.4.4 provide instructions for its installation.

A–2.20.1.7 Shipment of Barometers of Unusual Type or of Kew Pattern

There are some types of barometers, not in common use in the United States, which do not have a provision for raising the level of the mercury to fill the cistern and upper part of the tube. Since the cistern and the tube in such cases are only partly full when the barometer is in the normal, erect position, these instruments are more liable to damage during shipment than the types of barometers which have an adjustable cistern. Therefore, Kew-pattern fixed-cistern barometers and other barometers having a fixed cistern are most safely transported by hand. With special reference to the Kew-pattern fixed-cistern barometer, the box or carrying case containing the instrument should be held during transit in an inclined position or inverted with the *cistern end uppermost* (see sec. A–2.20.2 regarding the use of a carrying case for this purpose). When Kew-pattern fixed-cistern barometers must be shipped where carrying by hand is not practicable, they are best shipped in an inverted position, with the cistern end uppermost. A possible arrangement for shipping these barometers in such a manner is described in sec. A–2.20.1.6. The Meteorological Office of the United Kingdom employs a so-called "barcrate" for shipping Kew-pattern barometers, and in earlier times has used a doolie for the purpose.[62]

The barcrate is a galvanized-metal framework from which two pans are suspended by means of stout springs (one to each corner of the respective pans). The long axis of the box containing the barometer is put in a vertical position so that the cistern end is uppermost. The base of the box is placed so that it rests in the lower pan of the barcrate, while the upper pan is fitted over the top of the box. Owing to the spring suspension, the barometer box is enabled to move relative to the barcrate frame; however, the springs act to damp out oscillations of the box and prevent it from striking against the surface on which the framework rests or against the sides of the framework. When in use, the barcrate is always placed in an upright position in such a manner that its wider end acts as a base, to secure stability.

The doolie consists of a framework having a large rectangular base and a narrow top with a lid. It is shaped somewhat like a miniature tent. A canvas covering serves for the sides of the doolie. Two pieces of horizontally projecting wood (or metal) on both sides are employed as carrying handles for it. Inside the framework of the doolie there are one or several pockets. The box containing the Kew-pattern instrument is placed in one of these pockets, in such a manner that the cistern end is uppermost. Packing material is placed in the pocket all around the barometer box to act as a buffer against jars and to prevent movement of the box within the pocket. When using the doolie to transport barometers, it is essential to keep it upright and to carry it only by the handles.

In cases where an unusual type of barometer has to be transported, it is best to seek the advice of the responsible instrument laboratory or supply depot regarding the most favorable method for performing the task. Special instructions of an appropriate nature are usually provided in such cases. Generally, carrying of the instrument by hand is recommended, under the condition that careful treatment of the equipment at all stages will be assured. Two important criteria must be kept in mind, namely, that the handling procedure should avoid the possibility of impairing the vacuum at the top of the tube by getting air into the space, and that the instrument must be properly packed and treated with care to avoid subjecting it to concussions or strains which can produce damage.

A–2.20.1.8 Reporting of Defective Barometers

In the event that a barometer has become defective or unserviceable while at a field station, the officer or meteorologist in charge should render a report on the facts to appropriate headquarters. The report should state clearly the condition of the instrument, and whether or not there is sufficient mercury left in the barometer to permit the instrument to be shipped with the mercury filling the glass tube by advancing the adjusting screw, in the case of the Fortin-type barometer (see secs. 2.2.7.0-2.2.7.5). Defective barometers are called in by the appropriate Headquarters or Instrument Laboratory following receipt of the report, and the defective equipment replaced.

A–2.20.1.9 Shipment of Defective Barometers, Emptied of Mercury

If a leak has developed in a barometer or the glass in the instrument has been broken

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[62] United Kingdom Meteorological Office, Air Ministry, "Handbook of Meteorological Instruments. Part I Instruments for Surface Observations," London, Her Majesty's Stationary Office, 1956.

so that the mercury has been nearly completely lost, a written report should be attached to the barometer describing the impaired condition of the instrument when it is packed for return. If any of the personnel at hand are authorized to disassemble barometers and the instrument is so seriously defective as to be unserviceable due to leakage of a considerable quantity of mercury, such authorized personnel should carefully empty the remainder of the mercury from the barometer and reassemble the instrument before packing it for shipment. The mercury saved from a leaking or damaged barometer, should be preserved in a clean bottle. The bottle with its contents of mercury is to be packed in the box with the barometer when the instrument is shipped back to the Laboratory. Care is necessary in such packing to prevent the possibility of the bottle clashing with the barometer during transit. All droplets of mercury which have fallen on the floor, work benches, desks, etc., must be collected and placed in the bottle for return to the Laboratory, since fumes of mercury are harmful (see sec. A–2.18). This means that droplets of the shiny liquid collected in cracks and crevices must also be taken up. The mercury should *not* be handled so as to make contact with the skin. With respect to the type of glass bottle that may be used for the shipment and storage of mercury, see the information in sec. A–2.14.

If none of the station personnel is authorized to disassemble barometers, and a mercury barometer at the station is leaking, the Official in Charge should notify headquarters and await instructions regarding the proper handling and disposition of the barometer, in accordance with the provisions of sec. A–2.20.1.8. Such personnel should not endeaver to remove the mercury until pertinent instructions are received.

A–2.20.2 Transporting Mercury Barometers in Carrying Cases

Special carrying cases are supplied for the transportation of barometers by hand. In using the leather carrying case to transport a Fortin-type barometer, the instrument is inverted in accordance with instructions in sec. 2.2.7.3. The barometer is secured in the hinged wooden sheath. When doing this, care is necessary to observe that the sheath closes tightly without straining either the milled head for regulating the vernier or the attached thermometer. If need be, the wood should be neatly cut away, but only sufficiently to receive these projecting parts. After the barometer is contained and properly secured in the wooden sheath, the assembly should be inserted into the leather case with the cistern uppermost (see fig. A–2.20.7).

When a barometer packed in a carrying case is being transported by motor vehicle, train, aircraft, ship, etc., the case should be securely fastened in place so that it cannot bounce, roll, slide, or swing in such a manner as to cause it to strike or pound against any part of the conveyance or other objects. All concerned must be alerted to the fact that a blow or jolt may cause breakage of the delicate instrument. In situations where the transportation is accomplished by

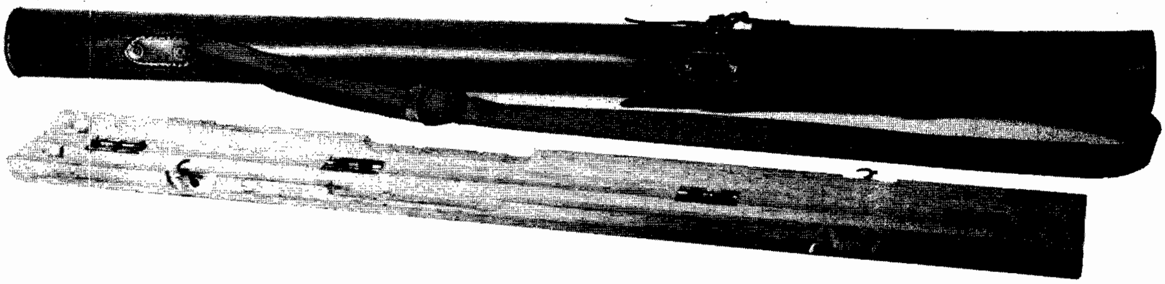

FIGURE A–2.20.7. Hinged wooden sheath for protecting barometer and leather carrying case, used to transport instrument by hand.

means of a panel truck, it is desirable to strap the carrying case to a board mounted on the inside of the truck. If space limitations do not permit transporting a Fortin barometer in a vertical, inverted position, it may be inclined to fit into the available space in the vehicle, provided the cistern end is maintained at least four inches above the hanger end of the tube at all points in transit. See secs. 2.2.7.0 - 2.2.7.5.

A hinged, aluminum carrying case has been developed for transporting a barometer by hand. This may be used for the purpose, in lieu of the leather carrying case, when available.

In preparation for transporting a Kew-pattern fixed-cistern barometer by hand, it should be inclined and inverted slowly in accordance with instructions in sec. 2.2.7.4. The carrying case suitable for this type of barometer is more or less similar to carrying cases mentioned above. It is considered best to maintain the cistern end higher than the tube end of the instrument during transportation until it is ready to be installed.

A–2.21 PACKING AND TRANSPORTATION OF ANEROID BAROMETERS, ALTIMETER-SETTING INDICATORS, AND BAROGRAPHS

A–2.21.0 Introduction

Since meteorological aneroid barometers, altimeter-setting indicators, and barographs are all actuated by sensitive aneroid pressure-measuring elements having delicate mechanisms, their characteristics are more or less similar and they must be handled accordingly with great care. On this basis we will classify them under the caption "Aneroid Instruments" for present purposes. In some respects the methods employed for packing and transporting these instruments must be necessarily different from those used for mercury barometers. With a view to dealing in an appropriate manner with the problems of getting an aneroid instrument unharmed from one place to another, depending upon the means of transportation, the following instructions are subdivided into three parts, according to whether the instrument is: (1) Carried by hand where personnel are limited to surface means of transport; (2) shipped unattended by surface vehicle; or, (3) shipped by air.

As a matter of general principle, the handling, packaging, and transportation of aneroid instruments must be carried out with a view to safeguarding them against jars, bumps, accelerations or decelerations, such as due to abrupt starting or stopping motions, since damage could thereby result to the instrument. Care must be taken never to drop or let fall such an instrument. Furthermore, they should never be left unattended without benefit of the protection afforded by having them installed on some type of mount which has good shock-absorbing properties, or by having them packed in multiple wrappings which provide at least two separate layers of cushioning material within sturdy containers. The applications of these main points are briefly specified in the next few paragraphs.

(a) Shock-Insulating Mount for Observational Installations.—When an aneroid instrument is transported by means of any kind of vehicle on land, sea, or air, and it is desired to have it immediately available for observational purposes, the instrument should be installed on a shock-insulating mount (see paragraph (d) below).

(b) Double Packaging Technique for Shipment Unattended.—If an aneroid instrument is to be shipped by any kind of vehicle where it will be unattended for any time, that is, where carrying of the instrument by hand is not always practicable and where the instrument is not required to yield observational data on an immediate basis, it is essential to safeguard the device by means of the so-called "double packaging technique." This technique generally makes use of two differently-sized sturdy boxes or cartons, the inner one of which contains the device enveloped in elastic packing material to protect it against physical damage, moisture, etc. This inner package is held within the center of the larger container by means of another layer of elastic packing material that serves to absorb shocks. It is necessary for the elastic packing material to occupy the space between the contents and container, both within the inner package and within the outer box, since the material must act to dampen out or hamper motions of the contents in each case relative to the walls of its container. The layer of elastic packing material must be sufficiently thick to provide adequate cushioning against concussions, and accelerations or decelerations without damage to the device; hence, it must have excellent resilient characteristics and be non-abrasive. Sec. A–2.21.2.1 presents a detailed operational list of instructions pertaining to the double packaging technique for aneroid barometers.

(c) **Elastic Packing Material.**—When choosing elastic packing material for the "double packaging technique," it is recommended that "bound cushioning material, firm" as defined in sec. A–2.20.1.0 (e) be used. (Note: One form of such elastic packing material which has been widely applied for packing barometers is called "rubberized curled hair," "rubberized curled pig hair" or simply "rubberized pig hair.") To procure the desired material by requisition in accordance with military specifications the following description will be employed: "Bound Fiber Cushion, Type III, MIL–C–7769." The desired thickness and size must be specified. Elastic packing material of the specified type is useful as an expedient shock-insulating medium when it is applied to envelope delicate equipment which is to be protected during shipment.

(d) **Designing of Shock-Insulating Mount.**—A shock-insulating mount is desirable for use when installing an aneroid instrument in a vehicle where it is likely to be subject to vibrations, jolts, accelerations, etc. Such a mount is deemed necessary for aneroid barometers or microbarographs on naval vessels in which the shock due to gunfire may be severe. The construction of a shock-insulating mount may be carried out locally and the mount should be tested for its effectiveness under actual operating conditions. One design of a shock-insulating mount consists of a shelflike cradle support provided with a suitably shaped piece of sponge rubber in which the aneroid instrument sets. Generally, the rubber is about one (1) inch thick when it comes in the form of a pad. The sponge rubber, which serves to absorb shocks, must be so shaped that it will not permit the instrument to free itself and fall off when the cradle support receives jolts or vibrations through the wall or bulkhead on which it is fastened by means of screws. Since the intensities and frequencies of shocks and vibrations on board vessels or on other kinds of vehicles vary with the surrounding conditions and the operations being conducted, it may be found that a single design is not equally effective as a shock-insulating mount and vibration insulator under all circumstances. In that event, it is desirable to develop the type of design which affords safe protection for the equipment under the worst conditions that might affect it and yields adequate reduction of vibration as well as shock effects under normal operating conditions. An anti-vibration mounting for use when installing microbarographs aboard ships has been developed by the British Meteorological Office.[62] The anti-vibration mounting last referred to is designed as a metal tray which holds the barograph suspended from fixed brackets by a number of elastic cords. The tray is supported by an arrangement which permits it to swivel about an axis parallel to its longer edge; hence, in this manner the motion of the ship is prevented from throwing the barograph pen off the chart. By making a suitable compromise choice in regard to the stiffness of the elastic suspension cords, the displacement of the instrument during rough seas has been held to within satisfactory bounds while the frequency of vibrations has been kept to within limits which permit the obtainment of good barograph traces.

(e) **Information Concerning Military Barometers.**—Personnel of the Military Services concerned with matters relating to the maintenance, packing, and shipment of instruments should study carefully the Technical Manuals and Handbooks of their respective Services which provide instructions on the operation and maintenance of the equipment. Such instructions from these Technical Manuals or Handbooks which deal with the specified matters will govern them. General guidance is provided by the information given herein.

At the time this Manual was prepared, the aneroid barometers being supplied for U.S. Army and U.S. Air Force use were as follows:

Federal Stock No.	Description of Aneroid Barometers
6685–223–5071	Barometer ML–331 ( )/TM is a precision aneroid barometer in a metal case which is shock mounted in a hardwood mounting case. A pump is provided for control of the air pressure to which the barometer is exposed during transport. The range is 1040 to 840 millibars. See figs. A–2.21.0 to A–2.21.4.
6685–223–5070	Barometer ML–332( )/TM which is identical to ML–331 ( )/TM except range is 1040 to 745 millibars.
6685–224–6348	Barometer ML–333( )/TM which is identical to ML–331( )/TM except range is 1030 to 540 millibars.
6685–224–6347	Barometer ML–102–( ) is an aneroid barometer designed for fixed or mobile use and for transport by hand or vehicle. The range is 31.5 to 22 inches. It is graduated in inches and millibars. See figs. A–2.21.5 to A–2.21.7.

The U.S. Navy was using aneroid barometers listed below at the time this Manual was written:

Federal Stock No.	Nomenclature of Aneroid Barometers
R6685–149–1970–HO35	Barometer, Precision Aneroid, type Aero–1936–USN, model 990.
R6685–600–3777–HO35	Barometer, Precision Aneroid, ML–448/UM.
R6685–515–4344–HO35	Barometer, Aneroid (Submarine), ML–457/UM.

When military precision aneroid barometers designated by ML–331/TM, ML–332/TM, and ML–333/TM are to be transported to the field from the Instrument Laboratory or from the Regional Control Offices, and are being used as inspection barometers for the purpose of standardizing other barometers, they should always be hand carried (see sec. A–2.21.1).

Figs. A–2.21.8(a) and A–2.21.9 show the type of temperature correction and pressure conversion charts issued with the aneroid barometer ML–331/TM, ML–332/TM, ML–333/TM, ML–102–D, ML–102–G, or ML–316/TM, respectively. The lower portion of the chart in each case gives the temperature correction factor based on the calibration of the instrument in a chamber whose pressure and temperature is carefully controlled. The middle portion of the chart contains scales used for pressure conversion and altitude surveying (see sec. 2.9.3.2, and Chapt. 9); while the uppermost portion of the chart yields correction factors used in altitude surveying for the purpose of making due allowances for the effect of air temperature and relative humidity.

In fig. A–2.21.8(b) there is presented a sample of the scale-calibration correction chart issued with each aneroid barometer of type ML–331/TM, ML–332/TM, and ML–333/TM. A chart of this character pertinent to the given instrument is mounted in the lid of the wooden barometer case. Such a chart is prepared for each instrument, based on a calibration of the aneroid by means of comparison of its readings at many scale points with the absolute pressure as determined with the aid of a standard mercurial barometer (see fig. A–2.4.0). The calibration is performed at various controlled pressures, while the temperature is maintained at 75° F.

When an aneroid barometer of the specified type is employed in the field in connection with the standardization of a station barometer, it is necessary that the pertinent scale correction be applied to the observed

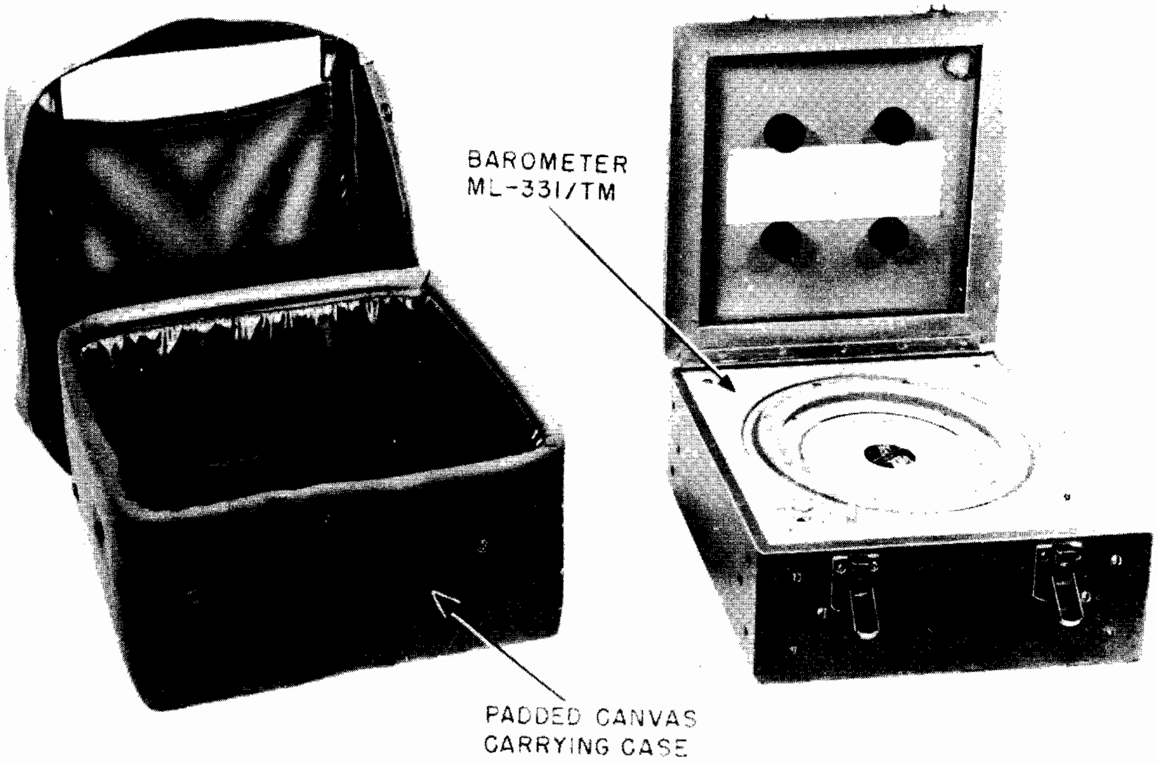

FIGURE A–2.21.0. Portable precision aneroid barometer ML–331/TM with padded canvas carrying case of type used by the U.S. Army and U.S. Air Force for comparative purposes in the field (U.S. Army photograph).

reading. The proper value of the scale correction which varies with the reading for the individual aneroid barometer should be obtained from the scale-calibration correction chart furnished for the instrument as illustrated in figs. A–2.21.8(b) and A–2.21.1. In addition, use should be made of the correction for departure of the instrument temperature from 75° F. as determined by means of the appropriate factor for the given scale reading, shown on the "Temperature correction and pressure conversion chart" pertinent to the particular instrument, as illustrated in fig. A–2.21.8(a). Thus, both the scale correction and the correction for departure of the aneroid barometer temperature from 75° F. must be applied algebraically with the proper signs to the observed reading in order to determine the corrected pressure. The correction for departure of aneroid instrument temperature from 75° F. is calculated as follows: Refer to the diagram presented at the bottom of the "Temperature correction and pressure conversion chart" pertinent to the given instrument; ascertain from the diagram the factor which corresponds to the observed scale reading, taking account of the algebraic sign (plus or minus) assigned to the factor for this reading; observe the temperature of the aneroid barometer, t in °F., and determine the difference (t — 75° F.) algebraically (taking the sign into account); multiply the appropriate factor referred to above by the temperature departure (t — 75° F.), algebraically; and the product thus computed is the required correction for departure of the aneroid barometer temperature from 75° F.

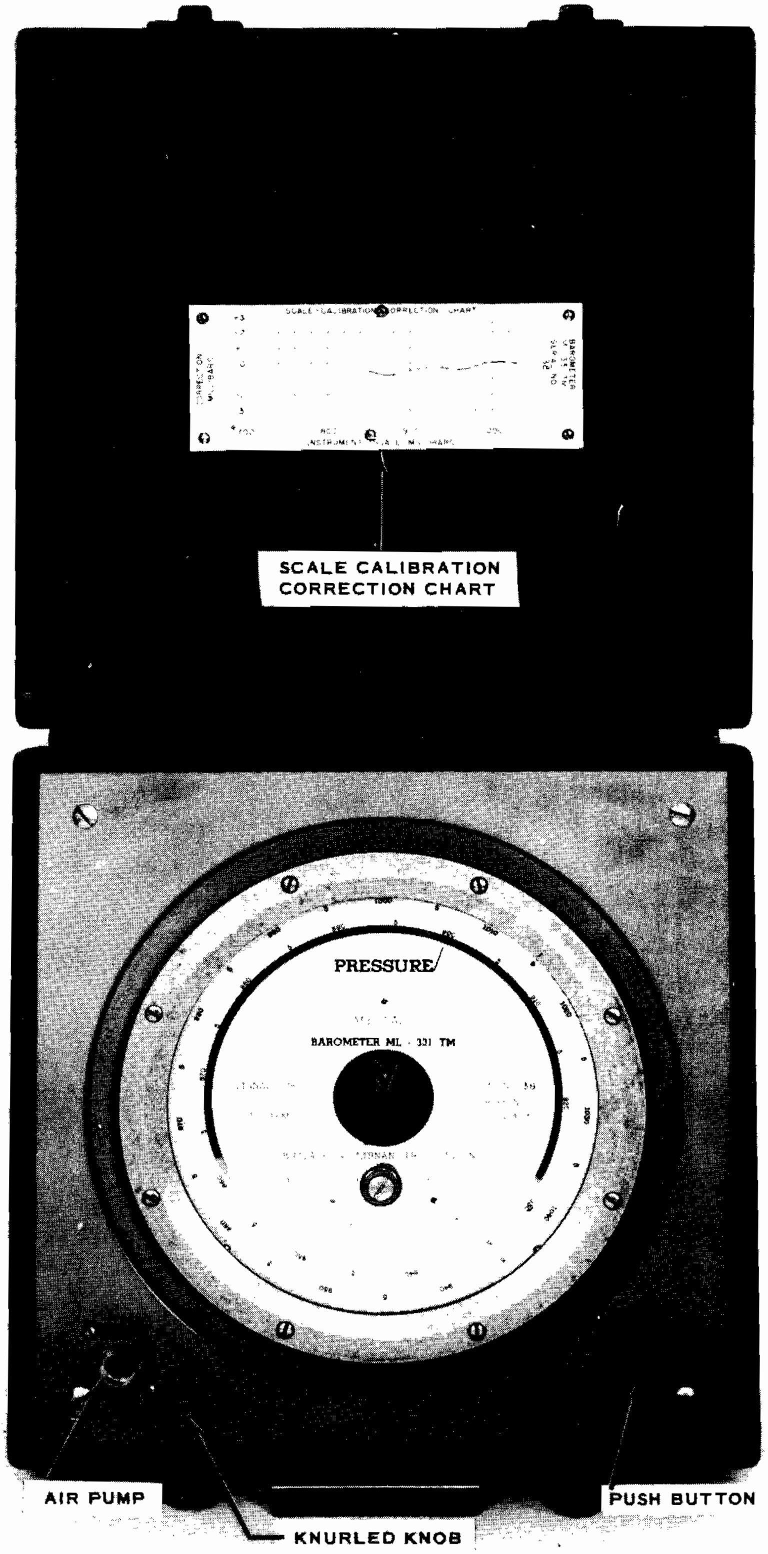

FIGURE A–2.21.1. Face view of precision aneroid barometer ML–331/TM in hardwood shock-mounting case, scale calibration correction chart in lid.

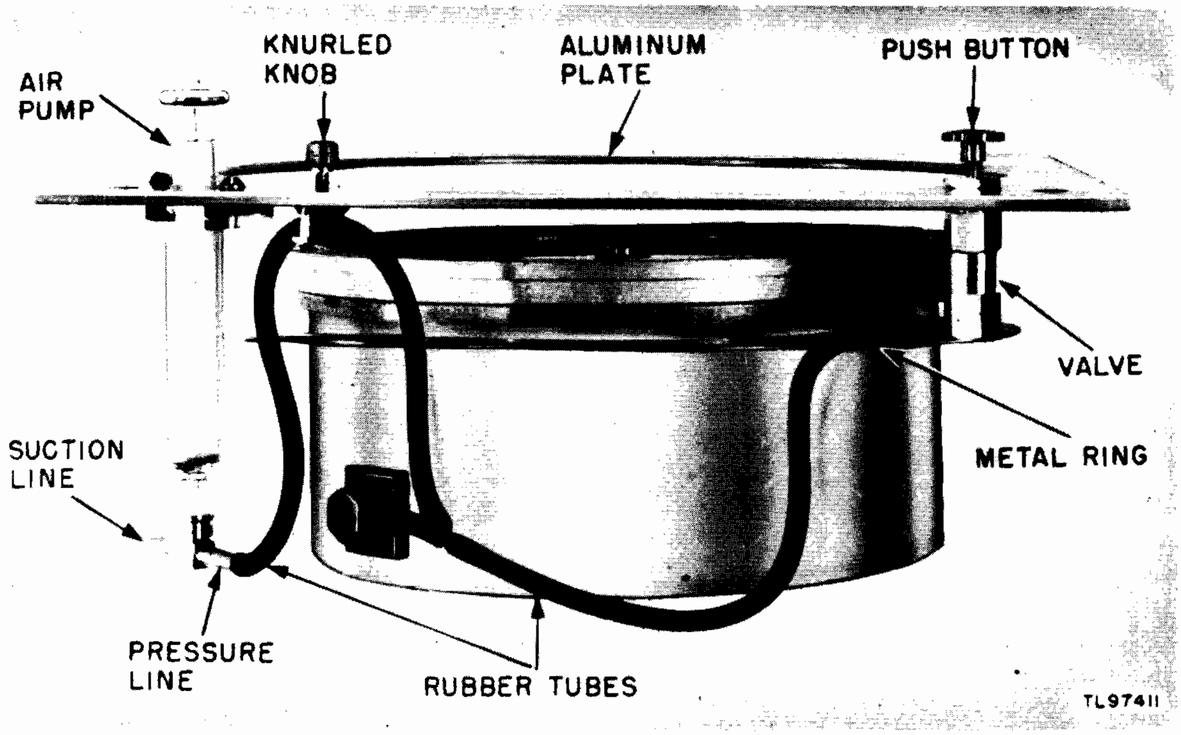

FIGURE A–2.21.2. Metal case used for control of air pressure in precision aneroid barometer, U.S. Army Signal Corps and U.S. Air Force types ML–331/TM, ML–332/TM, and ML–333/TM. (Mechanism is shown removed from hardwood shock-mounting case.)

Special treatment must be given to certain military precision aneroid barometers, particularly those equipped with a valve and air pump by means of which the internal pressure within the metal barometer case can be controlled. Included within the category of precision aneroid barometers thus equipped with an air pump are the instruments which have the numbers ML–331/TM, ML–332/TM, and ML–333/TM, already mentioned above (see figs. A–2.21.1 and A–2.21.2).

One mercurial and two aneroids of these barometers constitute a set used for inspecting the barometers in a region. The basis for selection of the appropriate barometers for the set is the altitude above sea level of the barometers that are to be inspected.

The special treatment necessary for those barometers may be described as follows: When aneroid barometers equipped with the valve and air pump are en route or in storage status (that is, not being actually used at the given time for the making of observations), the internal pressure within the metal case should be generally maintained at the average value of the atmospheric pressure which prevails at the location of the Regional Maintenance Shop or Laboratory representing the normal headquarters of the instruments. Such aneroid barometers should be shipped with the internal pressure in the metal case maintained at the specified value. The metal case of Barometers ML–331/TM, ML–332/TM, and ML–333/TM is shock-mounted in a hardwood case 11 inches square by 5 inches deep (see fig. A–2.21.3 and A–2.21.4). A padded canvas carrying case is employed to transport the instrument by hand (see fig. A–2.21.0).

(f) **General Rule for Hand Carrying of Inspection Barometers.**—This rule relates to precision aneroid barometers utilized in the field for the purpose of comparing their readings with those of ordinary station barometers with a view to standardizing the latter instruments. Instruments used for this purpose should be carried by hand.

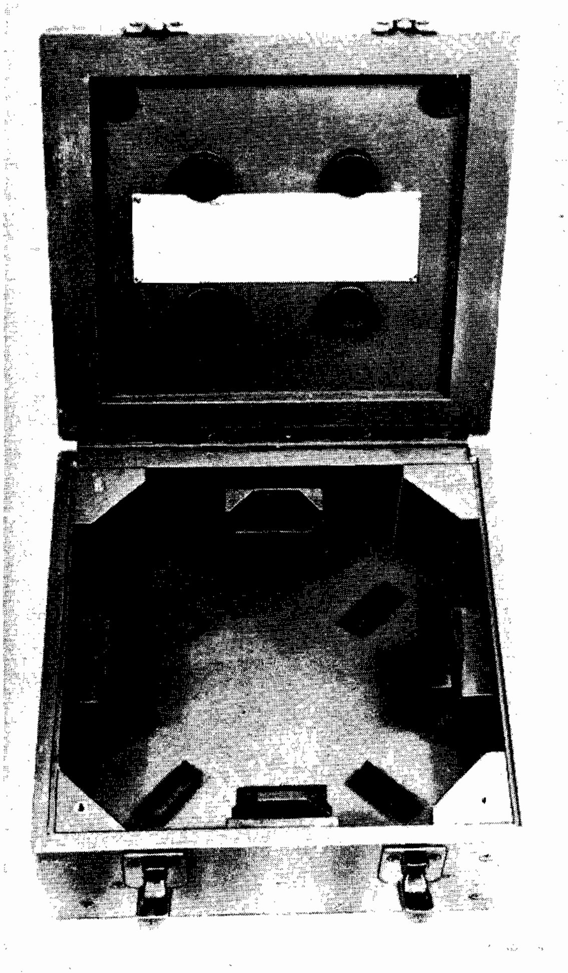

FIGURE A–2.21.3. Hardwood case showing rubber shock mounts used for protection of mechanism of portable precision aneroid barometer type ML–331/TM (U.S. Army photograph).

A–2.21.1 Hand Carrying of Aneroid Barometers

Waterproof carrying cases are provided for portable aneroid instruments. The design of the carrying case depends upon the size and the sensitivity of the mechanism. For certain aneroid barometers the carrying case is made of heavy cowhide lined with velveteen; and for others it is sometimes constructed of canvas (see fig. A–2.21.5). The better class of carrying cases, particularly for precision aneroids, is padded with shock-insulating material, which provides some protection against concussion and is a very desirable feature (see fig. A–2.21.3). Generally, snap fasteners are included, to permit the lid of the carrying case to be secured (see fig. A–2.21.4).

It is best to transport an aneroid instrument by hand, using either the appropriate carrying case designed especially for the device or the double packaging technique adapted for its protection, whenever the regular carrying case is not available. The latter technique is considered to provide a better degree of protection than the typical carrying case. See secs. A–2.21.2 and A–2.21.2.1 for details.

Care must be exercised never to drop an aneroid instrument. Personnel who deal with the instrument must avoid subjecting it to jolts.

Whenever it is necessary to put the instrument aside for any reason, the person responsible should take precautions to see that the device is cushioned against bumps, accelerations or decelerations, etc., wherever it may be placed. The arrangements or installation should be such that the device cannot drop down or be damaged under the given circumstances (as in case, for example, of transportation by means of a vehicle which may stop or start abruptly). It is better to have the carrying case on the floor well secured with padding all around than to leave it on a seat from which the instrument might fall.

If the transportation is conducted by air or if considerable changes in altitude above sea level occur en route, special steps are required to be taken to safeguard the equipment against possible adverse effects of abnormally large pressure variations, as outlined in sec. A–2.21.3.

Military personnel should refer to paragraph (e) under sec. A–2.21.0 with regard to the matter of special treatment involving the use of the air pump, which must be given precision aneroid barometers designated by numbers ML–331/TM, ML–332/TM, and ML–333/TM.

A–2.21.2 Shipment of Aneroid Instruments Unattended, by Surface Vehicle

A–2.21.2.0 General Information.—There are, of course, many situations under which it is necessary to ship such instruments by

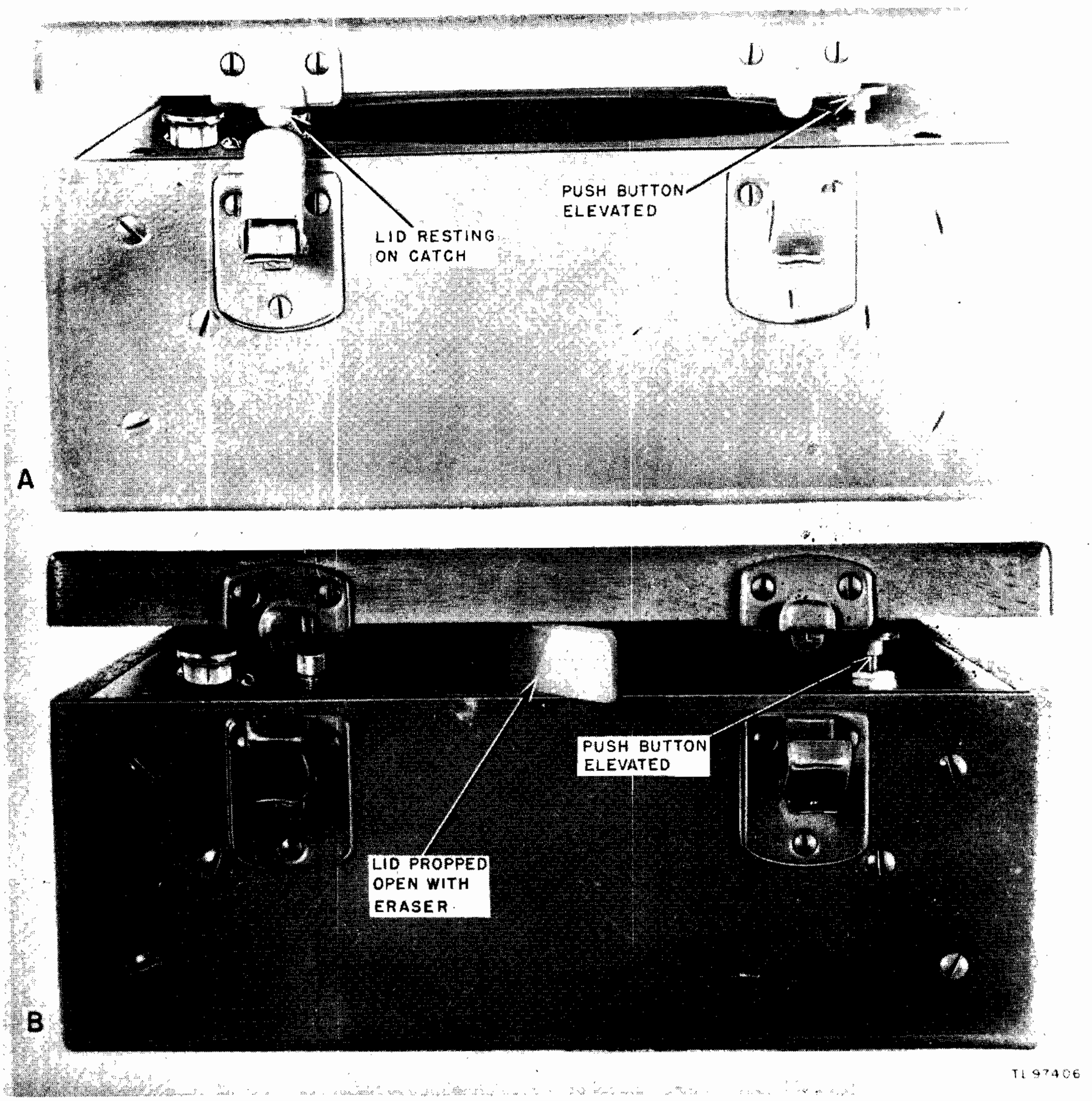

FIGURE A–2.21.4. Methods of keeping the case open when aneroid barometer ML–331/TM is at rest.

surface vehicle where they will be unattended. If the vehicle is a truck or a vessel with space provided for the installation of meteorological observing equipment, one may fasten the device on a shock-insulating mount, thereby permitting its use for direct observation (see sec. A–2.21.0, par. (d)). In general, however, aneroid instruments are shipped in containers, using the protection afforded by the double packaging technique.

One may summarize the purposes of the double packaging technique by two points: (1) To safeguard the instrument contained in the package against harm from concussions, bumps, accelerations, abrasions, or other mechanical factors; (2) to preserve the device from damages that might be caused by excessive heat or cold, dust, moisture, water, or any other inorganic or organic agents capable of affecting them adversely. Not only must the packaging

FIGURE A–2.21.5. Portable aneroid barometers ML–102–F (or ML–102–B); ML–102–E; and ML–102–D (or ML–316/TM), with carrying cases of type used by the U.S. Army and U.S. Air Force for fixed or mobile stations and for transport by hand or in vehicles (U.S. Army photograph).

technique be designed to accomplish these objectives, but the methods of handling, shipping, and storing the packages must be compatible.

Procedures applicable for packing aneroid barometers and altimeter-setting indicators differ somewhat from those for packing barographs (including microbarographs). Instructions pertaining to the packing of the former instruments are given in sec. A–2.21.2.1; while instructions concerned with the latter are presented in sec. A–2.21.2.2. See also sec. A–2.21.3.

When military personnel are authorized to ship aneroid barometers unattended, they should consider the provisions of paragraph (e) under sec. A–2.21.0. If the instrument comes already equipped with a hardwood case (for example, ML–331/TM, etc.), steps (1) - (4) of the instructions given below do not apply.

A–2.21.2.1 Packing of Aneroid Barometers and Altimeter-Setting Indicators for Unattended Shipment by Surface Vehicle.—The following double packaging technique is recommended, when the instrument is not already packaged in a manner approved by the responsible Depot, Instrument Laboratory, or Headquarters:

(1) First, the instrument should have a piece of crepe paper placed to protect its glass face and it should be wrapped in tissue paper.

(2) Next, it should be wrapped to a thickness of at least two (2) inches with elastic packing material.

(3) Then, kraft paper is employed to wrap the package, being careful to seal it completely with a suitable kind of tape, to keep out dust, moisture, etc.

(4) The package is placed in a small, but sturdy corrugated cardboard box or carton which is packed with additional elastic packing material so that all crevices are filled up and movement of the contents within the carton will be hampered. The carton is finally sealed.

(5) For shipping purposes, this carton is placed in a larger, sturdy box, and the inner one containing the instrument is surrounded on all sides with at least 4 inches of elastic packing material, using an amount of the latter sufficient to prevent the smaller one from jarring loose within the larger and to cushion against shocks. After the packing has been done satisfactorily to protect the contents, the larger box should be closed and sealed. If it is made of wood, the cover should be screwed on, since no hammering on it is permitted. Wooden shipping boxes are preferable for shipment over rough terrain and over long distances, such as transcontinental or overseas.

(6) Appropriate labels should be painted, written, and pasted on the *shipping box*

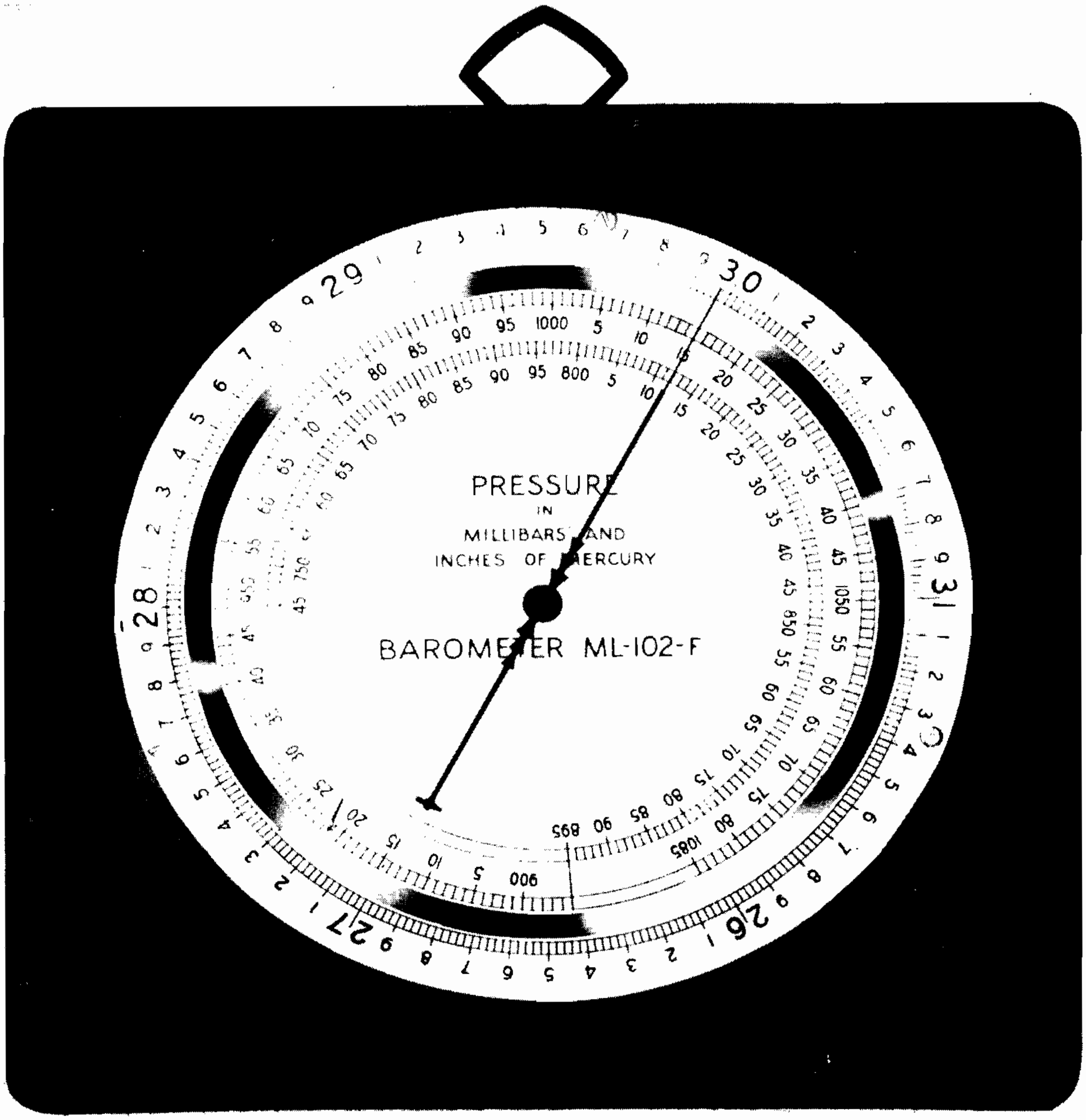

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FIGURE A–2.21.6. Aneroid barometer ML–102–F (or ML–102–B, or ML–102–E), close-up of dial (U.S. Army photograph). (See fig. A–2.21.5.)

> to give directions regarding proper handling of the box and its contents; for example, "Delicate Instrument," "Do not Drop or Jar," "Glass," "Handle With Care," "Keep Dry," and stock number of the instrument.

Whenever the shipment is to be made into regions or under conditions which can lead to exposure of the box or its contents to moisture which is excessive in degree or prolongation, additional protection against these elements is necessary. This protection will usually consist of the use of several bags of desiccant (drying agent) packed on a corrugated fiberboard tray placed within the inner package on top of the layer of elastic packing material; and the employment of a moisture-vaporproof barrier bag to surround all of the contents of the shipping box.

Instruments Depots, Laboratories, Headquarters, or manufacturers generally will

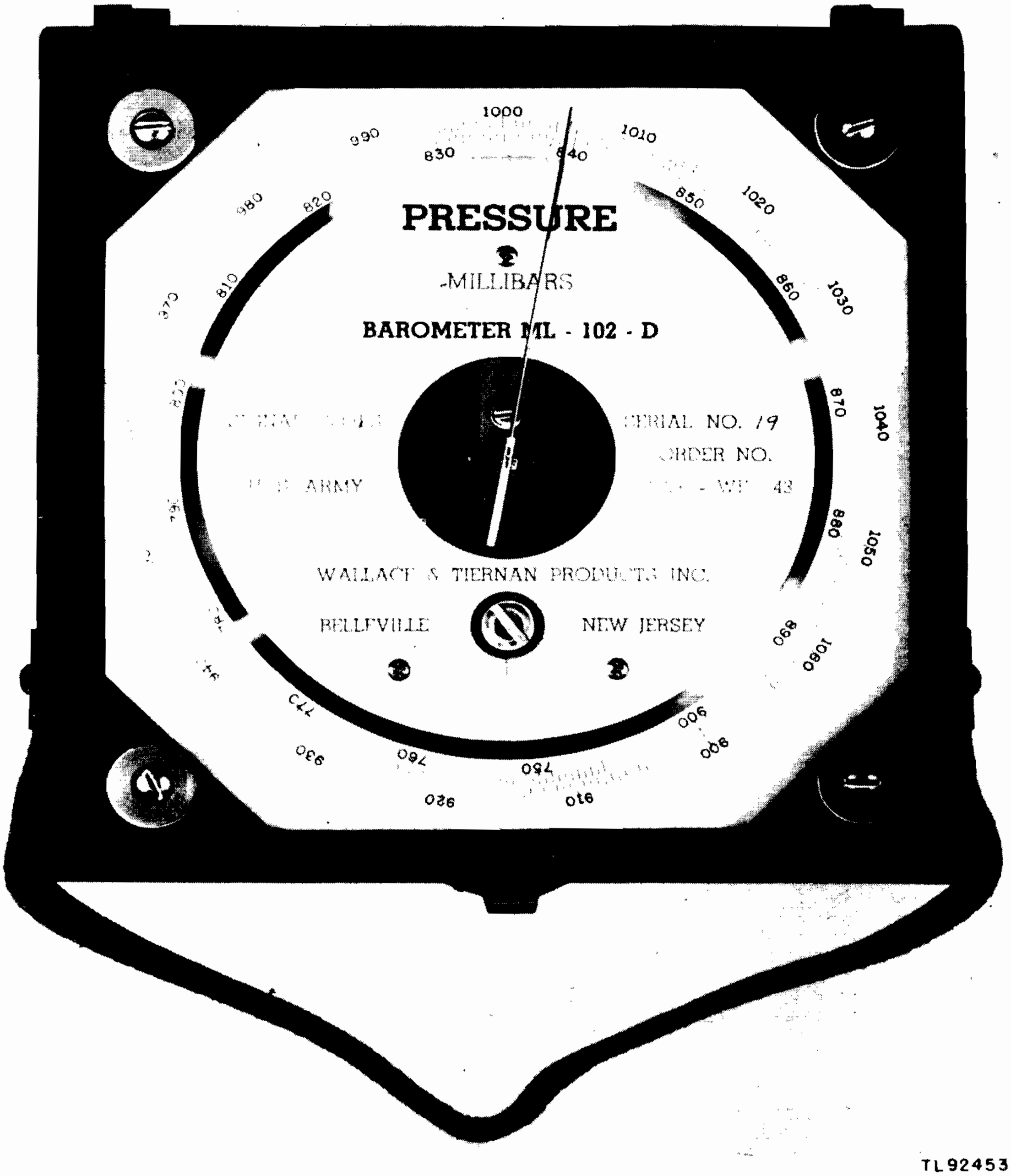

FIGURE A–2.21.7. Aneroid barometer ML–102–D (or ML–316/TM), close-up of dial (U.S. Army photograph). (See fig. A–2.21.5.)

ship aneroid instruments in a manner conforming to specifications approved by responsible officials. Under these circumstances the prevailing accepted method of packing the equipment can be learned by personnel who study carefully the method thus employed. Whenever an instrument shipment is received from the Depot, Laboratory, etc., all of the packing materials, cartons, boxes, and other relevant items used in connection with the shipment or safeguarding of the apparatus should be put away in a dry, clean place for safekeeping and possible future use on condition that this is practicable.

Military personnel should *consult the per-*

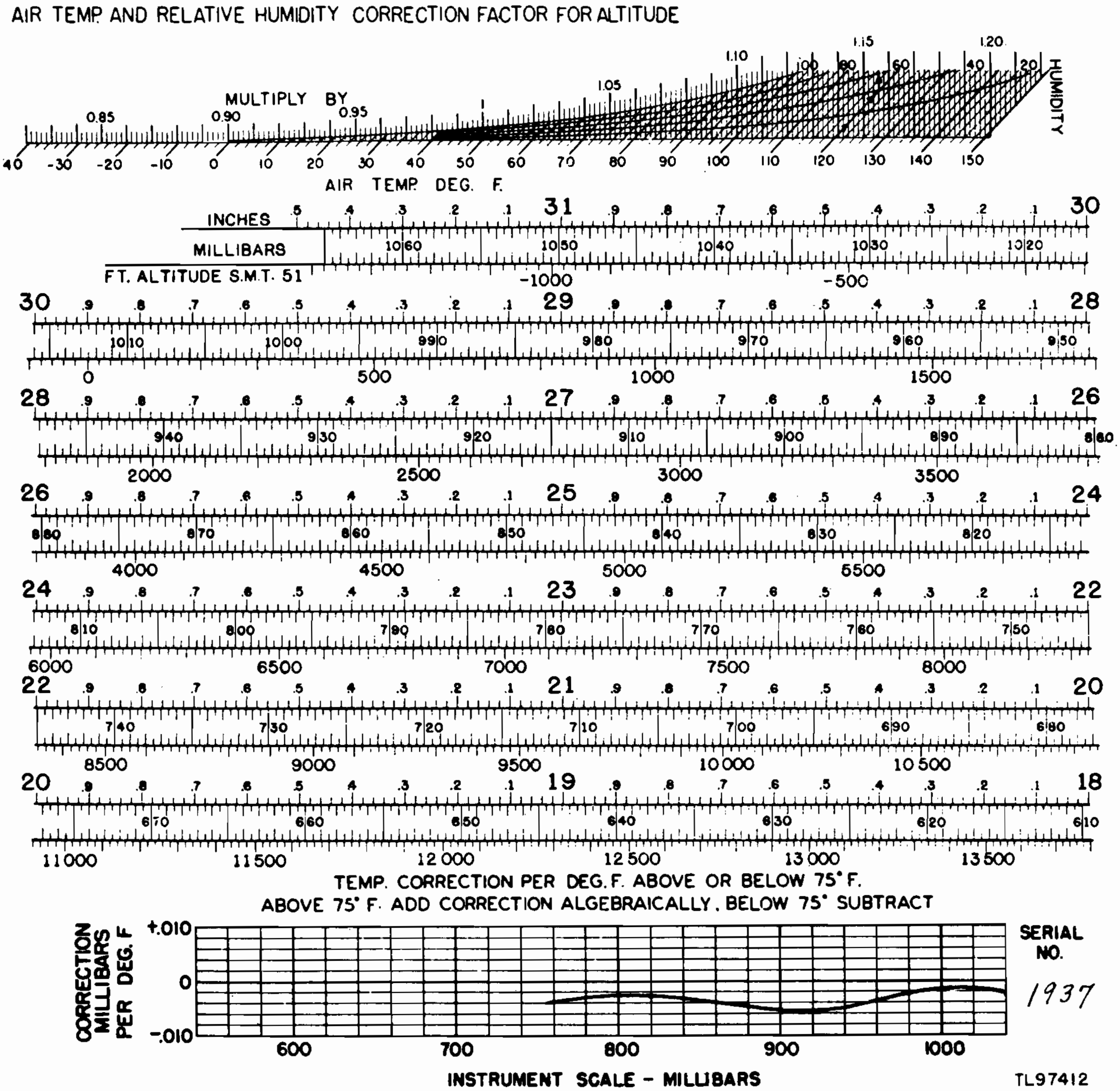

FIGURE A–2.21.8(a). Chart of temperature correction curve and pressure conversion scales used with precision aneroid barometer ML–331/TM, ML–332/TM, and ML–333/TM (U.S. Army photograph).

tinent Technical Manual or Handbook of their Service which gives the Operation and Maintenance Instructions for the particular equipment under consideration. Such sources will usually give additional details on the subject of packaging of the instruments for shipment.

A–2.21.2.2 Packing of Barographs and Microbarographs.—The term "microbarographs" as employed here refers to the open scale barographs, which generally have a pen movement of 2 and 1/2 inches for a pressure change of 1 inch of mercury. The term "barograph" is now usually applied to signify the class of measuring instruments which give a graphical record of pressure, or is limited sometimes to those members of the class which have a 1–inch movement of the pen for a pressure change of 1 inch of mercury.

Procedures for packing these instruments depend upon their particular design and upon the methods of handling preferred by the organization which controls the equip-

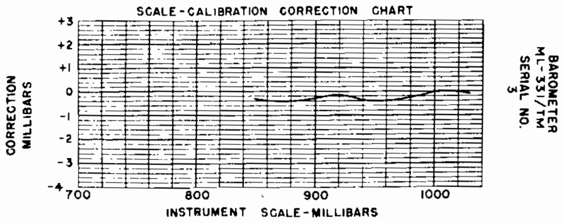

FIGURE A–2.21.8(b). Example of chart showing corrections to the scale readings of a particular aneroid barometer of type ML–331/TM plotted against scale reading, under conditions of ordinary room temperature, as determined by calibration in the laboratory.

ment. Therefore, the procedures adopted by the U.S. Weather Bureau, Air Force, and Navy differ in certain respects; hence the instructions given below for packing the instruments should be followed according to the organization involved. Separate instructions pertinent to the handling of various models or designs of the instruments will be issued by the respective organizations, if necessary. Owing to differences in details of design, it is not practicable to describe here the methods of handling deemed best for every different model or variant thereof; however, the instructions given in the following, depending upon the agency, are intended to cover the majority of cases. Military personnel who are concerned with these matters should consult the latest Handbooks and Technical Manuals issued by their respective organizations to secure special instructions pertinent to the instruments involved. The problems of storage of equip-

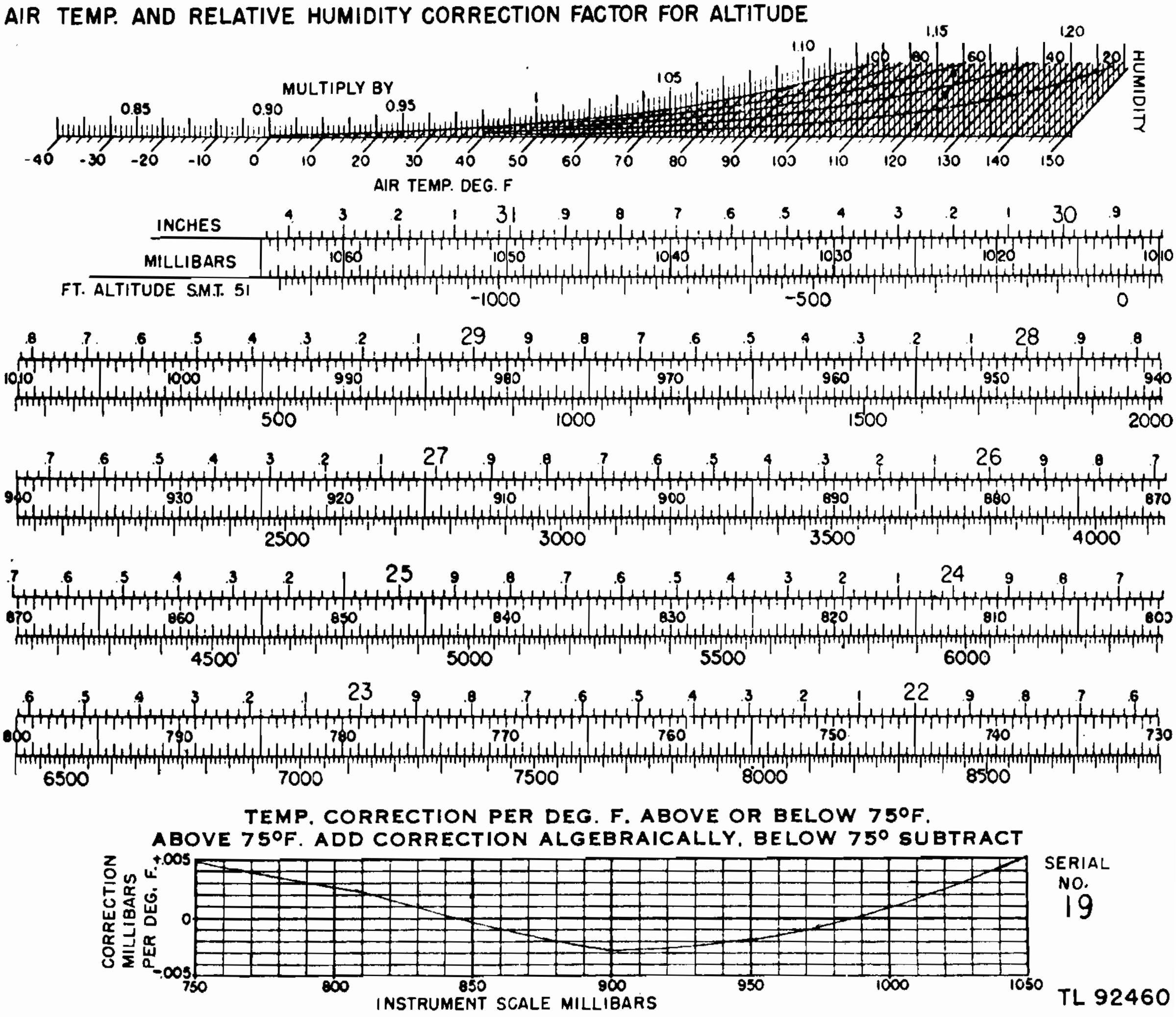

FIGURE A–2.21.9. Chart of temperature correction curve and pressure conversion scales used with aneroid barometer ML–102–D (or ML–316/TM) (U.S. Army photograph).

ment under tropical, moist conditions necessitate an appropriate type of packaging which is briefly mentioned in the latter part of instructions relating to the Navy instruments.

Weather Bureau procedure for packing open scale barographs.—By means of the pen arm shifting lever, the pen is raised away from the cylinder. The pen arm is then loosely tied to the shifting rod, permitting the pen to move up or down with changes of pressure, but protecting the pen arm and related parts from damage during transit. By use of an eye dropper, the fluid is removed from the dashpots, provided the microbarograph is equipped with them. Some barographs have damping units that do not require the removal of the damping material when the barograph is transported. One such "damper" consists of two concentric cylinders. One is fastened to the shaft that carries the pen arm and the other is stationary. The adjacent surfaces of the cylinders are only a few thousandths of an inch apart. A thin layer of high viscosity damping fluid is introduced into the space between the cylinders. This "fluid" is intended to remain in the damping unit until overhaul of the barograph or the accumulation of dust, etc., over a long period of time requires that the "fluid" be replaced.

With regard to those types of microbarographs which have a clock mounted within the cylinder, tissue paper is packed on top of the clock cylinder to prevent it from becoming loose during transit and the case of the instrument is closed. The microbarograph case is securely wrapped with double-faced corrugated cardboard especially to protect the glass. Next, the package at this stage is wrapped with kraft paper, and all joints in the wrapping are sealed to keep out dust and moisture. If available, a plastic bag is placed around the package for the same purpose.

The instrument thus wrapped is surrounded with about 2 inches of elastic packing material (for description of such material see sec. A–2.20.1.0). Finally, the package is placed in a sturdy carton or box, whose dimensions typically are about 22 in. x 15 in. x 15 in.

With regard to those types of microbarographs which have the clock movement installed on the base of the instrument, the cylinder is removed from the apparatus after the pen is tied to the shifting rod and the cylinder is wrapped separately in corrugated cardboard, followed by kraft paper. Then, the cylinder thus wrapped is packed in the carton, surrounded by a layer of elastic packing material as was the remainder of the apparatus, so that it will not work loose during transit or make contact with anything in the container which can cause damage. All crevices in the carton must be filled with the packing material to afford maximum protection to the contents.

When the instrument is being shipped to a new station, it is necessary to include a supply of suitable charts, together with a small bottle of ink and a small bottle of dashpot fluid, if required for the given type of microbarograph. These items are also wrapped separately for protection. The carton should be sealed securely to keep out moisture, etc. All sides of the carton or box should be appropriately labeled; for example, "Glass," "Fragile—Handle With Care," "This Side Up" for the top, etc. In the case of transportation overseas, it is deemed advisable to employ a wooden container for the outside shipping box, having a cover which is held in place by means of screws.

Air Force and Navy procedures for packing open-scale barographs.—The instructions in this section relate explicitly to open-scale barograph of the type designated as follows:

Air Force	Federal Stock Number (FSN) 6685–223–5104
Navy	Federal Stock Number (FSN) R6685–145–0578–HO35

Both the Army and the Air Force designate this instrument as Type ML–3 or ML–3A. It is similar in general appearance to the microbarograph shown in fig. 2.9.0. Also, fig. A–2.21.10 indicates the open-scale barograph with its cover open, and identifies the parts to which reference is made in these instructions.

The open-scale barograph or microbarograph under consideration is a portable precision instrument which measures and

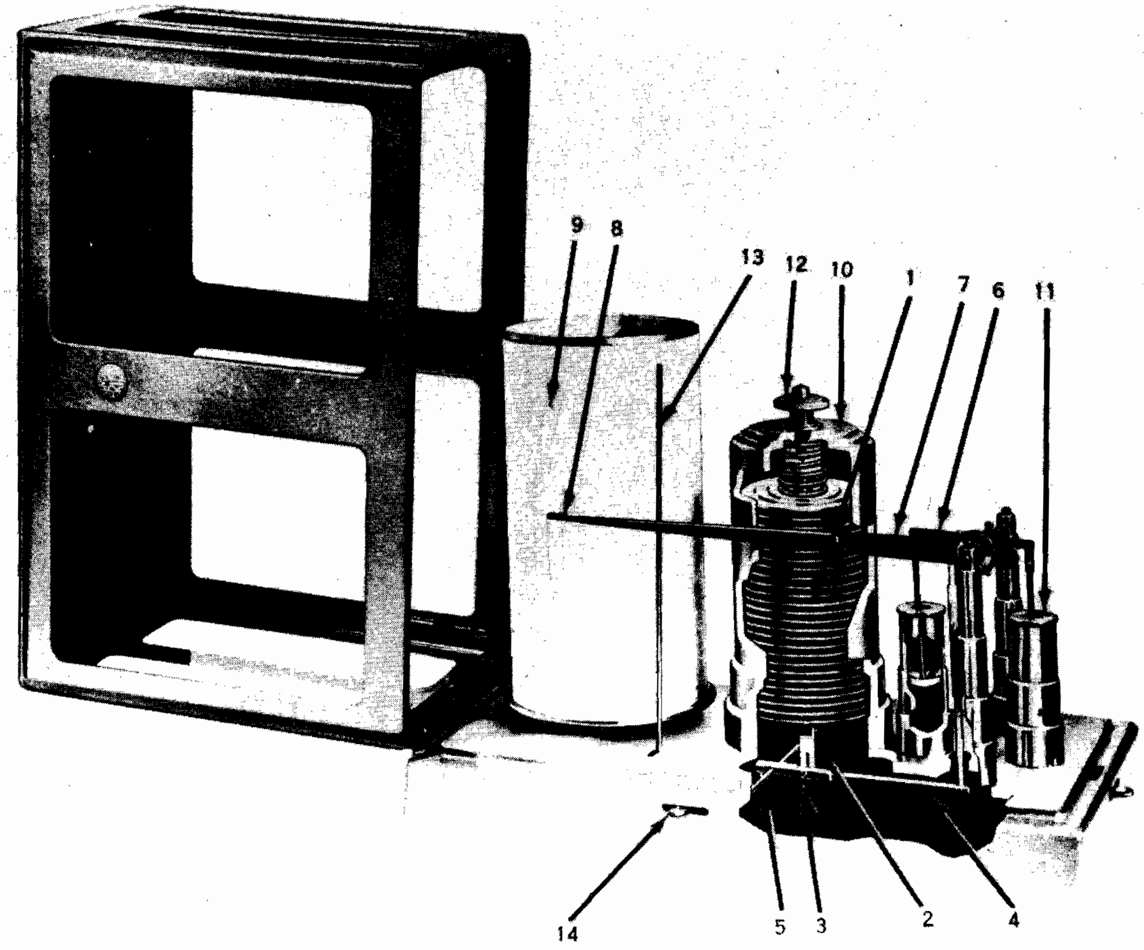

FIGURE A–2.21.10. Open-scale barograph (2.5–1), cutaway view, with cover open (U.S. Navy photograph), showing parts listed below identified by number:

1. Aneroid element
2. Aneroid element link
3. Screw pin
4. Link lever
5. Temperature compensating shaft
6. Magnification lever
7. Pen arm
8. Pen
9. Chart cylinder
10. Dome
11. Dashpot
12. Station pressure adjustment screw
13. Pen shifting rod
14. Shifting lever.

records the atmospheric pressure. The pressure sensing element consists of two bellows which are connected by suitable levers to a pen arm whose pen point rests on a chart for the purpose of making the record trace. The chart is mounted on a drum which houses a spring-driven clock. Rotational movement of the drum under the pen produces an ink record of the air pressure. A range of pressure from 28 to 31 inches of mercury is covered by the instrument. Four days' record is provided on one chart.

An open-scale barograph especially constructed for marine use is designated as follows:

Navy........................ Federal Stock Number (FSN) R6685–551–3661–HO35

This instrument is identical mechanically with the one depicted in fig. 2.9.1. It is equipped with an airtight case and a damper as described in sec. A–2.16.4. Since this marine open-scale barograph does not have dashpots, preparations for packing this instrument will not involve any need to remove the dashpot oil. Certain features of the mechanical construction of the marine open-scale barograph differ from those of the barograph shown in figs. 2.9.0 and A–2.21.10. Therefore some of the details relating to the preparation of the marine open-scale barograph for packing will be different from those pertinent to the design of barograph referred to in the first two paragraphs.

In order to provide specific information relating to the maintenance and handling of the marine open-scale barograph, which is a matter that depends upon the special characteristics and design of the instrument, the manufacturer supplies, under contract, a handbook on the operations and service instructions pertinent to the equipment. While the detailed instructions regarding the *preparation* of the marine open-scale barograph for packing will not be the same as those for the barograph shown in figs. 2.9.0 and A–2.21.10, the instructions given herein in connection with the *actual packing procedures* will generally apply as outlined under (IV) below. It is important for personnel to obtain from the appropriate handbook the necessary guidance and information pertinent to the proper method of preparation of the marine open-scale barograph for packing.

With regard to the task with which this section is primarily concerned, it is necessary to distinguish between phases of the operation under two general categories: (a) preparations of the instrument before packing can begin; and (b) actual packing of the barograph itself. The work of preparation is classified under three phases referred to by numbers (I), (II), and (III) as described below; while the work of actual packing is classified under one phase, (IV). In order to aid the reader in identifying the named components, part numbers have been assigned (for example, "pen arm (7)"); and the corresponding parts and numbers have been indicated by association in fig. A–2.21.10, to which reference should be made.

As the first stage in preparing an open scale barograph for packing, personnel should follow the directions given below under (I), consisting of steps numbered (1)–(4).

The next phase of the preparations for packing depends upon the altitude range within which the shipment is destined to take place. Thus, if the shipment is to occur at altitudes below 13,000 feet, follow the directions given below under (II), consisting of steps indicated by the small letters (a) and (b). However, if the shipment is intended to take place at altitudes above 13,000 feet, follow the directions given below under (III), consisting of steps indicated by the capital letters (A)–(H).

In order finally to pack the open scale barograph for shipment after the appropriate preparations mentioned above have been completed, follow the directions given below under (IV), consisting of steps designated by items 1p.–6p. (where it will be understood that the letter p indicates the actual packing phase of the operation).

(I) *Preparation for Packing Open Scale Barographs in All Cases:*

(1) Shift the pen arm (7) away from the chart cylinder with the aid of the shifting rod (13), by turning the shifting lever (14) to the right.

(2) Remove the chart cylinder (9) from the arbor.

(3) Remove the oil from the two dashpots (11), using preferably an eyedropper for this purpose. Emptying the dash pots may also be accomplished by quickly inverting the instrument.

(4) Detach the pen point (8), remove all of the ink, and clean the pen. The cleaning may be done by washing the pen in warm, soapy water, rinsing it in clear water, and wiping it dry. Replace the pen point on the end of the pen arm (7).

(II) *Preparation for Normal or Low Altitude Shipment Only (Below 13,000 feet)*

(a) Turn the station pressure adjustment screw (12) at the top of the dome (10) in such a manner as to lower the pen (8) until it reaches the bottom of its travel.

(b) Raise, by hand, the pen arm (7) until the pen (8) is at the top of its travel; and tie the pen arm (7) with a string to the shifting rod (13).

(III) *Special Preparation for High Altitude Shipment (Above 13,000 feet)*

(A) Perform operations (a) and (b) as indicated above, in regard to preparation for shipment below 13,000 feet.

(B) Remove the plate (base cover) from the under side of the base. This plate is secured to the base by screws located near the rubber feet.

(C) Remove the small screw pin (3) from the link lever (4) in order to release the aneroid link (2). Replace the screw pin in the link lever without passing it through the aneroid link.

(D) Insert three corrugated paper board strips, 1/5 inch thick by 1-1/2 inches wide by 6 inches long, between the aneroid element (1) and the inside of the dome (10). These are intended to prevent damage to the aneroid element owing to friction between it and the dome.

(E) Wrap the aneroid link (2) with some tissue and fold it up to the bottom of the aneroid element (1), and secure it with a pad of packing tissue.

(F) Replace the plate (base cover), and fasten it with the screws provided.

(G) Turn the station pressure adjustment screw (12) at the top of the dome (10) clockwise to raise the aneroid element (1) all the way to the top.

(H) Tie the pen arm (7) to the pen shifting rod (13) with the pen at the bottom of its travel.

(IV) *Packing of Open Scale Barographs for Shipment After Preparations Are Completed*

The packing of open scale barographs is only to be undertaken after completion of the pertinent preparations indicated in the foregoing, depending upon whether the shipment is to be made at altitudes below 13,000 feet or at altitudes above 13,000 feet. Regardless of the altitudes at which shipment is to be conducted, it is necessary first of all to carry out the instructions given under items (1)–(4). Then, if the shipment is to be made at altitudes below 13,000 feet, the directions given under items (a) and (b) should be followed. However, if the shipment is to be made at altitudes above 13,000 feet, the directions under items (A)–(H) should be followed.

Instructions for packing the instruments after completion of the foregoing are given below, and they apply equally well to all shipments of the equipment, regardless of the altitudes to be reached in transit:

1p.—Wrap the chart drive mechanism (chart cylinder, 9) separately in tissue, then with kraft paper, sealed to form a neat package. If a waterproof bag is available, next place the package in the bag, squeeze the excess air from the bag, and seal the bag. If the original carton in which the chart cylinder was received is available, pack it in this carton, sealed in the waterproof bag. Use a layer of elastic packing material all around the protective bag to safeguard its contents against damage in the carton; and seal the carton. When the original carton is not available, employ a larger carton for the chart cylinder but be certain to have it surrounded with elastic packing material sufficiently thick to prevent the contents from being crushed or moving about. Label the sealed carton to indicate the nature of the contents.

2p.—In the case of shipment to the field, the following four items are to be included: a supply of the appropriate type of barogram charts for the instrument, a bottle of recording ink, a bottle of dash pot oil, and an Instruction Manual or pamphlet. The barograph charts should have the printed values on the scale suitable for the station to which the instrument is to be shipped, and should cover the desired length of record (such as 7 days, 4 days, 12 hours). Personnel should follow the relevant instructions given in sec. A–2.16.3.9 regarding the proper selection of barograph charts. Where pertinent, the personnel preparing the shipment should make certain the bottom line of the charts has printed a value ending in a whole inch or a half inch pertinent to the station. When preparing the items for shipment, they should be packed to form a separate package either in a small carton or wrapped in corrugated cardboard and kraft paper, which is sealed. It is necessary for personnel to check all bottles to see that they are securely corked before being wrapped. The bottles should be surrounded with a suitable protective layer of elastic packing material for cushioning purposes, in such a manner that they will not spill or be crushed. Appropriate labels should be placed on the outside of the package thus prepared to reveal the nature of the contents and the precautions necessary in handling.

3p.—Place the main body of the open scale barograph in a water-vaporproof bag, squeeze out all of the excess air from the bag, and seal it. If the original carton in which the instrument came from the manufacturer is available, place the barograph with its enveloping bag in the carton, and seal the carton with tape. However, if the original carton is not available, pack the instrument in a sturdy cardboard carton well padded with elastic packing material to protect it from damage; and seal the carton with tape. If a water-vaporproof bag is not available, wrap the instrument first with crepe paper, then with corrugated cardboard, and finally with heavy kraft wrapping paper, which is to be sealed with tape. The package thus obtained is to be packed in a carton as indicated above.

4p.—Obtain a sturdy box for packing and shipping together the three packages prepared in accordance with instructions given above under paragraphs 1p, 2p, and 3p. Place the three packages in the box, pad it well with elastic packing material arranged on all sides, beneath, over, and between the packages to protect the contents from being crushed or from suffering other damage. Close the box and seal it with tape. For shipment overseas, it is desirable to employ a wooden shipping box, whose cover should be screwed on. (See also paragraph 6p. in case there is to be prolonged storage of the equipment.)

5p.—Mark the shipping box prominently with appropriate labels: "This Side Up" (on the top); "Delicate Instrument–Handle With Care"; "Do Not Drop." Indicate the contents according to word description (such as "Contents: Open-Scale Barograph") and mark the stock number. Depending upon whichever altitude range of shipment the instrument was prepared for, mark the one involved, such as: "Prepared for Normal or Low Altitude Shipment" or "Prepared for Special or High Altitude Shipment."

6p.—If there is to be a prolonged period of storage of the equipment, it is desirable to store the shipping box with its contents in a dehumidified storage depot. If a dehumidified space is not available, several bags of drying agent (such as silica gel which is an excellent desiccant) should be placed within the box on a corrugated cardboard tray before the box is sealed. Additional protection against adverse effects of moisture is secured by placing the entire box in a water-vaporproof bag, squeezing all excess air from the bag, sealing the bag, and packing the sealed bag in another cardboard carton, which should itself be finally sealed. This carton must be labeled in regard to contents, as indicated under paragraph 5p. above.

A–2.21.3 Shipment of Aneroid Instruments by Air

Shipment by air requires special considerations for the preservation of the equipment. The reasons for this are primarily that accelerations may be unusually heavy and that ambient atmospheric pressure at the ceiling of the aircraft flight may be less than the lower limit of pressure which the instrument can sustain. In order to avoid damage to the apparatus from these causes, certain precautions are necessary. These may be covered under two headings: (A) Method of Packing for Shipment by Air; and (B) Special Precautions or Preparations for Shipment by Air.

(A) Method of Packing for Shipment by Air.—The methods for wrapping and packing aneroid instruments for shipment by air are essentially similar to those applicable in the case of transportation by surface vehicle, as previously given for the same type of equipment, depending upon whether it be an aneroid barometer, altimeter-setting indicator, or barograph. However, one principal difference between packing for air shipment and packing for land vehicle transportation lies in the thickness of elastic packing material recommended for use. Specifically, when the instrument is to be largely unattended in the case of air shipment, it is strongly recommended that the layer of elastic packing material be at least four (4) inches thick wherever the instruction pertaining to the transportation by land vehicle suggests the use of a layer two (2) inches thick. The reader is referred to sec. A–2.21.2.1 in connection with shipment of aneroid barometers and altimeter-setting indicators unattended, by surface vehicle; and to sec. A–2.21.2.2 in connection with shipment of barographs under similar conditions; but in securing the packing boxes he should keep in mind the need to allow for extra space which will be occupied by the additional thickness of elastic packing material here recommended for shipment by air.

Bound fiber cushion of the kind described under sec. A–2.21.0 is considered most desirable for use as the elastic packing material under these conditions. The double packaging technique must be employed to obtain the necessary protection for the equipment.

(B) Special Precautions in Preparing for Shipment by Air.—The principal question to be considered in the present connection is whether the instrument can withstand undamaged the extreme differences of pressure to which it will be subjected, such as at the highest and lowest points of the flight. An instrument should only be shipped by air if assurance exists that the answer to this question is: "Yes."

With regard to precision aneroid barometers ML–331/TM, ML–332/TM, and ML–333/TM, used by the U. S. Air Force and some other military organizations for comparison with and standardization of field barometers (see figs. A–2.21.0 and A–2.21.1), it will be noted that these instruments are equipped with a valve and an air pump which permit one to control the internal pressure within the metal case surrounding the aneroid element. The following general rule will be applied in regard to these instruments: Between times at which the ML–331/TM, ML–332/TM, and ML–333/TM, precision aneroid barometers are being put to actual use for calibration or comparison purposes (that is, during periods of shipment, storage, or resting to overcome hysteresis effects), the internal pressure within the metal case of the barometers should be maintained at an adopted constant value which approximates the average atmospheric pressure prevailing at the originating Instrument Laboratory or Regional Control Office. (For example, with particular reference to the specified type of aneroid barometers whose headquarters is the Evans Signal Laboratory, Belmar, New Jersey, it is the general practice to maintain the internal pressure pumped up to a value of 1000.0 millibars, during periods of shipment or storage of the instruments.) Aneroid barometers of the specified type have been designed to withstand normal air transport while their internal pressure in the metal case is kept at such a value. If circumstances should justify a deviation from the general rule stated above with regard to barometers ML–331/TM, ML–332/TM, or ML–333/TM, it is incumbent upon the responsible Instrument Laboratory to provide the necessary and pertinent instructions to field personnel who handle those barometers operationally. Questions which may arise concerning these matters should be referred to the responsible Instrument Laboratory, through appropriate headquarters, for resolution.

Whenever any aneroid instrument is sealed at some definite internal barometric pressure, a tag should be affixed to the instrument with a written record indicating the reading of the device when it was sealed, and the date and place of sealing.

If any limitations exist regarding the lowest and highest ambient atmospheric pressure which a given type of aneroid instrument can withstand safely, or if there are limitations concerning the maximum permissible differential between internal and external pressure when the instrument case is kept sealed, the responsible Instrument Laboratory should advise accordingly all personnel who have occasion to handle the equipment. Authoritative information relevant to this matter received from such sources should serve to guide personnel in regard to safe air transport of the instruments. An inquiry should be directed promptly to the appropriate headquarters whenever doubt first arises concerning the matter.

Apart from precision aneroid barometers ML–331/TM, ML–332/TM, and ML–333/TM, to which reference has already been made, some aneroid instruments are equipped with a nozzle and an air-tight case, so that it is possible to seal off the case at a definite pressure. Such instruments should not be shipped by air unless they can undergo without damage the conditions to which they will be subjected during flight.

Under certain circumstances, the air-tight case can be sealed off at an internal pressure which will permit existence of a safe differential between inside and outside pressure at all points during the trip by air. The need for caution arises owing to the fact that an excessive difference between inside and outside pressure could cause a violent disruption of the instrument case, with resultant possibility of serious harm. Consequently, if shipment of the instrument by air is contemplated, the maximum permissible difference between inside and outside pressures should be ascertained from the responsible Instrument Laboratory or headquarters and calculations made to determine whether the maximum difference that can be expected during the flight will be less than the maximum permissible amount, before the final decision to utilize air transport is settled. Only if the expected maximum difference is significantly less than the permissible maximum difference of pressure is it permitted to ship the sealed instrument by air. Users of the instrument at the destination should bear in mind the influences of drift, hysteresis, and after-effect of an aneroid element as described in Chapter 2, secs. 2.10.3–2.10.5. If during shipment and storage of the instrument, the pressure in the case is maintained at a value significantly different from the ambient pressure at the time the case is opened, the influences of those phenomena should be considered before attempting to utilize the observations. The normal procedures established in connection with the use of aneroid barometers ML–331/TM, ML–332/TM, and ML–333/TM are designed to take these phenomena into account and to circumvent the major part of the attendant error (see sec. A–2.21.0 (e)); but with other types this is not usually the case.

Whenever undertaking the shipment of a barograph by air, the instructions given in sec. A–2.21.2.2 concerning preparation of the instrument before it is packed should be followed with special care.—Attention is invited to the fact that in the case of open scale barographs under the control of the Navy Department, the preparations for shipment of the instruments at altitudes below 13,000 feet are different from those for shipment at altitudes above 13,000 feet. (See the instructions in sec. A–2.21.2.2 relative to the Navy open-scale barographs.)

CHAPTER 3. GRAVITY CORRECTION FOR MERCURY BAROMETERS

3.0 INTRODUCTION

When a meteorological station is established or moved to a new location the gravity correction will ordinarily be computed at the appropriate Central Headquarters and furnished to the station. In emergencies the gravity correction may be computed at the field station or at the Regional Headquarters. In such cases the correction should be submitted to the Central Headquarters for verification as soon as practicable.

This chapter gives instructions for computing the correction for gravity. Such a correction must be applied to all readings of mercury barometers; but it is important to note that aneroid barometer readings do *not* require this correction. In the case of mercury barometer readings, the need for the correction arises owing to the fact that gravity at the location of the instrument is a factor governing the weight of the mercury column which counterbalances, and is used to measure, the atmospheric pressure acting upon the surface of the liquid in the cistern. Since gravity is affected by latitude and altitude and, therefore, generally varies from place to place over the globe, the direct readings of the mercury barometer would not be comparable if they were not corrected for the effects of gravity. Therefore, the correction for gravity has been designed to render on a comparable basis the pressure data obtained from stations subjected to different values of the *local acceleration of gravity* (g_l). In order to provide a uniform, comparable gravity basis for pressure data over the entire world, various international organizations have agreed to adopt a *standard acceleration of gravity*, denoted here by g_o, which has been assigned the constant value

$g_o = 980.665$ cm./sec.$^2 = 32.17405$ ft./sec.^{2}
(See Appendix 1.4.1.)

It is commonly said after the correction for gravity has been applied to the mercury barometer readings that *"the readings are reduced to standard gravity."* This statement may be understood from the fact that the purpose of the correction in any case is to adjust the given reading in such a manner that the resultant corrected value represents what the reading would become if the actual local acceleration of gravity (g_l) which exists at the station were replaced by the standard acceleration of gravity (g_o). The correction for gravity is therefore somesometimes called "the reduction of the barometer to standard gravity."

If we let B = barometer reading of the mercury instrument, then we find

$$\textit{Correction for gravity} = \left(\frac{g_l - g_o}{g_o}\right) B.$$

The symbol we employ in this Manual to represent the "correction for gravity" is K_g. It may be remarked that, if desired, this could be properly termed "the correction to reduce barometer readings to standard gravity," on the basis of the theoretical derivation given in Appendix 1.4.2 and the brief explanation outlined above. Clearly, the algebraic sign of the "correction for gravity" depends upon the sign of the difference ($g_l - g_o$). That is, when the algebraic sign of the difference is positive (+), the correction is to be added to B; but when the difference is negative (−), the numerical value of the correction is to be subtracted.

According to the above expression, the correction for gravity can be computed readily after one knows the value of the local acceleration of gravity, g_l. Instructions are presented in the underlying sections of this chapter regarding methods of determining g_l for various kinds of topographic conditions; and these instructions are followed by others describing how the correction may be ascertained on the basis of the difference

($g_l - g_0$) and the barometer reading B. A simplified procedure can be employed *at sea* in the case of mercury barometer observations for routine meteorological purposes made on board ships, as explained in the next paragraph. The succeeding paragraphs will guide the reader in finding the sections of this chapter that are pertinent to his needs for determining the correction.

At Sea

Sec. 3.1 gives instructions directed to mariners for finding the gravity correction applicable to mercury barometers installed on board ship, for use while at sea. To follow these instructions one must refer either to Table 3.1.1 or 3.1.2, whichever is pertinent, and use the latitude and the barometer reading as arguments for the purpose of extracting the correction from the body of the tables. For those who are interested in precise scientific applications, Annex A–3.1 of this chapter indicates a somewhat more accurate method relating to oceans.

Land Stations

Sec. 3.2.0 provides general information regarding three possible methods of determining g_l at land stations, and indicates the recommended priority. These three methods involve (1) the use of the gravimeter; (2) the use of the Bouguer or free-air anomalies; (3) the use of theoretical formulas. The latter should be put into effect first (see secs. 3.2.3 and 3.2.4).

Gravimeter Method

Sec. 3.2.1 briefly outlines the method of employing a gravimeter which is an instrument capable of yielding highly precise relative measurements of gravity on a comparative basis, by giving the difference between gravity at one place where it is already known and local gravity at a station for which g_l is required. This method is recommended as a means of checking the results obtained by any other method used, since it is the most accurate of all three methods listed. It necessitates availability of the gravimeter apparatus and knowledge of the value of gravity at the point of departure.

Bouguer or Free-Air Anomaly Method

Sec. 3.2.2 relates to the use of the so-called "Bouguer and free-air anomalies" which may be applied to determine g_l. In order to utilize this method the assistance of some geodetic agency, e.g., the U.S. Coast and Geodetic Survey must be sought. When such agencies have obtained local gravity data for a sufficiently dense network of stations in some area, they generally prepare charts to represent the gravity fields over these areas. This is usually accomplished by constructing on the charts lines of constant departure of observed local gravity from the theoretical value of gravity for the same point, based on a calculation made by means of either of two formulas, namely, the Bouguer formula or the free-air formula. Such departures are called "Bouguer anomalies" and "free-air anomalies," respectively. In cases where such charts are available, experts in the field of gravity surveys at such agencies are enabled to estimate from the isopleths of constant anomaly what the anomaly is at various points in the area covered by the charts. Finally, if one needs to secure an estimate of g_l for any point in the area, the experts are generally enabled to provide it on the basis of the anomaly estimated for the point taken in conjunction with the theoretical value calculated with the aid of the pertinent formula. Annex A–3.2 to Chapter 3, together with sec. 3.2.2, give additional details relating to this subject. The method based on the use of Bouguer or free-air anomalies may be utilized to check and possibly improve the results derived by the "theoretical formula method" outlined in secs. 3.2.3 and 3.2.4, provided charts of the anomalies are available in the files of the geodetic agencies concerned.

Theoretical Formula Method

Inland Stations

Sec. 3.2.3 presents a method for calculating the value of local gravity pertaining to inland stations, based on the use of a theoretical formula. This method should be employed as soon as these instructions go into effect, and whenever new stations are put into operation. Results thus obtained should be checked with the aid of a gravimeter as soon as one becomes available. Tables 3.2.1, 3.2.2, and 3.2.3 are provided to facilitate the computations involved in the use of the theoretical formula. Examples of such computations are given. Topographic maps are needed to permit implementation of this procedure.

Coastal or Island Stations

Sec. 3.2.4 indicates how a theoretical formula may be employed to compute g_l in the case of stations located on coasts or islands. Data from Tables 3.2.1 and 3.2.2 are used in this regard, and examples of the relevant calculations are also given. This method should be put into use as soon as practicable. Topographic maps showing both the land and sea-bottom contours around the station are required to enable one to implement this procedure.

Computation of Gravity Correction After g_l Is Known

Finally, sec. 3.3 gives instructions for the calculation of the correction for gravity of mercury barometers for cases in which the local acceleration of gravity (g_l) has been determined. Tables 3.3.1 and 3.3.2 have been provided to facilitate the calculation under these circumstances. An example is shown to indicate how the correction for gravity may be computed for use in routine engineering and meteorological observations involving a mercury barometer.

3.1 GRAVITY CORRECTION FOR MERCURY BAROMETERS ON BOARD SHIP

In the case of observations with *mercury barometers at sea,* the gravity correction varies with latitude. Therefore, it changes as the ship crosses circles of latitude, and a different correction is generally necessary for each observation provided the mercury barometer is used. The routine method of determining the gravity correction in this event is outlined in the remainder of this section. If anyone requires gravity data more accurately evaluated than by the routine method, he should refer to Annex A–3.1 of this chapter.

Tables 3.1.1 and 3.1.2 give the correction for gravity applicable to mercury barometer readings obtained at sea. When the barometer is graduated to read in inches, the observer should refer to Table 3.1.1; and when the barometer is graduated to read in millibars or millimeters, he should refer to Table 3.1.2. The observer should find the correction for gravity in the body of the tables corresponding to the following two arguments: (1) the latitude, ϕ; and (2) the observed reading of the mercury barometer, B.

The correction for gravity (K_g) obtained at sea is applied with a positive sign (+) when the latitude is *north* of latitude 45° 32′40″ N., and also when the latitude is *south* of latitude 45°32′40″ S.; hence the correction is to be added in the case of ship locations anywhere in those regions. However, when at sea at locations between those two circles of latitude, the correction is applied with a minus sign (—), signifying that the numerical value of the correction is to be subtracted. The tables indicate the proper sign with which the correction is to be applied, depending upon latitude.

The following list illustrates values of the correction for gravity corresponding to various observed barometer readings and latitudes, as determined with the aid of Tables 3.1.1 and 3.1.2:

It is customary to apply the correction for instrumental error (K_i), the correction for temperature (C_t), and the reduction to sea level at the same time as the correction for gravity (K_g) is applied. The correction for instrumental error is usually shown on the "Barometer Correction Card" pertaining to the given mercury barometer. On the other hand, the correction for temperature should be obtainable from a special table pertinent to the given instrument and supplied by the laboratory where the barometer was calibrated. Alternatively, it is possible in some cases to ascertain the temperature correction for fixed-cistern barometers by the method illustrated in the example given at the end of sec. 5.3. In order to be enabled to make use of that method it is necessary to have information relating to four quantities pertinent to the given fixed-cistern

EXAMPLES

Corrections for gravity pertinent to mercury barometer readings taken at sea

Example No.	Barometer reading B	Latitude ϕ	Correction for gravity K_g	Table No. from which corrections are taken
1	29.80 inches	55°22′ N	+0.027 in	3.1.1
2	30.24 inches	27°45′ N	−0.047 in. [1]	3.1.1
3	30.15 inches	23°32′ S	−0.055 in. [1]	3.1.1
4	29.56 inches	52°50′ S	+0.020 in	3.1.1
5	998.5 mb	50°18′ N	+0.4 mb	3.1.2
6	1021.6 mb	32°43′ N	−1.2 mb. [1]	3.1.2
7	1009.2 mb	24°30′ S	−1.8 mb. [1]	3.1.2
8	995.7 mb	56°25′ S	+0.9 mb	3.1.2

[1] Since the sign of the correction is minus (—) in these cases, the numerical value of the correction is to be subtracted when applying the correction to the barometer reading. In the remaining cases the correction is to be added.

CAUTION: The correction for gravity *never* applies to aneroid barometer readings.

barometer, these quantities being as follows: (1) the "barometer constant," b; (2) the "reference temperature," t_r; (3) the temperature at which the scale of the barometer is accurate, t_a; and (4) the correction for instrumental error, also called the "index correction," K_i. The manufacturer of the barometer or the laboratory at which the instrument was calibrated should be able to supply the data regarding the four quantities b, t_r, t_a, and K_i. Details concerning the procedure which involves the application of these data to determine the correction for temperature of fixed-cistern barometers are given in sec. 5.3.

Figs. 3.1.0 and 3.1.1, which follow this paragraph, present examples indicating how the various corrections are applied to the readings of the mercury barometer in order to obtain the pressure reduced to sea level. It should be recalled that these examples are *not* valid in the case of aneroid barometer readings. The notes (a)—(g) given in connection with the examples indicate the sources of the data. With a view to determining the reduction of pressure to sea level pertinent to observations made on board ship, use may be made of the data contained in Table 7.1, taking account of the height of the cistern above sea level and the outside temperature at the time of the observation; care being taken to convert height from feet to meters before referring to Table 7.1.[2] It will be obvious that the evaluation of mercury barometer observations by the method employed in the examples necessitates references to several tables, and involves a certain amount of arithmetic. In order to avoid this effort use is made in some cases of the so-called "Barometer-correction slide" which is described in the following two paragraphs.

Kew-pattern marine barometers are often equipped with a "barometer-correction slide" which yields the corrections required (see: United Kingdom Meteorological Office, Air Ministry, "Handbook of Meteorological Instruments"; Part I, "Instruments for Surface Observations"; London, Her Majesty's Stationery Office, 1956, pages 32–33). This device, invented by Col. E. Gold, formerly of the British Meteorological Office, is constructed of a solid brass stock on which is mounted a mercury-in-glass thermometer. It has a movable slide which carries one scale for height of the barometer above the water line and another for correction of the barometer for instrumental error (termed "index correction"). This slide can be moved up or down by means of a rack and pinion. In addition, the device is provided with a movable plate which is set in a slot in the stock and carries a scale of latitude. Opposite the latter scale is a scale of "index correction." When installing the "barometer-correction slide," it is necessary to fix a balance weight to the rear of the barometer case at the same level as the rest of the slide. The purpose of this weight is

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[2] Information regarding more precise and accurate procedures for ascertaining the reduction of pressure to sea level is given in Chapter 7; see especially sec. 7.1 which will be pertinent to the situation on ships in most cases.

Name of ship S. S. MORNING STAR Fixed-cistern barometer No. 125

Barometer constant, b, 1.92 inches "Reference temperature," t_r 30°F.

(Note: (a)) (See Section 5.3.)

Temperature at which scale is accurate, t_a 62°F. (Note: (a)) (See Sec. 5.3.)

Height of Barometer Cistern above Water-Line, H_z 43 ft. = 13.1 meters

Latitude, ϕ 55°22' N. Outside temperature, t_o 40°F.

Temperature of attached thermometer, t 55°F. $(B + b + K_i) = 31.710$ in.

COMPUTATIONS

	Negative Terms	Positive Terms	Notes
Barometer reading observed, B		29.805 inches	
Instrumental (index) correction, K_i	-0.015 in.		(a)
Correction for gravity, K_g............		+0.027 inches	(b)
Correction for temperature, C_t	-0.071 in.		(c)
Reduction of pressure to sea level.....		+0.048 inches	(d)
Sum of terms	-0.086 in.	29.880 inches	(e)
Pressure reduced to sea level......... (net) sea-level pressure		29.794 inches	(f)
Sea-level pressure converted to millibars		1009.0 mb.	(g)

<u>Notes</u>: (a) Values of b, t_r, t_a, and K_i for the given barometer must be secured from the laboratory which calibrated the instrument.

(b) Obtain K_g corresponding to B and ϕ from Table 3.1.1.

(c) Obtain by method shown in example presented at end of Sec. 5.3.

(d) Obtain from Table 7.1 on basis of outside temperature, t_o, and height H_z.

(e) Indicate the sum of negative and positive terms, respectively.

(f) The pressure reduced to sea level is obtained by subtracting from the sum of positive terms the numerical value indicated by the sum of negative terms.

(g) Use Table 1.4.1 to convert pressure from inches of mercury to millibars.

FIGURE 3.1.0. Example of application of various appropriate corrections to mercury barometer readings taken at sea (English units).

Name of Ship S. S. MORNING STAR Fixed-cistern Barometer No. 85

Barometer constant, b 65 mb. "Reference temperature," t_r 1.0°C.

(Note: (a)) (See Sec. 5.3.)

Temperature at which the scale is accurate, t_a 0.0°C (Note: (a)) (See Sec. 5.3.)

Height of barometer cistern above water-line, H_z 56 ft. = 17.1 meters

Latitude, ϕ 4°02' N. Outside temperature, t_o 88°F.

Temperature of attached thermometer, t 86°F. = 30°C. $(B + b + K_i) = 1072.1$ mb.

COMPUTATIONS

	Negative Terms	Positive Terms	Notes
Barometer reading observed, B.......		1006.8 mb.	
Instrumental (index) correction, K_i....		+ 0.3 mb.	(a)
Correction for gravity, K_g...........	-2.7 mb.		(b)
Correction for temperature, C_t	-5.1 mb.		(c)
Reduction of pressure to sea level.....		+ 1.9 mb.	(d)
Sum of terms........................	-7.8 mb.	1009.0 mb.	(e)
Pressure reduced to sea level (net); sea-level pressure		1001.2 mb.	(f)

Notes: (a) Values of b, t_r, t_a, and K_i for the given barometer must be secured from the laboratory which calibrated the instrument.

(b) Obtain K_g corresponding to B and ϕ , from Table 3.1.2.

(c) Obtain C_t by the method shown in example presented at end of Sec. 5.3.

(d) Obtain the reduction of pressure to sea level from Table 7.1 on basis of outside temperature, t_o, and height H_z.

(e) Indicate the sum of negative and positive terms, respectively.

(f) Obtain result by applying the sum of negative terms algebraically to the sum of positive terms.

FIGURE 3.1.1. Example of application of various appropriate corrections to mercury barometer readings taken at sea (millibar units).

to enable the barometer to hang vertically when the correction slide is attached.

When the "barometer-correction slide" is put into service for any given barometer, it is necessary to adjust the position of the latitude-scale plate so that the short red line on the left-hand side of the plate is exactly opposite the value of the index correction of the given instrument on the index-correction scale, using the index correction at 1000 mb. for the latter value. The purpose of the "barometer-correction slide" is to indicate the total of all corrections, comprising the algebraic sum of the correction for gravity, the correction for instrumental error (index correction), the correction for temperature, and the reduction of pressure to sea level depending upon the height above the water-line. In order to use the "barometer-correction slide" after proper installation, it is necessary to move the slide until the latitude of the ship as read on the latitude scale is set opposite the height of the cistern of the barometer above the water-line as read on the height scale. The observer may then determine the required total correction simply from a reading of the value shown by the correction scale on the slide opposite the top of the mercury column on the thermometer. In case the correction appears on the red part of the scale, that is prefixed with a minus (—) sign, it is negative and the numerical value of the correction should be subtracted from the actual observed reading of the barometer. On the other hand, if the correction appears on the black part of the scale, that is prefixed with a plus (+) sign, the indicated correction is to be added. Sometimes the corrections yielded by the "barometer-correction slide" are subject to slight errors, most commonly of the order of a few tenths of a millibar, largely owing to the fact that the effects of variations of outside temperature and pressure on certain of the correction terms have been neglected.

3.2 DETERMINATION OF LOCAL GRAVITY AT LAND STATIONS

3.2.0 Introduction

The foundation for gravity calculations approved by the World Meteorological Organization[3] is the following formula which gives the acceleration of gravity at sea level ($g_{\phi,o}$) as a function of latitude (ϕ):

$$g_{\phi,o} = 980.616\,(1 - 0.0026373 \cos 2\phi + 0.0000059 \cos^2 2\phi) \text{ in cm./sec.}^2$$

This is the basis of the so-called "Meteorological Gravity System." It may be noted that when the latitude ϕ is taken as 45° in the formula, it yields the value $g_{45°,o} = 980.616$ cm./sec.^{2} for the acceleration of gravity at latitude 45°, at sea level. This constant is based on gravity determinations from pendulum observations at various key stations at several latitudes. The other constants in the formula are derived theoretically and depend upon the assumed figure of the earth (an ellipsoid of revolution whose equatorial radius is 6,378,388 meters, and whose flattening is 1/297).

Table 3.2.1 provides data representing the acceleration of gravity at sea level ($g_{\phi,o}$) as a function of latitude (ϕ), in accordance with the formula given above, as the basis for the "Meteorological Gravity System." It may be pointed out that geodesists employ the so-called "Potsdam Gravity System" which is somewhat similar to the adopted system referred to above, except that all values in the Potsdam System are 0.013 cm/sec.^{2} higher than those on the Meteorological Gravity System.

It is necessary to regard the formula for $g_{\phi,o}$ as an approximate relationship used for reference purposes, since local gravity on the surface of the sea and at mean tide level on sea coasts may differ appreciably from the value calculated by means of the formula. (See Annex A–3.1).

There are several different methods of determining the value of local gravity, g_l, depending upon the accuracy desired and upon the availability of appropriate equipment or data. The following secs. 3.2.1–3.2.4, describe the various methods in order of accuracy, as here listed:

(A) gravimeter—most accurate;

(B) Bouguer or free-air anomalies—generally next in accuracy;

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[3] World Meteorological Organization, Commission for Aerology, Abridged Final Report of the First Session, Toronto, 10th August-5th September, 1953" pp. 59–63 (W.M.O.-No. 18. R.P. 8).

(C) theoretical formula — generally least accurate.

Operational practice should be governed by the instructions in numbered paragraphs (1), (2), (3) hereunder.

(1) Method (C) can and should be applied as soon as practicable in all cases (see secs. 3.2.3 and 3.2.4). The value of local gravity, g_l, thus computed should be used as a basis for calculating the correction for gravity (see sec. 3.3). This value will be applied until or unless an improved result is determined by a more accurate method.

(2) If a gravimeter is at one's disposal or becomes available later, method (A), explained in sec. 3.2.1, should be employed to improve the result yielded by method (C), which serves as a check.

(3) If circumstances permit the obtainment of an estimated value of the local Bouguer or free-air anomaly from a geodetic organization, method (B), described in sec. 3.2.2 and Annex A–3.2 of this chapter, should be used firstly to check the datum computed by method (C). When the geodetic organization recommends giving preference to method (B) over method (C) in the given case, this advice can be accepted as a basis for revising the result obtained by method (C).

3.2.1 Use of the Gravimeter

A gravimeter (gravity meter)[4] [5] is a convenient apparatus employed by geodesists and geophysical prospectors to measure the local value of gravity at a land station relative to the known acceleration of gravity at some other station, where it has been determined by independent means, usually by accurate pendulum observations. The gravimeter enables one to ascertain the difference in gravitational acceleration between the two points. It is a highly precise and accurate instrument. Whenever there exists a basic network of stations at which gravity has been determined by any accurate means, it is considered that the most reliable method of determining the local acceleration of gravity at other points is to make differential gravimeter measurements between one or more stations in the basic network and the other points at which the value of g_l is desired. It should be kept in mind that the Potsdam Gravity System used by geodesists is 0.013 cm./sec.^{2} higher than the Meteorological Gravity System employed herein.

The use of gravimeter data to determine g_l is illustrated by the following instruction: Suppose g_a represents the *known* local acceleration of gravity at a certain point "*A*," usually a gravity base station established by a geodetic organization, where g_a is on the *Potsdam Gravity System*, and suppose further that g_l represents the unknown local acceleration of gravity on the "*Meteorological Gravity System*" at some other known point "*X*" for which the value of g_l is desired. Let Δg denote the difference in gravity acceleration at the two places, as observed by means of a gravimeter. That is, Δg is the value at point "*X*" *minus* the value at point "*A*" on a consistent system. Then g_l is given by the equation

$$g_l = g_a + \Delta g - 0.013$$

where each quantity is in the terms of the unit cm./sec.^{2}

3.2.2 Use of Bouguer or Free-Air Anomalies

Geodetic institutions such as the U.S. Coast and Geodetic Survey have made measurements of the local acceleration of gravity at many places on land by means of pendulum apparatus and gravimeter. For these same places they have also calculated what the value would be on the assumption of theoretical gravity formulae, including a correction for elevation devised by a French geodesist named Bouguer. The deviation of the actually observed local gravity from the theoretical value based on Bouguer's formula is called the "Bouguer anomaly." Geodesists have prepared tables which give the Bouguer anomalies at stations in an exten-

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[4] D. H. Clewell, et al., "Instrumentation for Geophysical Exploration," The Review of Scientific Instruments, vol. 24, pp. 243–266 (1953).

[5] H. Landsberg, Editor, "Advances in Geophysics," vol. 1, (1952), New York, Academic Press, Inc. (Chapter by G. P. Woollard, 'The Earth's Gravitational Field and Its Exploitation," pp. 281–311).

sive network covering large areas. Isopleths of constant Bouguer anomalies have been constructed on maps for some countries. From these tabular data or isopleths geodesists can estimate by interpolation what the Bouguer anomaly would be at points within the area covered by the network. Using such an estimated value it is possible to determine approximately the value of the local acceleration of gravity at points where gravity has not actually been measured. This method yields fairly reliable results provided the original network of gravity stations had a density greater than that corresponding to a spacing of about 60 miles between stations. Annex A–3.2 gives the details pertinent to this method. In order to apply the method, it is necessary to consult an organization like the U.S. Coast and Geodetic Survey, which makes gravity measurements and has tabular data giving the distribution of the Bouguer anomaly over the area of interest.

Another type of anomaly in wide use among geodesists is the so-called "free-air anomaly." The significance of these various anomalies may be grasped from the following equations which serve to define them on the Meteorological Gravity System, where

g_l = local value of acceleration of gravity (in cm./sec.^{2}) at station P_1 based on the "Meteorological Gravity System";

$g_{\phi,o}$ = theoretical value of gravity at sea level (in cm./sec.^{2}) at the latitude of station P_1 based on the "Meteorological Gravity System" (see Table 3.2.1);

H = elevation (in feet) above mean sea level of the point at station P_1 where g_l applies;

A_B = Bouguer anomaly (in cm./sec.^{2})

A_F = free-air anomaly (in cm./sec.^{2})

Formula for Bouguer Anomaly

$$g_l = g_{\phi,o} - 0.00005998H + A_B$$

Formula for Free-Air Anomaly

$$g_l = g_{\phi,o} - 0.00009406H + A_F$$

The term "Bouguer correction" is used in reference to the quantity ($-0.00005998\ H$); and the term "Free-Air Correction" to the quantity ($-0.00009406\ H$) denoted by C_f.

Geodesists determine the anomalies by measuring g_l and H at the given station of known latitude, then solving the equations for A_B and A_F.

However, when it is desired to estimate g_l for a station in any case where A_B or A_F may be estimated from the tabular data or maps of isopleths of the anomalies, the above formulae may be applied to calculate g_l, provided that the proper elevation and latitude are known.

It should be noted that since g_l and $g_{\phi,o}$ must be expressed on a single, consistent gravity system, any given anomaly is the same in value on the "Potsdam Gravity System" as on the "Meteorological Gravity System."

3.2.3 Use of Theoretical Formula Giving Local Gravity for Inland Stations

If a gravimeter is unavailable or if the Bouguer anomaly method cannot be employed for some reason (e.g. if a sufficiently dense network of gravity stations does not exist in the area of interest), it will be necessary to fall back upon the method of calculating the value of local gravity (g_l) by means of a theoretical formula. Tables are provided to facilitate the calculations (see Tables 3.2.1, 3.2.2, and 3.2.3). The theoretical formula which is found to yield generally the most reliable results for *inland stations* is the following:

$$g_l = g_{\phi,o} - 0.00009406\ H_z + 0.00003408\ (H_z - H'),\ \text{in cm./sec.}^2 \quad (1)$$

where

$g_{\phi,o}$ = theoretical value of the acceleration of gravity at sea level at the latitude ϕ, of the station, based on the "Meteorological Gravity System" (see Table 3.2.1);

H_z = elevation in *feet* above mean sea level of point at which local acceleration of gravity (g_l) is required;

H' = elevation in *feet* of the general terrain within a radius of 100 miles of the point, averaged over the circle area.

The quantity $-0.00009406\ H_z$ represents the "free-air gravity correction," and the quantity $+0.00003408(H_z - H')$ may be called the "free air-Bouguer correction," since it is based on a combination of the free-air gravity correction and the Bouguer correction (see Annex A–3.2) depending upon the elevation of the station *relative* to the elevation of the general terrain included within a radius of 100 miles.

In Tables 3.2.2 and 3.2.3, which yield data for the foregoing quantities, the following notation is employed:

Table 3.2.2, "free-air gravity correction" $= C_f = -0.00009406\ H_z$;

Table 3.2.3, "free air-Bouguer correction" $= C_b = 0.00003408\,(H_z - H')$.

The instructions given below in paragraphs (A)—(D) will be followed in calculating the value of the local acceleration of gravity (g_l) in the case of stations having *inland locations.* Examples of the computations are presented immediately after paragraph (D). Instructions for calculating g_l in the cases of stations having locations on coasts or islands are covered in sec. 3.2.4.

(A) (a) Determine the geographic latitude (ϕ) of the station from the best available large-scale map or from some authoritative source of information, such as the U.S. Coast and Geodetic Survey. (b) Refer to Table 3.2.1 and find the theoretical value of the acceleration of gravity ($g_{\phi,o}$) at sea level at the given latitude. Interpolate at least according to the nearest minute of latitude (1/60 degree), if known. Acceleration of gravity will be expressed in cm./sec.^{2} (centimeters per second per second).

(B) (a) Determine the actual elevation of the barometer (H_z) in feet, in accordance with instructions given in Chapter 1. (b) Refer to Table 3.2.2 and determine the "free-air gravity correction," by applying a minus sign to the value given in the table corresponding to H_z, the actual elevation of the barometer, interpolating if necessary. (c) Then apply this correction algebraically to the value of $g_{\phi,o}$, found in accordance with instructions in paragraph (A) above; this process yielding ($g_{\phi,o} - 0.00009406\ H_z$).

(C) Determine if possible from topographic maps the elevation (H' in feet) of the general terrain within a radius of 100 miles. The most accurate procedure for estimating H' is to construct a circle of 100 miles radius on the topographic map. Divide the circle into smaller areas each of which has terrain of approximately uniform average elevation. Multiply the small area in each case by the average elevation within it. Add up the products thus obtained and divide the sum by the total area of the circle. This yields the mean value H' for the circle.

(D) (a) Next compute the value of the algebraic difference ($H_z - H'$), in feet. (b) Refer to Table 3.2.3 and find the "free air-Bouguer correction," namely

$$0.00003408\,(H_z - H').$$

One should give this correction the same algebraic sign as the value of ($H_z - H'$). (c) Finally apply this correction algebraically to the value ($g_{\phi,o} - 0.00009406\ H_z$) found in accordance with paragraph (B) above. This process leads to the value of local gravity,

$$g_l = g_{\phi,o} - 0.00009406\ H_z + 0.00003408\,(H_z - H'),\ \text{in cm./sec.}^2$$

Examples of Calculation of Local Acceleration of Gravity (g_l) for Inland Stations

	Example I	Example II
(A) (a) From the map, find accurately	latitude (ϕ) = 40°50′00″	latitude (ϕ) = 36°11′30″
(b) Referring to Table 3.2.1., find the theoretical value of the acceleration of gravity at sea level at the given latitude	$g_{\phi,o} = 980.241$ cm./sec.^{2}	$g_{\phi,o} = 979.834$ cm./sec.^{2}
(B) (a) By leveling, the actual elevation of the barometer is found to be	$H_z = 4276.3$ feet	$H_z = 6584.5$ feet
(b) Refer to Table 3.2.2 and find by interpolation the value of $0.00009406\ H_z$; prefix a *minus* (—) sign, and thus obtain the "free-air gravity correction"	$-0.00009406\ H_z = -0.402$ cm./sec.^{2}	$-0.00009406\ H_z = -0.619$ cm./sec.^{2}

(c) Apply the "free-air gravity correction" algebraically to $g_{\phi,o}$, thus obtaining $(g_{\phi,o} - 0.00009406\ H_z)$, which yields

979.839 cm./sec.^{2}	979.215 cm./sec.^{2}

(C) Determine from topographic maps the average elevation H' of the general terrain within a radius of 100 miles, thereby obtaining

$H' = 5800$ feet	$H' = 4700$ feet

(D) (a) Compute the algebraic difference $(H_z - H')$, thus obtaining

$(H_z - H') = -1523.7$ feet	$(H_z - H') = +1884.5$ feet

(b) Referring to Table 3.2.3 find the "free air-Bouguer correction," which has the same algebraic sign as $(H_z - H')$, thus securing for the "free air-Bouguer correction," the value

-0.052 cm./sec.^{2}	$+0.064$ cm./sec.^{2}

(c) Apply this correction to the value of $(g_{\phi,o} - 0.00009406\ H_z)$ obtained in accordance with instructions under paragraph (B), thereby obtaining the local acceleration of gravity,

$$[g_{\phi,o} - 0.00009406\,H_z + 0.00003408\,(H_z - H')]$$

$g_l = 979.787$ cm./sec.^{2}	$g_l = 979.279$ cm./sec.^{2}

A question arises with regard to the reliability of values of g_l calculated by means of the theoretical formula as presented above. An unpublished manuscript supplied June 9, 1948, by J. A. Duerksen, Gravity and Astronomy Branch, U.S. Coast and Geodetic Survey, indicates that the thus calculated values of g_l may differ from the observed values by various amounts as illustrated for several stations in the following table:

Table

Examples of Difference Between Observed and Calculated Values of Local Acceleration of Gravity (g_l) According to Duerksen

Name and number of gravity station	H_z elevation of station	H' Average elevation of region within radius of 100 miles	Observed *minus* calculated values of g_l
	Feet	*Feet*	*Cm./sec* ^{2}
Pikes Peak, Colo. (#43)	14,085	7,500	−0.021
Dallas Center, Iowa (#1134)	1,067	1,045	−0.034
Wymont, Wyoming (#437)	10,709	6,140	+0.023
Grand Canyon, Ariz. (#69)	2,779	5,700	−0.011
Seattle, Wash (#56)	243	1,600	−0.068

3.2.4 Use of Theoretical Formula Giving Local Gravity for Coastal and Island Stations

The procedure of this sec. is to be applied if the methods outlined in sec. 3.2.1 (Gravimeter measurements) or in sec. 3.2.2 (Interpolation of Bouguer anomalies) cannot be carried out for any reason. We define:

g_l = local acceleration of gravity at the station, in cm./sec.^{2};

$g_{\phi,o}$ = theoretical value of the acceleration of gravity (in cm./sec.^{2}) at sea level at the latitude of the station, based on the equation cited in sec. 3.2.0 (see Table 3.2.1);

H_z = actual elevation (in feet) of the barometer (or station);

H' = average elevation (in feet) of the land portion of the area contained within a circle of radius 100 miles centered on the station;

D' = average depth (in feet) of the ocean-bottom portion of the area contained within a circle of radius 100 miles centered on the station;

k = ratio of land portion of area to total area of circle considered.

When a station is situated on a sea coast or island, in such a location that the circle of radius 100 miles includes areas both of land and sea, the following theoretical formula will be used in calculating local gravity, (g_l) at the station:

$$g_l = g_{\phi,o} - 0.00009406\ H_z + k(0.00003408)\ (H_z - H') + (1-k)\ (0.00002096)\ D' + (1-k)\ (0.00003408)\ H_z$$

in cm./sec.^{2},

Example I

Wahiawa, Island of Oahu
Latitude (ϕ) = 21°29.6′ N.
Longitude (λ) = 158°02.0′ W.
Elevation, H_z = 866.2 feet

Average elevation of land area within circle of 100 miles radius,

$H' = 1000$ feet

Average depth of ocean-bottom area within circle of 100 miles radius,

$D' = 11{,}100$ feet

Ratio of land area to total area of circle,

$k = 0.07$

It follows that $(1 - k) = 0.93$, and $(H_z - H') = (866.2 - 1000)$ ft. $= -133.8$ ft.

Also, from Table 3.2.1, we find

$g_{\phi,o} = 978.728$ cm./sec.^{2}

Substituting the pertinent data in the above formula, we obtain

$$\begin{aligned} g_l &= 978.728 - (0.00009406)\ (866.2) \\ &\quad + (0.07)\ (0.00003408)\ (-133.8) \\ &\quad + (0.93)\ (0.00002096)\ (11{,}100) \\ &\quad + (0.93)\ (0.00003408)\ (866.2) \\ &= 978.728 - 0.0815 - 0.0003 + 0.2164 \\ &\quad + 0.0275 = 978.8901 \text{ cm./sec.}^2, \end{aligned}$$

calculated value on the "Meteorological Gravity System."

(Note: The actual observed value on this system was 978.899 cm./sec.^{2} Thus, the calculated value is 0.009 cm./sec.^{2} too low in this case.)

The following examples give the raw data together with results in the last column showing the extent to which calculated gravity may differ from true, observed gravity.

EXAMPLES

Name and number of gravity station		H_z Elevation of station	H' and k Average elevation of land and ratio of land to total area respectively	D' and $(1-k)$ Average depth of ocean and ratio of ocean to total area respectively	Observed minus calculated value of gravity
		Feet	*Feet*	*Feet*	*cm./sec.^{2}*
No. 2:	Mauna Kea, Hawaii..........	13,061	3,750 (.20)	11,700 (.80)	+0.045
No. 55:	Mount Hamilton, Calif.......	4,205	800 (.67)	2,850 (.33)	−0.032

EXAMPLE II

San Gregorio, California (Gravity Station U.S. 257)
Latitude (ϕ) = 37°19.4′ N.
Longitude (λ) = 122°23.3′ W.
Elevation, H_z = 54.1 feet

Average elevation of land area within circle of 100 miles radius,

$H' = 800$ feet

Average depth of ocean-bottom area within circle of 100 miles radius,

$D' = 9000$ feet

Ratio of land area to total area of circle,

$k = 0.50$

It follows that $(1 - k) = 0.50$, and $(H_z - H') = (54.1 - 800)$ ft. $= -745.9$ ft.

Also, from Table 3.2.1, we find

$g_{\phi,o} = 979.932$ cm./sec.^{2}

Substituting the relevant data in the above formula, we obtain

$$\begin{aligned} g_l &= 979.932 - (0.00009406)\ (54.1) \\ &\quad + (0.50)\ (0.00003408)\ (-745.9) \\ &\quad + (0.50)\ (0.00002096)\ (9000) \\ &\quad + (0.50)\ (0.00003408)\ (54.1) \\ &= 979.932 - 0.0051 - 0.0127 \\ &\quad + 0.0943 + 0.0009 \\ &= 980.009 \text{ cm./sec.}^2 \end{aligned}$$

calculated value on the "Meteorological Gravity System."

(Note: The actual observed value on this system was 979.940 cm./sec.^{2} Thus, the calculated value was 0.069 cm./sec.^{2} too high in this case.)

3.3 CALCULATION OF CORRECTION FOR GRAVITY APPLICABLE TO MERCURY BAROMETER READINGS AT LAND STATIONS

The following notation is employed:

g_l = local acceleration of gravity, in cm./sec.^{2};

g_o = standard acceleration of gravity = 980.665 cm./sec.^{2};

c = $(g_l - g_o)/g_o$ = constant factor involved in the correction for gravity at the station; also equal to $(g_l/g_o - 1)$;

B = observed reading of the mercury barometer;

B_{ct} = reading of the barometer corrected for instrumental error and temperature (see sec. 5.1);

B_n = normal annual value of B_{ct}; that is, the average that would be observed at the station over a long period of years in regard to the mercury barometer readings corrected for both instrumental errors and temperature;

P_n = normal annual value of station pressure at the level of the barometer;

K_g = correction for gravity applicable to mercury barometer readings.

Two cases, depending upon the character of the observations that involve the correction for gravity, will be treated:

Case (*a*) Routine observations for ordinary meteorological and engineering purposes, in which case we shall consider $K_g = cB_n$; and

Case (*b*) Special observations for scientific purposes where the highest possible degree of accuracy is desired, in which case $K_g = cB_{ct}$. Procedures pertinent to these two cases are the same in certain respects; namely, in regard to the determination of the factor c and the performance of the indicated multiplication, either $c \times B_n$, or $c \times B_{ct}$. These latter products represent the correction for gravity. The difference between the two cases arises in regard to the evaluation of B_n or B_{ct}, whichever is pertinent.

To deal first with the steps which are common to the two cases, an operational procedure along the lines indicated below should be followed:

Step (1): Determine g_l in accordance with the instructions in sec. 3.2, being guided by the material and examples in secs. 3.2.1, 3.2.2, 3.2.3, and 3.2.4, whichever is appropriate.

Step (2): Compute the difference $(g_l - g_o)$.

Step (3): After B_n or B_{ct} has been determined in the proper manner as outlined below, or as indicated in Chapter 5, respectively, depending upon the case, the value of the product $c \times B_n$ or $c \times B_{ct}$ should be ascertained. For this purpose one may use Table 3.3.1 when B_n or B_{ct} is in inches, and use Table 3.3.2 when these latter quantities are expressed either in millibars or millimeters. The two arguments employed in referring to these tables are $(g_l - g_o)$ and B_n or B_{ct} (or a similar barometric height such as B, if approximate data are acceptable) while the result yielded by the tables on this basis is the required correction for gravity. When a computing machine is available, it is often more convenient and accurate to calculate the correction for gravity on the basis of the formula; for example,

$$K_g = (g_l/g_o - 1)B_n.$$

Two examples are given in the following to illustrate the application of the foregoing three-step procedure for computing the correction for gravity.

EXAMPLE I

Step (1): Suppose that one determined $g_l = 979.787$ cm./sec.^{2} for the station. (See Example I of sec. 3.2.3 and fig. 3.3.0.)

Step (2): Then, $(g_l - g_o) = (979.787 - 980.665)$ cm./sec.^{2} = -0.878 cm./sec.^{2}

Step (3): Suppose that B_n or B_{ct} is 25.580 inches, then referring to Table 3.3.1, and using this value as an argument in conjunction with the difference $(g_l - g_o) = -0.878$ cm./sec.^{2} found under Step (2), one obtains the correction for gravity from the table, namely, $K_g = -0.023$ inch, taking note of the fact that the algebraic sign of K_g is the same as that of the difference indicated under Step (2). On the other hand, if B_n or B_{ct} is 866.2 "millibars," one finds from Table 3.3.2 that $K_g = -0.78$ mb. Double interpolation should be employed, if necessary, to ascertain the correction from the tables.

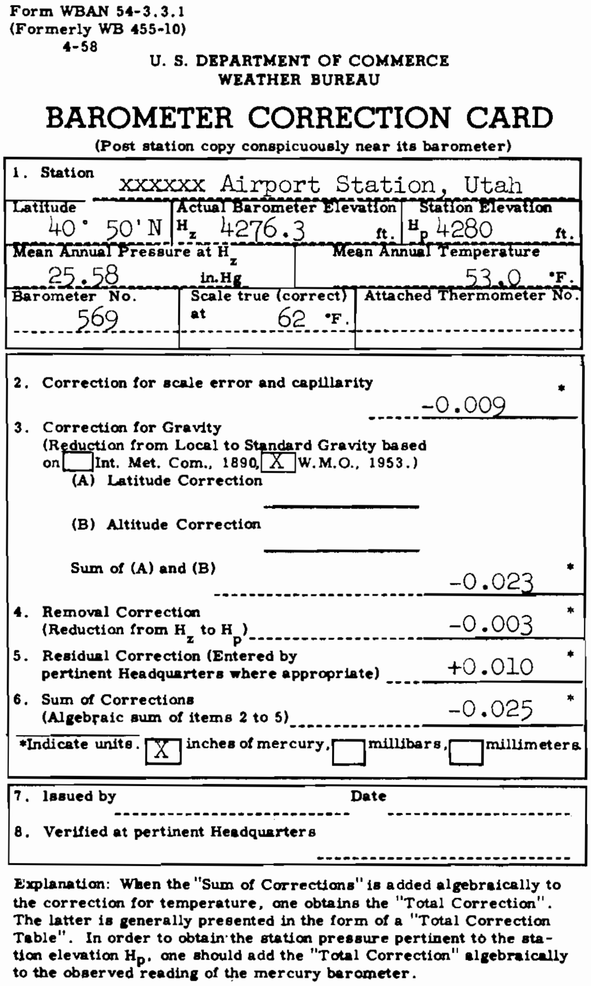
EXAMPLE II

Step (1): Suppose that one has determined $g_l = 982.658$ *cm./sec.*^{2} at latitude 71°00′ on the northern coast of Alaska.

Step (2): Then, $(g_l - g_o) = (982.658 - 980.665)$ *cm./sec.*^{2} = $+1.993$ *cm./sec.*^{2}

Step (3): Suppose that B_n or B_{ct} is 29.899 inches (1012.5 mb.), then referring to Tables 3.3.1 and 3.3.2, one finds the correction for gravity corresponding to the given data, namely,

$K_g = +0.061$ *inches* $= +2.06$ *mb.*, respectively. When a calculating machine is employed to compute the correction for gravity on the basis of the formula, one has $K_g = (g_l/g_o - 1)B_n = (1.002032 - 1)$ 29.899 *in.* $= +0.002032 \times 29.899$ *in.* $= +\ 0.061$ *in.*
Similarly, when B_n (or B_{ct}) is in metric units, one would obtain $K_g = +0.002032 \times 1012.5$ *mb.* $= +2.06$ *mb.*



Form WBAN 54-3.3.1
(Formerly WB 455-10)
4-58

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU

BAROMETER CORRECTION CARD
(Post station copy conspicuously near its barometer)

1. Station xxxxxx Airport Station, Utah

Latitude 40° 50'N	Actual Barometer Elevation H_z 4276.3 ft.	Station Elevation H_p 4280 ft.
Mean Annual Pressure at H_z 25.58 in.Hg	Mean Annual Temperature 53.0 °F.	
Barometer No. 569	Scale true (correct) at 62 °F.	Attached Thermometer No.

2. Correction for scale error and capillarity * -0.009
3. Correction for Gravity
(Reduction from Local to Standard Gravity based on ☐ Int. Met. Com., 1890, ☒ W.M.O., 1953.)
(A) Latitude Correction
(B) Altitude Correction
Sum of (A) and (B) * -0.023
4. Removal Correction (Reduction from H_z to H_p) * -0.003
5. Residual Correction (Entered by pertinent Headquarters where appropriate) * +0.010
6. Sum of Corrections (Algebraic sum of items 2 to 5) * -0.025

*Indicate units. ☒ inches of mercury, ☐ millibars, ☐ millimeters.

7. Issued by Date
8. Verified at pertinent Headquarters

Explanation: When the "Sum of Corrections" is added algebraically to the correction for temperature, one obtains the "Total Correction". The latter is generally presented in the form of a "Total Correction Table". In order to obtain the station pressure pertinent to the station elevation H_p, one should add the "Total Correction" algebraically to the observed reading of the mercury barometer.

FIGURE 3.3.0. Example of a barometer correction card showing sample entries.

Determination of B_n and B_{ct}

Case (a): Routine Observations

When purely routine observations are involved, for regular synoptic, meteorological or engineering purposes, it is the conventional practice in the United States to calculate the correction for gravity (K_g) in accordance with the formula

$$K_g \doteq |(g_l - g_o)/g_o|\ B_n = cB_n,$$

where B_n denotes the normal, annual value of the barometer reading corrected for instrumental error and temperature.

If actual statistical data of station pressures at the point of interest are not available, it is usually sufficiently accurate, for such purposes, to determine B_n on the basis of climatic data representing station pressures in the region surrounding the point of interest where the barometer is installed. When estimating what the normal, annual station pressure is likely to be at the level of the barometer from such climatic data, it is necessary to make proper allowances for both horizontal and vertical differences between normal pressures at surrounding stations already established and the probable normal at the point of interest. Table 3.3.3 contains a compilation of mean, annual station pressures for a number of stations in the United States covering various indicated periods of record. These data can be regarded, for present purposes, as close approximations to the *normal, annual station pressures* which we denote by the symbol P_n; while the station elevation to which the station pressure refers in any instance is designated by the symbol H_p.

In order to estimate the probable value of P_n at the point of interest on the basis of data representing P_n at surrounding stations having different elevations (heights above sea level), it is recommended that first of all a selection of stations surrounding the point of interest be made from the list given in Table 3.3.3, and, secondly, a graph be prepared showing the relevant values of P_n plotted against the corresponding values of station elevation, H_p. A smooth curve can generally be drawn through the plotted points. Finally, one can read from the curve at the level corresponding to the elevation (height above sea level) of the point of interest an estimated value of P_n for this point.

When it is necessary to extrapolate the data, it is often useful to employ the information contained in Table 8.1 which shows the altitudes in the standard atmosphere corresponding to various pressures. Extrapolation on this basis should only be done with the aid of pressure ratios or differences of logarithms for corresponding heights above sea level, making use of a technique such as that illustrated in Chapter 7, sec. 7.3.2.2.2.1.

If climatic data are not available for the region in which the point of interest is located, it is possible *as a temporary measure* to estimate P_n for the point from the pressure value given in Table 8.1 corresponding to the known height (altitude) of the barometer above sea level.

The value of P_n determined for the station or point of interest should be converted to the corresponding value of B_n in accordance with the following formula, based on the theory shown in Appendix 1.4.2:

$$B_n = (g_o/g_l)P_n.$$

An approximation of this expression which it is satisfactory to employ is given by

$$B_n = P_n - cP_n, \text{ approximately.}$$

In the latter expression the second term of the right-hand side can be readily evaluated with the aid of Table 3.3.1 or 3.3.2. Examples of the application of these formulas are presented below.

EXAMPLE I

Given: $g_l = 979.787$ cm./sec.^{2} for the station; and the estimated value of the normal, annual station pressure is $P_n = 25.557$ inches of mercury.

To find B_n, one has, according to the first formula,

$$B_n = (980.665/979.787)25.557 = 25.580$$

inches of mercury.

Also, one has $(g_l - g_o) = -0.878$ cm./sec.^{2} (See previous Example I.) Referring to Table 3.3.1, one finds that $cP_n = -0.023$ inch of mercury. Then, in accordance with the second formula, one computes

$$B_n = 25.557 \text{ in. Hg} - (-0.023 \text{ in. Hg}) = 25.580 \text{ in. Hg.}$$

EXAMPLE II

Given: $g_l = 982.658$ cm./sec.^{2} for the station; and the estimated value of the normal, annual station pressure is $P_n = 1014.6$ mb.

To find B_n, one may employ the first formula as follows:

$$B_n = (980.665/982.658)1014.6 \text{ mb.} = 1012.5 \text{ mb.}$$

Alternatively, to proceed on the basis of the second formula, one ascertains

$$(g_l - g_o) = +1.993 \text{ cm./sec.}^2$$

(as shown in previous Example II); whence by referring to Table 3.3.2, one finds that $cP_n = 2.1$ mb. Finally, by making use of the second formula one determines

$$B_n = 1014.6 \text{ mb.} - 2.1 \text{ mb.} = 1012.5 \text{ mb.}$$

Case (b): Special Observations for Scientific Purposes

When results of the highest possible degree of accuracy are required, the correction for gravity should be calculated by means of the equation $K_g = [(g_l - g_o)/g_o]B_{ct} = cB_{ct}$, where B_{ct} represents the current reading of the barometer corrected for instrumental error and temperature.

Procedures for evaluating B_{ct} are described in Chapter 5. In the particular case where the instrument is a Fortin-type barometer, equations (3) and (4) of sec. 5.1, or equation (23) of Appendix 1.4.2, reveal the appropriate expression for B_{ct}. These equations involve a function f, defined in sec. 5.1 as a function of the attached thermometer reading (t) and of the temperature at which the scale of the mercury barometer reads true (t_a). Appendix 1.4.2 provides further details concerning this function.

In the case where the readings are obtained from a fixed-cistern barometer, equation (III) of sec. 5.3 presents a general relationship for B_{ct} pertinent to this type of instrument.

Contrasts Between Results Determined Under Cases (a) and (b).

Under Case (a) it was assumed that one could consider the correction for gravity as given by the formula $K_g = cB_n$; whereas, under Case (b) it is proper to determine the correction on the basis of the equation $K_g = cB_{ct}$.

Therefore, a discrepancy may arise in the former instance. The error is given by the expression

$$\text{Error under Case (a)} = c(B_n - B_{ct})\,;$$

while the relative error is shown by the ratio

$$\text{Relative Error} = (B_n - B_{ct})/B_n.$$

At the center of a low-pressure area of ordinary intensity, the relative error is generally of the order of magnitude of 0.02 to 0.04; however, at the center of a very intense hurricane, the relative error may be of the order of magnitude of about 0.08 to 0.125, the latter being extremely rare and of short duration, attended by rapid variations in pressure. The larger discrepancies are generally encountered in *subtropical and* neighboring regions near sea level where the values of c generally have a value in the range of about —0.0014 to —0.0023, and a typical value of B_n is about 1015 mb. Thus, under Case (a) the correction for gravity would be calculated on the basis of these data as falling within the range of about —1.42 to —2.33 mb. If one assumes a relative error of 0.04, the absolute errors corresponding to these values of the corrections for gravity become 0.057 to 0.093 mb. However, if one assumes a relative error of 0.10, which represents a pressure of 914 mb. in a hurricane, the absolute errors corresponding to these two values of the correction for gravity would be about 0.14 to 0.23 mb. A discrepancy of this magnitude is not considered serious for synoptic pressure data observed under the extremely variable conditions which occur in hurricanes. The last statement is made with the understanding that a mercury barometer exposed to those conditions would exhibit "pumping" of such a violent character as to hamper accurate readings of the instruments.

ANNEX TO CHAPTER 3

AUXILIARY GRAVITY INFORMATION

A–3.1 CALCULATION OF LOCAL ACCELERATION OF GRAVITY AT ANY POINT OVER THE OCEAN

The information contained in this Annex is consistent with that given in the "Guide to International Meteorological Instrument and Observing Practice," published by the World Meteorological Organization, 1954.

If it is necessary for any reason to endeavor to calculate the local acceleration of gravity at a point lying above the ocean surface, the following procedure is recommended by the World Meteorological Organization:

The local value of the acceleration of gravity at a given point within an elevation (H) above mean sea level of not more than about 10 km., where the point lies over the seawater surface, is computed by means of the equation:

$$g_l = g_{\phi,o} - 0.00009406\,H - 0.00002096\,(D - D')$$

where

g_l = local calculated value of the acceleration of gravity, in cm./sec.^{2}, at the given point;

$g_{\phi,o}$ = theoretical value of the acceleration of gravity, in cm./sec.^{2}, at mean sea level at geographic latitude ϕ, computed in accord with the equation $g_{\phi,o} = 980.616\ (1 - 0.0026373 \cos 2\phi + 0.0000059 \cos^2 2\phi)$, in cm./sec.^{2} on the Meteorological Gravity System;

H = actual elevation of the given point, in feet above mean sea level;

D = depth of water, in feet, below the given point;

D' = mean depth of water, in feet, included within a circle whose radius is about 85 nautical miles centered at the given point.

Over the great deeps of the Pacific Ocean, the results given by the foregoing equation may be in error by as much as +0.155 cm./sec.^{2}

A–3.2 USE OF BOUGUER ANOMALIES

If a gravimeter is unavailable for use as recommended in sec. 3.2.1, next preference should be given to employment of interpolated Bouguer anomalies (A_B) as a means for obtaining g_l (local acceleration of gravity) at a given point, provided that a contour chart of these anomalies is available from a geodetic organization, or a net of gravity stations spaced at a density of at least one station per 10,000 square kilometers (100 kilometers, 62 miles, or less distance between stations) exists in the environment of the point. Gravity nets of somewhat less density can be used as a basis provided that the geodetic organization advises that this method is expected to yield more reliable results than those that can be obtained by the method outlined in sec. 3.2.3.

After it is found by interpolation, the Bouguer anomaly (A_B) is used to compute g_l by means of the following equation:

$$g_l = g_{\phi,o} - CH + A_B, \text{ in cm./sec.}^2 \quad (1)$$

where

$g_{\phi,o}$ = the theoretical value of the acceleration of gravity (in cm./sec.^{2}) at latitude ϕ, at sea level, as given on the Meteorological Gravity System. (Values of $g_{\phi,o}$ are presented in Table 3.2.1 which expresses this quantity as a function of latitude);

H = elevation (in feet) above sea level at the point to which g_l refers;

g_l = local value of the acceleration of gravity (in cm./sec.^{2}) at the given location and elevation based on the "Meteorological Gravity System."

A_B = Bouguer anomaly (in cm./sec.^{2});

C = elevation correction factor used in computing Bouguer anomaly (for example, using a crustal density of 2.67 g./cm.^{3}, this factor is 0.00005998 cm./sec.^{2} per foot of elevation).

EXAMPLE

A station at latitude 40°50′ and elevation H = 3280.8 feet above mean sea level is found to have a Bouguer anomaly (A_B) of −0.220 cm./sec.^{2} by interpolation on the chart.

The value of $g_{\phi,0}$, representing theoretical gravity at sea level on the "Meteorological Gravity System," is found from Table 3.2.1 to be 980.241 cm./sec.^{2} for this given latitude.

Taking $C = 0.00005998$ cm./sec.^{2} per foot of H, we calculate with the aid of the equation

$$g_l = 980.241 - (0.00005998)(3280.8) - 0.220 \text{ cm./sec.}^2$$
$$= (980.241 - 0.197 - 0.220) \text{ cm./sec.}^2$$
$$= 979.824 \text{ cm./sec.}^2$$

CHAPTER 4. "REMOVAL CORRECTION" AND "RESIDUAL CORRECTION"

4.0 INTRODUCTION

The "removal correction" is a correction applied for the purpose of reducing the pressure at the actual elevation of the barometer to the pressure at an adopted station elevation. An advantage accruing from the use of the "removal correction" is that climatological records of pressure data are thereby enabled to refer to a constant adopted station elevation, even though the actual elevation of the barometer may be changed from time to time as the station is moved from one location to another in a limited area (for example, removal from one floor to another; or from an airport hangar to the airport terminal building). Maintenance of the records of "station pressure" for a single station elevation throughout the history of a station provides continuity of the series of pressure observations pertinent to a fixed level. This facilitates climatological studies of the data and permits the use of one set of tables for reducing pressure to sea level, without the need to change the tables each time the barometer undergoes a vertical displacement.

The "residual correction" is a correction for instrumental error that may be required in the case of barometers after they have been calibrated in the laboratory and have subsequently been in field use. A correction for "scale errors and capillarity" is determined by laboratory calibration, and this is embodied in the "Barometer Correction Card" when the barometer is initially issued from the laboratory (see sample "Barometer Correction Card" near end of Chapter 3). However, experience shows that for certain reasons explained later (see sec. 4.4), the internal condition of the barometer undergoes changes with time in such a manner that there develops an additional error, not overcome by the correction for "scale errors and capillarity" found earlier by the laboratory study. The "residual correction" is designed to compensate for this additional error.

4.1 GENERAL INFORMATION REGARDING "REMOVAL CORRECTION"

A "removal correction" is included among the corrections applied to the barometer when the actual elevation of the barometer (H_z) differs from the adopted station elevation (H_p). The "removal correction" serves to reduce the pressure from the level H_z to the level H_p.

The "removal correction" depends upon (a) the difference ($H_z - H_p$); (b) the normal annual mean pressure at the level $(H_z + H_p)/2$; and (c) the assumed average outdoor temperature in the height interval (H_z to H_p). It should be noted that the algebraic sign of the "removal correction" is the same as that of ($H_z - H_p$).

Table 4.1.1 gives "Tabular Values Showing the Change in Pressure (in. Hg) Corresponding to a Change in Height of One Geopotential Foot." The "removal correction" can be calculated with the aid of Table 4.1.1. If the difference ($H_z - H_p$) is relatively small and the maximum deviation of actual outdoor temperature from the assumed average outdoor temperature is relatively small, the "removal correction" may be considered a constant; but if the facts are contrary to these conditions, the "removal correction" must be treated as a variable, depending upon the outdoor temperature. Criteria for determining whether the correction shall be treated as constant or variable are given in the next section.

4.2 INSTRUCTIONS FOR CALCULATING THE "REMOVAL CORRECTION"

The following procedure will be used in determining the "removal correction." Examples are shown in sec. 4.3.

(a) Ascertain the actual elevation of the barometer (H_z) and the adopted station elevation (H_p), in feet. Calculate the difference ($H_z - H_p$).

(b) Ascertain the probable or best estimate of the mean annual barometric pressure at the mean altitude $(H_z + H_p)/2$. If climatological pressure data are not available for this purpose, estimate the required pressure from the standard atmosphere Pressure—Altitude Table given below, corresponding to the mean altitude. See Table 8.1.

Standard Atmosphere Pressure–Altitude Table

Altitude m.s.l. feet	Pressure inches of mercury	Altitude m.s.l. feet	Pressure inches of mercury
−1,000	31.02	10,000	20.58
0	29.92	11,000	19.79
1,000	28.86	12,000	19.03
2,000	27.82	13,000	18.29
3,000	26.82	14,000	17.58
4,000	25.84	15,000	16.89
5,000	24.90	16,000	16.22
6,000	23.98	17,000	15.57
7,000	23.09	18,000	14.94
8,000	22.22	19,000	14.34
9,000	21.39	20,000	13.75

(c) Ascertain from climatological records the best available estimate of the "annual normal temperature" at the level of the station thermometer. (See for example fig. 7.2.0, "Isotherms of average annual temperature for the United States," also Tables 7.1.2 and 7.1.3.) Reduce this temperature to the level $(H_z + H_p)/2$ assuming a standard lapse rate of 0.003566° F. per foot under ordinary conditions; that is, a decrease of temperature with altitude at this rate from the station thermometer height to the level $(H_z + H_p)/2$. Consider the result the "annual normal temperature" at the mean altitude $(H_z + H_p)/2$.

(d) Refer to Table 4.1.1, and, by means of double interpolation determine the value of the "change in pressure corresponding to a change in height of one foot," using as arguments:

(1) the mean annual barometric pressure at the level $(H_z + H_p)/2$ referred to in paragraph (b) above; and

(2) the "annual normal temperature" at the mean altitude $(H_z + H_p)/2$ referred to in paragraph (c) above.

This process yields an appropriate factor from the body of the table.

(e) Multiply this factor algebraically by the difference ($H_z - H_p$). The product thus obtained represents the "removal correction" corresponding to the "annual normal temperature." It will be noted that the specified "removal correction" should be positive (+) when H_z exceeds H_p, and negative (−) when H_z is less than H_p. "Removal corrections" with algebraic signs attached, should be expressed to the nearest 0.001 inch of mercury.

(f) Next, repeat the above-outlined process of obtaining the removal correction, except that now use the probable absolute annual *minimum* and *maximum temperatures*, respectively, as the temperature argument in referring to Table 4.1.1 instead of the "annual normal temperature." This procedure gives the removal corrections corresponding to the above-specified minimum and maximum temperatures, respectively. Data regarding absolute annual minimum and maximum temperatures at selected stations will be found in Tables 7.1.2 and 7.1.3. If the given station is not among those listed in these tables, estimates of the required absolute annual extreme temperatures at that point may be obtained by interpolation. In this case use is made of the data for two or more nearby listed stations which have climatological and topographical conditions similar to those of the given station.

(g) If each of the removal corrections calculated for the annual minimum and maximum temperatures differs by 0.004 inch of mercury or less from the removal correction corresponding to the "annual normal temperature," the removal correction computed on the basis of the latter temperature will be used as the constant removal correction for the station, so long as the original given values of the data (such as H_z and H_p) are pertinent. However, if the difference between the removal correction for either the minimum or maximum temperatures differs from the removal correction corresponding to the annual normal temperature by more than 0.004 inch of mercury, the removal correction will be treated as a variable, taken as a function of observed outdoor temperature. In the latter case, calculate the removal correction corresponding to every ten degrees of temperature Fahrenheit, over a range sufficient to cover the limits of absolute minimum and maximum temperature that may be expected to occur at the station. Prepare a table showing the removal correction corresponding to every 10° F. of temperature in this range. Indicate the proper algebraic sign for the data.

In case the criterion permitting use of the constant removal correction is satisfied, enter the value with the proper algebraic sign on the "Barometer Correction Card," on the line labeled "(Reduction from H_z to H_p)."

4.3 EXAMPLES OF DETERMINING "REMOVAL CORRECTION"

Example I

(a) Given:
Actual elevation of barometer, $H_z = 1518.9$ ft.
Adopted station elevation, $H_p = 1500.3$ ft.

Algebraic difference, $(H_z - H_p) = +18.6$ ft.
(b) Mean altitude =
$(H_z + H_p)/2 = (1518.9 + 1500.3)/2 = 1509.6$ ft.

Climatological pressure data are not available. According to the Standard Atmosphere Pressure-Altitude Table, the mean annual pressure at the mean altitude will be about 28.33 inches of mercury.

(c) "Annual normal temperature" at the level of the station thermometer (1503 feet), according to available climatological records is 54.8° F. Difference between mean altitude (1509.6 feet) and this level (1503 feet) is 6.6 feet. Assuming a standard lapse rate (0.003566° F./foot), the vertical temperature change corresponding to this difference in altitude (6.6 feet) is the product (0.003566° F./foot × 6.6 feet). A thus-computed vertical temperature change which is less than 0.1° F. in rounded value will be considered negligible for present purposes. Thus, we take the "annual normal temperature" at the mean altitude (1509.6 feet) as 54.8° F.

(d) Referring to Table 4.1.1 with pressure argument 28.33 inches of mercury, and temperature argument, 54.8° F., we find by double interpolation that the factor is 0.0010315 inch of mercury per foot change of height.

(e) The "removal correction" corresponding to the "annual normal temperature" is the product of the factor 0.0010315 inch of mercury per foot change of height and the difference of height, $(H_z - H_p) = 18.6$ ft. This product is +0.019 inch of mercury. Note that the "removal correction" is additive; since the actual elevation of the barometer is greater than the station elevation. (It would be subtractive if the reverse were true.)

(f) According to available climatological data the probable absolute annual minimum temperature is −36° F., and the absolute annual maximum temperature is 94° F. Referring to Table 4.1.1, we find the factor corresponding to a pressure of 28.33 inches of mercury to be as follows:
for −36° F., factor = 0.0012526; and
for +94° F., factor = 0.0009585 inch of mercury per foot change of height. Multiplying these factors by the value of $(H_z - H_p)$, namely 18.6 feet, we obtain the products +0.023 and +0.018 inch of mercury, respectively, for the "removal corrections" pertaining to the absolute annual minimum and absolute annual maximum temperatures, respectively. The largest difference between these extreme "removal corrections" and the normal "removal correction" (+0.019 inch of mercury) is 0.004 inch of mercury. Since this does not exceed the tolerable limit of 0.004 inch of mercury, the normal "removal correction" will be accepted for general use. The value of the normal "removal correction" is entered on the Barometer Correction Card, as the "(Reduction from H_z to H_p)."

Example II

(a) Given:
Actual elevation of barometer, $H_z = 746.0$ ft.
Adopted station elevation, $H_p = 794.0$ ft.

Algebraic difference, $(H_z - H_p) = -48.0$ ft.
(b) Mean altitude =
$(H_z + H_p)/2 = (746.0 + 794.0)/2 = 770.0$ ft.

Climatological pressure data are not available. According to the Standard Atmosphere Pressure-Altitude Table, the mean annual pressure at the mean altitude will be about 29.10 inches of mercury.

(c) "Annual normal temperature" at the level of the station thermometer (752 feet above mean sea level) is 56.2° F. The difference between mean altitude (770.0 feet) and this level (752 feet) is 18.0 feet. Assuming a standard lapse rate (0.003566° F./foot), the vertical temperature change corresponding to this difference in altitude (18.0 feet) is the product (0.003566° F./foot × 18.0 feet) which is 0.064° F.; that is, about 0.1° F., rounded value. Therefore, we take as the "annual normal temperature" at the mean altitude (770.0 feet) the value at 752 feet, (namely 56.2° F.), *minus* 0.1° F., the vertical temperature change (a decrease with altitude), corresponding to the height difference of 18.0 feet. This yields 56.1° F., as the "annual normal temperature" at the mean altitude (770.0 feet).

(d) Referring to Table 4.1.1 with pressure argument 29.10 inches of mercury, and temperature argument 56.1° F., we find by double interpolation that the factor is 0.0010569 inch of mercury per foot change of height.

(e) The product of this factor (0.0010569 in. mercury/ft.) and the difference ($H_z - H_p$), namely —48.0 feet, yields —0.051 inch of mercury as the "removal correction" corresponding to the annual normal temperature. The minus (—) sign signifies that numerical value is to be subtracted from the readings at the actual barometer elevation (H_z) to reduce to the level of the station elevation (H_p).

(f) The absolute annual minimum and maximum temperatures are found to be —28° F. and +102° F. Referring to Table 4.1.1 with pressure argument 29.10 inches of mercury and temperature argument —28° F., we find the corresponding factor to be 0.0012628° F. per foot. Multiplying this by —48.0 feet, the value of ($H_z - H_p$), we find the "removal correction" corresponding to the minimum temperature to be —0.061 inch of mercury. This differs by 0.010 inch of mercury from the "removal correction" corresponding to the annual normal temperature. Since the difference exceeds 0.004 inch of mercury, a variable "removal correction" table must be prepared and used. See fig. 13.3.1.

With the aid of the data in Table 4.1.1, the following variable "removal correction" table is computed, based on pressure 29.10 inches of mercury:

Variable Removal Correction Table

Name of Station: Jamestown, ...

Actual elevation of barometer, $H_z = 746.0$ ft.

Station elevation, $H_p = 794.0$ ft.

Outdoor temperature (° F.)	Removal correction	Outdoor temperature (° F.)	Removal correction
	Inches of mercury		*Inches of mercury*
−30	−0.061	50	−0.051
−20	−0.060	60	−0.050
−10	−0.058	70	−0.049
0	−0.057	80	−0.048
10	−0.056	90	−0.048
20	−0.055	100	−0.047
30	−0.053	110	−0.046
40	−0.052		

As a regular procedure, under the conditions of Example II, the removal correction corresponding to the current, observed outdoor temperature is to be determined from the table following each barometer observation. Care is necessary in applying the removal correction with the proper algebraic sign.

In the case of mercurial barometer observations, the removal correction should be applied with the "sum of corrections" together with the correction for temperature. It is also applicable in the case of aneroid barometer observations. (See sec. 6.7.1.)

4.4 "RESIDUAL CORRECTION"

The residual correction of a barometer located at a station is the correction found necessary to overcome the instrumental error which remains even after one has applied the "correction for scale errors and capillarity" determined by calibration against a standard barometer in the headquarters laboratory. Need for a residual correction arises when a barometer in the field departs by a significant amount from its original calibration. A common cause of the departure is the influence of small bubbles of moist air originally entrapped along the inside wall of the glass tube of the mercurial barometer. These bubbles may eventually rise through the mercury, and escape into the space above the meniscus, thus increasing the imperfection of the vacuum, and yielding a back pressure at the top of the column. Another frequent cause is the capture of impurities by the mercury, especially in a moist atmosphere. This has the effect of changing the "capillary depression." Sometimes the need for a residual correction arises when the scale of the barometer slips or the ivory (zero) point drops down.

In the case of aneroid barometers, a drift may occur owing to gradual changes in the elastic and crystalline properties of the solid of which the evacuated capsule is composed.

When the departure of a barometric instrument from its previous calibration exceeds a certain tolerance, it is desirable to determine the "residual correction" at the station in order to permit canceling out the deviation from the proper reading which a standard barometer would yield. The "residual correction" may be found by use of two or more special barometers brought to the station for comparison purposes and returned to headquarters for checking to see that they have not changed their calibration during transit. Procedures for making comparative barometer readings should be carefully followed in each case. See Chapter 6.

It is desirable that the "residual correction" be verified by at least two consistent determinations in this manner.

After such verification it is considered that the last "residual correction" should be entered on the "Barometer Correction Card" subject to approval by headquarters. The "residual correction" then may be combined with the other known corrections to form a "sum of corrections." (See sample "Barometer Correction Card" near the end of Chapter 3.)

CHAPTER 5. TEMPERATURE CORRECTION OF MERCURY BAROMETERS

5.0 INTRODUCTION

The purpose of Chapter 5 is to indicate the manner in which temperature corrections of mercurial barometers are determined, and to give instructions regarding the application of these corrections. With regard to the effect of temperature on aneroid barometers see sec. 2.8.2.

Sec. 5.1 presents technical information pertaining largely to the formulas on whose basis the correction for temperature of Fortin-type barometers and U-tube mercury manometers has been calculated. Since the correction for instrumental error, the correction for gravity, and the "removal correction" are generally applied in conjunction with the correction for temperature, sec. 5.1 also shows the various ways in which the corrections may be combined, both by means of exact and approximate methods; the exact methods being intended for scientific work of the highest possible degree of accuracy, and the approximate ones for routine engineering and meteorological observations. Mathematical derivations of the formulas will be found in Appendix 1.4.2. In order to have a basis for the construction of the tables which yield the correction for temperature of Fortin-type barometers and U-tube mercury manometers, it is assumed that all of these instruments are equipped with *brass scales* having a definite value of the coefficient of linear thermal expansion, accepted in international meteorological practice.

Sec. 5.2 gives instructions for ascertaining the correction for temperature of Fortin-type barometers (and U-tube mercury manometers) with the aid of Tables 5.2.1, 5.2.2, and 5.2.3. Examples are shown in regard to the combination of the corrections for routine purposes (see figs. 5.2.1–5.2.4).

Sec. 5.3 is concerned exclusively with the correction of fixed-cistern barometers for temperature. The correction for barometers of this type differs in a significant manner from that pertinent to Fortin-type barometers.

Sec. 5.4 presents instructions relating to the use of "total correction tables," which provide the most expeditious means of ascertaining the "total correction"; that is, the resultant of the algebraic addition of the correction for temperature of Fortin-type barometers and the so-called "sum of corrections," where the latter represents the algebraic sum of the correction for instrumental error, the correction for gravity, and the "removal correction"; also the "residual correction," if known. Table 5.4.1, the "Total Correction Table," is provided to permit implementation of this effective scheme for obtaining the "total correction" in the case of routine observations involving a Fortin-type barometer whose scale reads true at a temperature of 62° F. A different table will be necessary for such barometers whose scales read true at a temperature of 32° F.

It is considered worthwhile at this point to present some qualitative information concerning the reasons which necessitate the use of corrections for temperature of the barometer. All mercury barometers require such a correction owing to (a) the effects of temperature on the density of the mercury, and (b) the effects of temperature on the length of the scale; while the fixed-cistern barometer requires an additional component of correction owing to (c) the effects of temperature on the volume of mercury contained in the barometer in relation to the effective cross-sectional areas of the cistern and the glass tube. These three effects are fairly briefly discussed under the captions below:

(a) Temperature Effects on Density of Mercury.—At the temperature of 32° F. (0° C.), pure mercury is considered to have its standard density (13.5951 grams/cu. cm.) on the basis of which the standard units of pressure are defined (see sec. 1.4). When the temperature *t* of the liquid increases above 32° F., the mercury expands in volume and its density decreases to values less than that which it would have if its temperature remained at the standard of 32° F. Since the barometer is intended to permit us to measure the atmospheric pressure in terms of the weight of the column of mercury which counterbalances this pressure, it is necessary, in effect, to ascertain the weight of the mercury column. Physics has shown that this weight is given by the product of (1) the true height of the column; (2) the local acceleration of gravity; and (3) the actual density of the mercury. Inasmuch as the density of the mercury is affected by the temperature, it is necessary to include in the correction a part which permits us to make allowance for the actual density of the mercury at the existing temperature, *t*. The correction for temperature has been so designed that after the correction has been applied to the observed barometer reading, the corrected reading may be considered to be the true height of the column obtained when the temperature of the mercury is reduced to the standard value, 32° F.

(b) Temperature Effects on Length of Scale.—Although solid materials vary in length with change in temperature, there is always some temperature at which the scale of any given barometer would read accurate in accordance with a perfect standard scale. To save words we shall often denote by the symbol t_a, the temperature at which a scale reads accurate (true) on the basis of this definition, where it will be understood that a "perfect standard scale" is one that yields exact measurements in accordance with the accepted international standard of length and is unaffected by external conditions such as temperature, pressure, etc. (see sec. 1.4). Ordinary barometer scales are composed of brass which expands with increase in temperature of the scale, designated here by *t*. Therefore, when *t* is greater than t_a, the scale is expanded with respect to the perfect standard scale and its readings on this account alone are too small with reference to the standard. Similarly, when *t* is lower than t_a, the reverse is true. On these grounds a part of the correction for temperature is necessary to make allowance for the effects of changes of the scale length with temperature, specifically to reduce the readings to the equivalent of those obtainable from a standard scale unaffected by temperature. This part of the correction is designed to yield "*true* height of the mercury column," in the sense of being in accordance with the accepted international standard of length which supposes a rigid measuring rod not influenced by temperature.

(c) Temperature Effects on Ratio of Mercury Volume to Effective Cross-Section.—It should be noted that Fortin-type barometers, primary barometers, and U-tube manometers do *not* suffer from the effects dealt with under this caption; that is, these effects pertain only to fixed-cistern barometers. In the case of fixed-cistern barometers, a rise in temperature above the standard for the instrument causes an increase both in the volume of the mercury and in the effective cross-sectional areas of the cistern and the glass barometer tube; while a fall in temperature acts in the reverse manner. Thus, the changes in capacity of these vessels tend to offset partially the changes in volume of the liquid contained in the fixed-cistern barometer; and therefore in the case of this type of barometer a special correction to allow for the effects of these changes is necessary (see secs. 2.6 and 5.3).

Significance of the Correction for Temperature

In referring to the correction for temperature applicable to the barometer reading, terms such as the following have been employed: "reduction of the barometer to 32° F. (0° C.)," "reduction of the barometer to standard temperature," "reduction of the mercury column to standard temperature," and "reduction of the barometer to the freezing point." Neglecting effects due to purely instrumental errors (such as imperfect vacuum, capillarity, inaccurate positioning of the zero of the scale, etc.), these terms are intended to imply that after the correction for temperature has been applied to the barometer reading, the corrected reading represents the "*true height of a column of mercury having standard density*" which would counterbalance the mercury column at its existing temperature in the actual barometer, both columns assumed to be under the same acceleration of gravity. In the foregoing statement, the words "true height" signify the height that would be measured with a perfect standard measuring scale unaffected by temperature; while the words "column of mercury having standard density" are meant to indicate that this column consists of pure mercury whose density is assumed to be the standard value 13.5951 grams per cubic centimeter which it would have normally if the mercury were at a temperature of 32° F. (0° C.), assuming the mercury to be incompressible (see sec. 1.4 and Appendix 1.4.1).

After both the corrections for temperature and gravity have been applied to the barometer reading, the corrected value represents the true height of a column of mercury having standard density and subjected to standard acceleration of gravity which would counterbalance (be in equilibrium with) the actual column of mercury at its existing temperature under the local acceleration of gravity. This concept is illustrated by the figure in Appendix 1.4.2.

5.1 TECHNICAL INFORMATION REGARDING TEMPERATURE CORRECTION OF FORTIN BAROMETER

The temperature correction necessary for the Fortin barometer (that is, the adjustable cistern type shown in figs. 2.2.0, 2.2.2, and 2.2.5) is different from that required for the fixed-cistern barometer illustrated in figs. 2.4.0, 2.6.0, and 2.6.1 Information concerning the temperature correction for the fixed-cistern barometer is presented in sec. 5.3.

Tables giving the temperature correction for the Fortin barometer are contained in Chapter 14 (see Tables 5.2.1, 5.2.2, 5.2.3, and 5.4.1 based on the assumption that the barometer scale is constructed of brass). These tables depend upon the temperature at which the scale of the barometer reads true (accurate), this temperature being denoted here by the symbol t_a. Clearly, a quantity such as t_a must enter into consideration owing to the fact that some barometers have their scale graduated so that it will read true units of length when the scale temperature is 62° F., while the scale in other barometers is graduated in such a manner that it will yield true units of length when the temperature of the scale is 32° F. (0° C.). Therefore, when initially preparing to obtain the temperature correction, the observer must be careful to pick the appropriate table, based on the proper value of temperature at which the scale reads true.

The value of t_a pertinent to each table is printed at the top of the pages of the table (for example, "Scale true at 62° F." or "Scale true at 0° C."). Form WBAN 54-3.3.1, the Barometer Correction Card, a copy of which is shown in Chapter 3, provides a space near its top where the Instrument Laboratory enters the value of temperature at which the scale of the given barometer reads true (accurate). An observer can ascertain the value of this temperature by referring to the card form. As a rule, the latter should be fastened near the barometer in a conspicuous place. Modern barometers should have a notation engraved on their scales indicating the temperature at which the scale reads true (see Appendix 1.4.1).

When a new barometer is received at a station, the observers should take note of the temperature at which the scale of the instrument reads true and check to see that the temperature correction table which will be used for it is based on the same value.

It has been shown that in order to utilize the readings of a Fortin barometer for the determination of atmospheric pressure, it is necessary to apply corrections for the effects of instrumental errors, gravity, and temperature (see Appendix 1.4.2). In addition, if the pressure is desired for an adopted station elevation (denoted by H_p) which is at a different level than the actual elevation of the ivory point of the barometer (denoted by H_z), then a so-called "removal correction" must also be applied, as explained in Chapter 4 (see Chapter 1 regarding the significance of the stated elevations). Thus, consideration must be given to the proper method of applying the four corrections mentioned above. Before doing this, it is necessary to introduce definitions of several factors or parameters which either express directly or relate to the corrections involved.

Let

K_i = correction for instrumental error of the barometer. (This comprises a resultant correction to overcome the effects of capillary depression, imperfect vacuum at normal room temperature and pressure, error of the zero index of the scale, and error of the scale due to imperfect graduation, assuming average conditions. A term sometimes used for K_i is "index correction.")

K_{zp} = "removal correction" to reduce the pressure from the actual elevation of the ivory point of the barometer (H_z) to the adopted station elevation (H_p). (Secs. 4.1—4.3 describe the method employed to calculate the "removal correction," which must be expressed in pressure units.)

g_l = local acceleration of gravity (in cm./sec.^{2}) at the actual barometer position.

g_o = standard acceleration of gravity (980.665 cm./sec.^{2})

c = $(g_l - g_o)/g_o$ = a constant factor which is involved in the correction for gravity.

t = temperature of the barometer (usually indicated by the reading of the attached thermometer).

t_a = temperature at which the scale of the barometer reads true. (That is, the scale must have the temperature t_a in order that it yield absolutely accurate measures of units of length, such as true inches or true millimeters, in accordance with the accepted standard of linear units. See the note at the end of sec. 1.4.)

f = $f(t, t_a)$ = a factor (function) which is involved in the correction for temperature, and which varies with t, the temperature of the barometer, and also depends upon the value of t_a defined above. A formula expressing f as a function of t and t_a is given below.

C_t = correction of the barometer for temperature. (This correction is proportional to f, and also depends upon the barometer reading. Details are given below.)

K_r = "sum of corrections" = algebraic sum of the correction for instrumental errors (K_i), the correction for gravity, and the "removal correction" (K_{zp}), if any is required at the station.

B = reading of the barometer (before any corrections are applied).

B_{ct} = barometer reading corrected for instrumental error and temperature only.

B_n = normal annual value of B_{ct}; that is, the normal annual barometer reading corrected for instrumental error and for normal annual temperature of the barometer, but *not* corrected for gravity or "removal correction."

B_o = barometric station pressure. This quantity may be considered to be the barometer reading corrected for instrumental error, gravity, "removal correction," if any, and temperature. On this basis the quantity is expressible in terms of true pressure units, such as those listed in sec. 1.4, or described at the end of Appendix 1.4.2.

The general formula for the factor f which always appears in the temperature correction of the Fortin-type barometer reading is given following the list of relevant symbols below:

t = temperature of the attached thermometer;

t_a = temperature at which the scale of the barometer is accurate (true);

t_s = standard temperature of the mercury (the adopted value being 0°C. = 32° F., as indicated in Appendix 1.4.1);

m = mean cubical coefficient of thermal expansion of mercury over the temperature interval between t and t_s;

l = linear coefficient of thermal expansion of the metal scale used on the mercurial barometer; and with this notation

$$f = \frac{m(t - t_s) - l(t - t_a)}{1 + m(t - t_s)}$$

When the temperatures are in degrees Celsius (Centigrade, ° C.), the pertinent values of the constants which enter into the formula are $m = 0.0001818$ per °C., and $l = 0.0000184$ per ° C. *for a brass barometer scale;* while in case the temperatures are in degrees Fahrenheit (°F.), the values are $m = 0.000101$ per ° F., and $l = 0.0000102$ per °F. *for a brass barometer scale.* Whenever the scale is made of a different substance, the value of l may differ accordingly. In the case of barometers whose scales are graduated in the metric system (millimeters or millibars), it has been the general practice to adopt for t_a the value 0° C.; however, with regard to barometers whose scales are graduated in the English system (inches), the older instruments generally were constructed so that $t_a = 62°$ F., whereas the newer barometers constructed in accordance with the provisions of the International Barometer Conventions described in Appendix 1.4.1 have their scales graduated so that $t_a = 32°$ F. (see Form WBAN 54–3.3.1 and the inscription on the barometer scale to find which value of t_a applies to a given barometer). For additional details regarding f and its derivation, the reader should consult Appendix 1.4.2.

As indicated by the relationships given in sec. A–2.5, the quantity m can be represented as a function of t, which is pertinent in precision barometry and manometry.

In the following discussion expressions will be given to indicate how the various corrections must be applied to the barometer reading of the Fortin-type instrument for the purpose of obtaining the barometric station pressure. With this end in view, we shall assume that a "removal correction" (K_{zp}) is necessary in general; however, if in any case a "removal correction" is not required, one may readily replace K_{zp} in the following equations by zero (0).

On the basis of equation (14) of Appendix 1.4.2, the station pressure, which represents the atmospheric pressure at the level of the station elevation (H_p), is given by the expression

$$B_o = (B + K_i)(1 + c)(1 - f) + K_{zp} \quad (1)$$

Equation (1) may be readily transformed into either equation (2) or (3) below.

$$B_o = [(B + K_i) + (B + K_i)c] - [(B + K_i) + (B + K_i)c]f + K_{zp} \quad (2)$$

$$B_o = [(B + K_i) - (B + K_i)f] + [(B + K_i) - (B + K_i)f]c + K_{zp} \quad (3)$$

Since the quantity c involves gravity and the quantity f involves temperature, it is evident that the expression in brackets given in equation (2) represents the barometer reading corrected for instrumental error and gravity; while the expression in brackets given in equation (3) represents the barometer reading corrected for instrumental error and temperature. From equation (2) one finds that the term $(B + K_i)c$ represents the correction which must be applied to $(B + K_i)$ in order to correct the latter for gravity (to reduce the data to standard gravity). Similarly, from equation (3) one finds that the term $-(B + K_i)f$ represents the correction which must be applied to $(B + K_i)$ in order to correct the latter for temperature.

Thus, equation (2) may be interpreted as signifying that one may first correct the barometer reading for instrumental error and gravity, thereby obtaining the expression in brackets given in equation (2). Then, this expression must be corrected for temperature as indicated by the second term in the right-hand member of equation (2). Finally, the "removal correction" (K_{zp}) must be applied, if necessary, in order to obtain the station pressure (B_o).

Similarly, equation (3) may be interpreted as signifying that one may first correct the barometer reading for instrumental error and temperature, thereby obtaining the expression in brackets given in equation (3). Next, this expression must be corrected for gravity as indicated by the second term in the right-hand member of equation (3). Lastly, the "removal correction" (K_{zp}) must be applied, if necessary, for the purpose of securing the station pressure (B_o).

The preceding discussion reveals that it is possible to make use of the corrections for gravity or for temperature at different stages of the computations leading to the required result (B_o). Thus, if one considers first the correction for gravity, one finds that it is given by a product, involving as a factor the quantity c, whose value depends upon the location (see Chapter 3). Analogously, if one considers the correction for temperature, one observes that it is given by a negative product which always involves a factor f, whose value depends upon the attached thermometer reading (t) and the constant t_a (that is, the temperature at which the scale indicates true units of length). It will also be noted that the other quantities which appear in the products mentioned above invariably contain terms involving $(B + K_i)$. The facts just outlined have useful applications as indicated in the next two paragraphs.

Since the gravity correction is proportional to some appropriate value of barometric height, say B' (usually B plus certain correction terms), the tables which yield the gravity correction are valid regardless of the value of B', provided that the proper values of B' and c or $(g_l - g_o)$ are employed as arguments in referring to the tables (see Tables 3.3.1 and 3.3.2).

Analogously, since the temperature correction is proportional to some appropriate value of barometric height, say B'', the tables giving this correction are valid irrespective of the value of B'', provided that the proper values of B'', t and t_a (governing f) are used as arguments in referring to the tables (see Tables 5.2.1, 5.2.2, 5.2.3, and 5.4.1).

Equations (1), (2), and (3) as given above are all accurate, not involving any approximations. They may therefore be applied for the evaluation of station pressure (B_0) on the basis of data obtained from a Fortin-type barometer or a primary barometer when results of the highest possible degree of absolute accuracy are desired.

Unfortunately, evaluation of the data in accordance with either of equations (1), (2), or (3) is somewhat more involved than seems justified for routine meteorological observations; and therefore certain approximate equations are adopted in place of (2) and (3) for such routine purposes. An approximate equation employed for this end as explained below is easier to evaluate and yields results which are regarded as sufficiently accurate for use in synoptic weather analysis.

In order to derive a convenient approximate relationship for the evaluation of the barometric data, we shall first note that the barometer reading corrected for instrumental error and temperature is given by the expression

$$B_{ct} = (B + K_i) - (B + K_i)f, \qquad (4)$$

as was indicated in the paragraph immediately following equation (3). We denote the normal annual value of B_{ct} by the symbol B_n (see sec. 3.3).

As the first step in the approximation, we substitute B_n for the expression in brackets preceding the factor c in equation (3). This step is justified for stations in middle or high latitudes on the following grounds: In middle latitudes the magnitude of c tends to be relatively small as may be deduced from Table 3.1.1; and in very high or low latitudes where the magnitude of c assumes its maximum value, it practically never exceeds 0.0027 near sea level, although in the case of stations on high mountains near the equator it may attain a magnitude of about 0.0037. The magnitude of c is less than 0.0027 for mountain stations in polar regions. Furthermore, the observed value of B_{ct} will typically deviate from its normal annual value B_n within about 4 percent (0.04) of the latter in the case of passage of low or high pressure areas of ordinary intensity. However, when the center of a hurricane, typhoon, or tornado is passing over a station, it is possible for the percentage deviation of B_{ct} from its normal to attain an extreme perhaps several fold greater than 4 percent, but when such severe storms pass over any point the pressure is varying rapidly, often with considerable fluctuations. Therefore, under these severe conditions, which occur infrequently, it is difficult to obtain precise readings of the barometer accurate to within several tenths of a millibar.

A little example will show how small is the error resulting from the first step in the approximation. To this end we shall assume that the value of c is equal to 0.0027, which is the extreme found at sea level in low and high latitudes; and we shall assume further that B_{ct} deviates from B_n by the amount 0.04 B_n, which may fit the situation in the centers of fairly typical cyclones (LOWS) and anticyclones (HIGHS). Finally, we shall suppose that $B_n = 1000$ millibars. A calculation made on the basis of these data leads to the conclusion that the error resulting from the specified deviation is only 0.1 mb. Over areas at middle latitudes near sea level the magnitude of c will generally be less than one-half of the value specified in the example, hence within these areas the error due to the deviation of B_{ct} from B_n will be proportionately smaller than indicated above; but it will be somewhat greater within regions of low latitude where the terrain is of considerable height above sea level. For this reason one might exclude use of the approximation for stations in low latitudes.

As the second and final step in the approximation which we shall consider regarding equation (3), the term $-K_i f$ will be dropped from the first expression in brackets following the equal sign. Since the value of K_i rarely exceeds 0.7 mb. in mercury barometers permitted to be used for meteorological observations, the magnitude of the error committed by this step will generally not be greater than 0.005 mb. which is considered negligible for routine purposes (see Appendix 1.4.2).

By virtue of the two approximations indicated above, equation (3) reduces to the simpler form

$$B_o = B + (K_i + B_n c + K_{zp}) - Bf, \text{ approximately.} \qquad (5)$$

According to the terminology employed on Form WBAN 54–3.3.1, which is the Barometer Correction Card, the quantity given in parentheses in equation (5) is called the "*sum of corrections*," which we denote by the symbol K_r. *This represents the algebraic sum of the correction for instrumental error* (K_i), *the correction for gravity* ($B_n c$), *and the "removal correction"* (K_{zp}).

On the basis of the term introduced in the last paragraph, we have

$$\text{"Sum of Corrections"} = K_r = (K_i + B_n c + K_{zp}). \qquad (6)$$

By substituting equation (6) in equation (5), one finds

$$B_o = B + K_r - Bf, \text{ approximately.} \qquad (7)$$

Equation (7) forms the basis of the evaluation of data obtained from a Fortin-type barometer for routine meteorological purposes. Since the quantity $-Bf$ represents the correction for temperature under the chosen method of approximation as outlined above, equation (7) may be interpreted in words by the following statement:

The station pressure is equal to the algebraic sum of the barometer reading (B), the "sum of correction" (K_r), and the temperature correction ($-Bf$).

By virtue of the minus (—) sign associated with the temperature correction ($-Bf$) and the character of the factor f as defined earlier, it will be seen that the temperature correction will be negative at ordinary room temperatures (such as 68° F.), hence in that case the magnitude must be subtracted.

The temperature correction tables in this manual always indicate how the temperature correction is to be applied, whether it is to be subtracted or added (see the legend at the head of the table and the algebraic sign, if any, prefixing the numerical values in the body of the table). Thus, if a minus (—) sign prefixes a numerical value in the body of the correction table, this will, of course, be interpreted as signifying that the magnitude indicated by the tabular value is to be subtracted when applying the correction.

Under the assumptions employed in developing equation (5) or (7), the temperature correction, which we denote by C_t, is given by the expression

$$C_t = (-Bf) = \text{correction of the Fortin-type barometer for temperature.} \qquad (8)$$

It may be noted that this is a close approximation to the proper temperature correction which should be $-(B + K_i)f$; hence the quantity given by equation (8) is subject to an error $K_i f$, whose magnitude is negligible as indicated above.

For later convenience in making computations involving the "sum of corrections" (K_r) and the temperature correction (C_t), the term "Total Correction" has been introduced, in accordance with the definition

$$\text{“Total Correction”} = (K_r + C_t), \quad (9)$$

which may be interpreted in the following words:

The "Total Correction" is equal to the result obtained by the algebraic addition of the "sum of corrections" (K_r) defined by equation (6) and the temperature correction (C_t) defined by equation (8).

Thus, by taking account of equations (8) and (9) in conjunction with equation (7) one finds that the latter reduces to the simple form

$$\begin{aligned} B_o &= B + (K_r + C_t) \\ &= B + \text{“Total Correction.”} \quad (10) \end{aligned}$$

From this expression we conclude that the station pressure (B_o) is determined by applying the "Total Correction" to the observed reading of the barometer (B); hence, if the "Total Correction" is negative (—), the magnitude of this quantity must be subtracted from the barometer reading; whereas, if the "Total Correction" is positive (+), the magnitude of this quantity must be added to the reading of the barometer in order to obtain the station pressure. Examples of computations based on equation (10) are given in sec. 5.2 (see figs. 5.2.1, 5.2.3, and 5.2.4).

In cases where the "removal correction" (K_{zp}) is variable with outdoor temperature, the "sum of corrections" (K_r) is no longer a constant and it is necessary to go back to equation (5) as the basis for making the computations.

With this end in view, we introduce the quantity K_{ig}, defined by

$$K_{ig} = (K_i + B_n c), \quad (11)$$

where K_{ig} represents the algebraic sum of the correction for instrumental error (K_i) and the normal gravity correction ($B_n c$).

Then, if one substitutes equations (8) and (11) in equation (5), one finds

$$\begin{aligned} B_o &= B + (K_{ig} + K_{zp} + C_t) \\ &= B + \text{“Total Correction,”} \quad (12) \end{aligned}$$

which may be interpreted as signifying that the station pressure (B_o) is determined by applying the "Total Correction" to the observed reading of the barometer (B), where the "Total Correction" in this case is given by the algebraic sum of the correction for instrumental error and gravity (K_{ig}), the "removal correction" (K_{zp}), and the temperature correction (C_t). (See fig. 5.2.2 in sec. 5.2 for an example of a computation on this basis.)

In the case where the "sum of corrections" (K_r) is a constant, it is possible to save time in determining the "Total Correction" by making use of a "Total Correction Table," such as Table 5.4.1. This is based on equation (9) taken in conjunction with equation (8), which yields

$$\begin{aligned} \text{“Total Correction”} &= (K_r + C_t) \\ &= K_r - Bf. \quad (13) \end{aligned}$$

Since the factor f depends upon t, the reading of the attached thermometer, equation (13) indicates that for constant values of t and K_r the "Total Correction" is a linear function of B, the observed barometer reading. Sec. 5.4 contains an illustration of a part of a "Total Correction Table" prepared for a specific value of K_r.

Since the temperature correction factor f depends upon t_a, the temperature at which the barometer scale reads true, it is essential that the value of t_a on which the temperature correction table is based be consistent with the value of t_a applicable to the scale of the barometer from which the readings are taken.

5.2 INSTRUCTIONS FOR CORRECTING FORTIN-TYPE BAROMETERS FOR TEMPERATURE

5.2.0 Introduction

These instructions apply to mercury barometers of the adjustable-cistern type in which an adjustment is always made immediately preceding each observation to set the level of the mercury in the cistern to the *zero point of the scale* (see secs. 2.4 and 2.5). In the case of the Fortin-type barometer the zero point of the scale is generally the *"ivory point"* in the cistern; also called the *"index."* These instructions do *not* apply to barometers of the fixed-cistern type, for which instructions are given in sec. 5.3.

The theory underlying the temperature correction for adjustable-cistern mercury barometers and for primary barometers is presented in Appendix 1.4.2; while the subject has been further elaborated in sec. 5.1. Various formulas are given in sec. 5.1 to show the proper and suggested methods for applying (1) the correction for instrumental error, (2) the correction for gravity, (3) the "removal correction," if any is required, and (4) the correction for temperature, depending upon the degree of precision demanded.

Scientists who are interested in obtaining atmospheric pressure data of greatest possible accuracy from their barometric readings will naturally refer to equations (2) and (3) of sec. 5.1, together with the discussion which follows equation (3), in order to secure details regarding the most accurate methods of determining the corrections. Such methods generally require a little more time for the evaluation of data than do the approximate methods also described.

Observers who are mainly concerned with the taking of barometer observations for routine engineering or meteorological uses will generally employ the simplest and most rapid method of determining the necessary "total correction" for the barometer, even though such a method involves certain approximations. As explained in sec. 5.1 and Appendix 1.4.2, the approximations produce only slight errors which are regarded as within acceptable tolerances for routine meteorological work, except perhaps in regions of high and low latitudes, more especially in the latter areas at points of considerable height above sea level. Observers are referred to information in sec. 5.4, which describes the simplest method for routine purposes, based on the use of the so-called "Total Correction Table" (see Table 5.4.1). Another method which may be employed for evaluating the corrections is indicated in sec. 5.2.5, which shows techniques especially useful for those who only rarely have occasion to determine the corrections.

5.2.1 Option Regarding Method of Determining Correction

Two alternative methods of ascertaining the temperature correction for the barometer may be considered: (A) the method described in sec. 5.2.5 based on the use of Tables 5.2.1, 5.2.2, 5.2.3, or the like; and (B) the method outlined in sec. 5.4 involving the use of a means which yields the "total correction" directly, as Table 5.4.1. Observers have an option in choosing between these two, for routine meteorological work at field stations. It may be pointed out, however, that the method indicated under (B) provides the required answers more quickly than that referred to under (A); and hence (B) is advantageous when employed in connection with many repeated mercury barometer observations.

5.2.2 Selection of Proper Temperature Correction Table

Various temperature correction tables are given, *depending upon the temperature at which the scale of the barometer is true (accurate).* The latter temperature has been designated by the symbol t_a herein. Compatibility between the tables and the scale with respect to this quantity t_a is necessary. Therefore, it is essential for the person in charge of the observers to make the proper selection of the table for the mercury barometer, according to the value of t_a which applies to the given instrument. To do this he must first ascertain the temperature at which the scale of the barometer reads true, and then in conformity with this value make the appropriate choice of table. The table should always show the value of t_a on which it was based, generally by a notation in the heading such as "Scale true at 62° F.," "Scale true at 32° F.," or "Scale true at 0° C." (see Tables 5.2.1, 5.2.2, 5.2.3, and 5.4.1).

In order to ascertain the value of t_a which pertains to a given mercury barometer, the observer should first look for the information in the upper part of the "Barometer Correction Card," Form WBAN 54–3.3.1, where there is a box having the notation "Scale true (correct) at ....° F." It is the responsibility of every Instrument Laboratory which furnishes barometers to enter in this space the appropriate value of t_a for the given instrument to which the form refers. Modern mercury barometers are also supposed to have engraved on their scales a suitable legend giving the pertinent information as indicated in Appendix 1.4.1, section IV. Therefore, the observer should also examine the barometer scale, locate the engraving if present, note the value of temperature at which the scale is true according to the figure engraved, and determine whether it agrees with the value given in the upper portion of the "Barometer Correction Card" (see Form WBAN 54–3.3.1). When the required value cannot be ascertained from the two sources indicated above, it is necessary to write to the responsible headquarters, Instrument Laboratory, or manufacturer and request the desired information, preferably well in advance of the time the barometer is to be put into use. In order to have a permanent record of the pertinent data, the observer is instructed to post in a conspicious place near the barometer the relevant "Barometer Correction Card," taking note of the fact that this should indicate the temperature at which the scale reads true (t_a), the latter being intended for the purpose of enabling him to pick the temperature correction table based on the corresponding value.

Observers should double-check the procedure to see that the proper selection of the table is made from this point of view at the time these instructions are introduced and every time in the future that a new barometer is placed into use. In other words, the barometer scale and the temperature correction table in effect must be based on a consistent value in regard to t_a, otherwise errors will be committed.

The units given in the table, expressing the "Height of the Mercury Column," should also agree with the units in which the scale of the barometer is graduated, whether inches, millibars, or millimeters.

Some barometers are equipped with two scales; for example, one reading in inches and the other in millibars (see figs. 2.4.2(a) and 2.4.2(b)). It is possible for the two scales to read true at different temperatures; for example, in the case of the inch scale one may have $t_a = 62°$ F., while in the case of the millibar scale one has generally $t_a = 0°$ C. In cases where such a disparity exists it is very important for the observers *not* to use the same temperature correction table for readings obtained from both scales, since an error will be made in connection with the data from one of them, even if the attached thermometer readings and the scale readings, respectively, are converted from one system of units to the other by means of the conversion factors (see sec. 1.4). Rather, the observers must use two different temperature correction tables, one for each of the scales, and appropriate according to the value of t_a pertinent to the individual scale, as previously explained.

5.2.3 Correction of Attached Thermometer Readings

Whenever the readings of the attached thermometer are subject to known errors of 0.5° F. or more, the readings must be corrected for these errors first, and then the corrected attached thermometer readings are to be referred to the proper tables for use as one of the arguments in determining the correction of the actual barometer readings for temperature. In cases where the errors are 0.5° F. or greater, it is necessary for the responsible Instrument Laboratory or manufacturer to supply a small table indicating the corrections applicable to the attached thermometer readings for various scale readings, such as at intervals of 10° F., usually beginning with an initial reading of 32° F. When necessary, this small table, properly labeled, should be posted near the "Barometer Correction Card" (see Form WBAN 54–3.3.1).

In order to avoid the necessity for correcting the indications yielded by the attached thermometers, it is a general policy to secure such thermometers which are generally accurate to within 0.5° F., so that no correction need be applied to attached thermometer readings obtained from instruments which satisfy this tolerance. Any attached thermometer which gives results falling outside this tolerance is withdrawn from service.

For routine observations, the attached thermometer is to be read to the nearest half degree Fahrenheit (0.5° F.) or to the nearest quarter degree Celsius (0.25° C.), depending upon the units in which the thermometer is graduated.

5.2.4 Algebraic Sign of Corrections of the Barometer for Temperature

Precautions are necessary to assure that the corrections of the barometer readings for temperature are applied with the proper algebraic sign. It will be understood that when a *negative sign* is prefixed to any value in the body of a temperature correction table, such as Tables 5.2.1, 5.2.3, and 5.4.1, this sign indicates that the absolute numerical value is to be *subtracted* from the barometer reading when applying the correction; while it will be understood with regard to those specific tables that if no algebraic sign is given or if the sign is indicated as *positive*, the numerical value is to be *added* when applying the correction. However, in the case of Table 5.2.2, which relates to a barometer involving metric measures (° C., and mb. or mm.), the corrections are to be applied in accordance with the instructions given at the head of the table. Examples of these points are given in figs. 5.2.1–5.2.4.

The algebraic sign of the correction depends upon the attached thermometer reading (t) and the temperature at which the barometer scale reads true (t_a), as summarized below:

(1) When $t_a = 62°$ F., the corrections must be applied with a negative sign for observations in which t is greater than 28.5° F., and with a positive sign for those in which t is less than 28.5° F. If t is exactly 28.5° F., the correction is zero (0), provided $t_a = 62°$ F.

(2) When $t_a = 32°$F. $= 0°$ C., the corrections must be applied with a negative sign for observations in which t is greater than 32° F. (0° C.), and with a positive sign for cases in which t is lower than this. If t is precisely equal

Attached thermometer reading, t .... 68.0°F.

Observed reading of barometer, B .... 25.496 inches

Sum of corrections, K_r .... -0.019 inch

Correction for temperature, C_t ...... -0.091 inch

(See Table 5.2.1, using arguments B and t as given)

Total correction, $(K_r + C_t)$........... -0.110 inch -0.110 inch

(Algebraic sum of above two corrections)

Station pressure, B_o .... 25.386 in. Hg

Algebraic sum of B and $(K_r + C_t)$

FIGURE 5.2.1. Illustration of a simple case where a constant removal correction is required and the barometer scale is true at 62° F.

Attached thermometer reading, t	71.5°F.	
Observed reading of barometer, B		29.315 inches
Algebraic sum of instrumental error and gravity correction, K_{ig}	+0.025 inch	
Variable removal correction corresponding to the current outdoor temperature of say, 52.0°F., K_{zp}...	-0.051 inch	
(See sample "Variable Removal Correction Table" and additional details in Chapter 4.)		
Correction for temperature, C_t	-0.113 inch	
(See Table 5.2.1, using arguments B and t as given)		
Total correction, ($K_{ig} + K_{zp} + C_t$)	-0.139 inch	-0.139 inch
(Algebraic sum of above three corrections)		
Station pressure, B_o		29.176 in. Hg
Algebraic sum of B and ($K_{ig} + K_{zp} + C_t$)		

FIGURE 5.2.2. Illustration of a case in which it is assumed that a variable removal correction is in use at the station and in which the scale of the barometer is true at 62° F.

to 32° F. (0° C.), for barometers having $t_a = 32°$ F., the correction is zero (0).

It is worth while pointing out a certain detail relating to Table 5.2.2 which gives the corrections of the Fortin-type barometer for temperatures expressed in °C., based on the use of a barometer scale that gives true readings at the value of $t_a = 0°$ C. Rule (2) summarized above fits this table. The instructions printed at the head of Table 5.2.2 imply that for any fixed height of the mercury column the absolute numerical value of the attached thermometer reading determines the absolute numerical value of the correction, while the algebraic signs involved are subject to the provisions of rule (2). We wish to point out that this implication is not strictly true; rather the relevant facts are as follows: (a) in the case of attached thermometer readings at and above 0° C., the corrections shown in Table 5.2.2 are accurate, since they were computed only for this range, strictly as $-Bf$ in accordance with the pertinent factor f which involves the temperature terms contained in equation (11) of Appendix 1.4.2, or equation (4) of sec. 5.1, account being taken of the definition of f, a function that depends upon t and t_a as indicated in sec. 5.1; whereas (b) in the case of attached thermometer readings below 0° C., the numerical values given by the table are not strictly accurate, being close approximations to the true values which would have been obtained from the product $-Bf$ if negative values of t had been inserted in the formula for f, where B represents the height of the mercury column. This disparity arises from the fact that the above-mentioned function f is not symmetrical with respect to positive and negative values of t.

In the following examples some idea is given regarding the degree of approximation with which the corrections are obtained from Table 5.2.2 when they refer to temperatures below 0° C., under the assumption that the reading of the barometer, B, is 1000 mb.

5.2.5 Use of Temperature Correction Tables, No. 5.2.1, 5.2.2, 5.2.3, etc.

Tables of the kind listed in the heading are valid for any Fortin-type barometer or U-tube mercury manometer having a brass scale. The selection of the table depends upon the temperature at which the scale reads true (denoted by t_a), as explained in sec. 5.2.2. Briefly, the following list shows how to pick the proper table; in order to secure the correction of the instrument for temperature:

(a) If $t_a = 62°$ F., and the barometer is graduated to read in inches, refer to Table 5.2.1.

(b) If $t_a = 0°$ C., and the barometer is graduated to read in millibars or millimeters, refer to Table 5.2.2.

(c) If $t_a = 32°$ F., and the barometer is graduated to read in inches, refer to Table 5.2.3.

The correction of the barometer (or U-tube mercury manometer) as given in the body of the tables is directly proportional to the reading of the barometer (or manometer), designated here by B; hence linear interpolation with respect to B is valid. It follows that the same tables may be used in accordance with any of the relevant equations contained in sec. 5.1, for the purpose of obtaining the appropriate correction for temperature; that is, one may ascertain from the tables data corresponding to B, or B *plus* any pertinent correction not involving temperature, such as the combined correction for instrumental error and gravity.

When referring to the tables for the purpose of determining the correction of the barometer for temperature, the observer must employ two arguments: (1) the attached

EXAMPLES

Discrepancies in the correction of the barometer for temperature inferred from Table 5.2.2. when the attached thermometer reading is below 0° C.

Column (1)	Column (2)	Column (3)	Column (4)
Attached thermometer reading (° C.)	Correction inferred from table 5.2.2 according to instructions	True correction calculated from formula $-Bf$	Absolute difference column (3)–column (2)
	mb.	*mb.*	*mb*
0	0.00	0.00	0.00
−10	1.63	1.64	0.01
−20	3.26	3.28	0.02
−30	4.88	4.93	0.05
−38*	6.17	6.25	0.08

*Mercury freezes at −38.87° C.

Note. The general expression for f is given in sec. 5.1. Since the data in the last three columns are based on the assumed barometer reading 1000 mb., one can readily calculate what the magnitude of the corrections should be for other values of B simply by multiplying the given data by the factor (B/1000), where B is the actual barometer reading, in mb.

Attached thermometer reading, t	27.5°C.	
Observed reading of barometer, B		853.70 mb.
Sum of corrections, K_r	-0.06 mb.	
Correction for temperature, C_t (See Table 5.2.2, using arguments B and t as given)	-3.82 mb.	
Total correction, ($K_r + C_t$) (Algebraic sum of above two corrections)	-3.88 mb.	-3.88 mb.
Station pressure, B_o Algebraic sum of B and ($K_r + C_t$)		849.82 mb.

FIGURE 5.2.3. Illustration of case in which pressure is in millibars and attached thermometer reading is in degrees C., with constant removal correction and barometer scale true at 0° C.

thermometer reading, *t*, to the nearest 0.5° F. or 0.25° C., corrected for the error in the thermometer, if necessary, in accordance with the instructions in sec. 5.2.3; and (2) the reading of the barometer.

With regard to item (2) described above as "the reading of the barometer," two cases should be distinguished: (I) In the case of routine observations for stations in middle and high latitudes, item (2) may be interpreted simply as "the observed actual reading of the barometer," symbol *B*; (II) in the case of observations for stations in low latitudes (say between the equator and latitude 25°) or otherwise when the pressure data are required to be of the greatest possible degree of accuracy for scientific purposes, item (2) should be interpreted as the barometer reading corrected for instrumental error and for gravity, taking account of the true barometer reading when determining the correction for gravity (see equation (2) of sec. 5.1). Also, in case (II) relating to scientific work of high precision, the correction for gravity should be ascertained for each observation depending upon the true barometer reading as argument, in accordance with the first formula shown in sec. 3.0, taking account of equation (2), sec. 5.1.

The correction for temperature of the Fortin-type barometer (or U-tube mercury manometer) having brass scales will be obtained from the body of the appropriate tables on the basis of the two arguments indicated in the preceding paragraph, while the proper algebraic sign of the correction must be determined in accordance with the instructions at the head of the tables.

It is essential for the observer to apply the correction for temperature on the basis of the appropriate algebraic sign, in conformity with the information presented in sec. 5.2.4.

Attached thermometer reading, t	-15.0°C.	
Observed reading of barometer, B		1011.65 mb.
Sum of corrections, K_r	+2.73 mb.	
Correction for temperature, C_t	+2.47 mb.*	
(See Table 5.2.2 using arguments B and t as given)		
Total correction, $(K_r + C_t)$	+5.20 mb.	+5.20 mb.
(Algebraic sum of above two corrections)		
Station pressure, B_o		1016.85 mb.
Algebraic sum of B and $(K_r + C_t)$		

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*Observer should note that the algebraic sign of the correction for temperature is opposite to the sign of the temperature given by the attached thermometer in degrees C.

FIGURE 5.2.4. Illustration of a case in which pressure is in millibars and attached thermometer reading is in degrees C., with temperature below zero, with removal correction equal to zero and barometer scale true at 0° C.

Owing to the fact that frequent use is made of *algebraic addition* which necessitates great care in regard to proper application of the given signs (+ or —), it is deemed worthwhile to recapitulate briefly the main points relating to this kind of operation for the purpose of obtaining the "resultant" or algebraic sum: One simple method of performing algebraic addition is first to add all of the positive (+) terms together, and then to add separately all of the negative (—) ones; thereby securing a sum of positive terms and a sum of negative terms, respectively. Finally, the numerical difference between these sums is determined, and algebraic sign given to the resultant is the sign possessed by the numerically larger of the two sums.

Figs. 5.2.1–5.2.4 illustrate the application of the various corrections. By definition, the term "sum of corrections" (symbol K_r) will be understood as the algebraic sum of the corrections for instrumental error, gravity, and "removal," if necessary. The term "total correction" will be understood as the quantity obtained by the algebraic addition of *all* of the pertinent corrections, including the correction for instrumental error, the correction for gravity, the "removal correction" if necessary, and the correction for temperature (symbol C_t). Therefore, the "total correction" is the result obtained by combining the "sum of corrections" algebraically with the correction for temperature; that is, $(K_r + C_t)$. The station pressure is determined finally by applying the "total correction" to the observed reading of the barometer, B.

In fig. 5.2.1 there is shown a typical case involving a Fortin-type barometer whose brass scale is true at 62° F.; hence, Table 5.2.1 is pertinent. This example is based on the assumption that the "removal correction" is a constant; and, accordingly, it should be noted that the "sum of corrections" (K_r) is likewise a constant, which permits a simplification of the computations as indicated.

Observers should take note of the fact that when Fortin barometers become available, having their scale graduated in inches and reading true at 32° F., the correction for temperature pertinent to such instruments will be secured from Table 5.2.3.

From the example presented in fig. 5.2.2, it may be seen that in cases where the "removal correction" is variable, the "total correction" is determined by the algebraic addition of the following three terms: (1) the algebraic sum of the corrections for instrumental error and gravity, denoted by K_{ig}; (2) the "removal correction" corresponding to the current outdoor temperature, denoted by K_{zp}; and (3) the correction for temperature, denoted by C_t. Since the scale of the barometer is true at 62° F. in this example, the correction for temperature is obtainable from Table 5.2.1.

The example shown in fig. 5.2.3 is designed to indicate the evaluation of the data when the barometer is graduated in "millibars" and the attached thermometer is read in °C., under the assumption that the "removal correction" is constant. By virtue of the fact that the "removal correction" is a constant, the "sum of corrections" (K_r) is a constant. For the given type of instrument the barometer scale is true at 0° C., hence Table 5.2.2 yields the correction for temperature, C_t. It should be noted that C_t is negative at temperatures above 0° C., while C_t is positive at temperatures below 0° C., in accordance with the instructions at the head of Table 5.2.2.

By a consideration of the data given in fig. 5.2.4, it will be seen that this example relates also to a barometer graduated in "millibars" with an attached thermometer which reads in °C. As in the previous case, the barometer scale reads true at 0° C., which again makes Table 5.2.2 pertinent as a source of the corrections for temperature, C_t. Fig. 5.2.4 by contrast with fig. 5.2.3 is intended to illustrate the rule that the correction for temperature has the opposite sign to that of the attached thermometer reading in the case of barometers which satisfy the conditions stated above in this paragraph.

5.3 CORRECTION OF FIXED-CISTERN BAROMETERS FOR TEMPERATURE

The discussion in this section is limited to some considerations relating to the fixed-cistern barometer, whose temperature correction differs from that for the Fortin-type barometer in certain respects. Theoretical formulas are presented for the temperature correction of the fixed-cistern barometer. However, since those formulas are not adapted to evaluation by means of the conventional tables which yield the temperature correction of the Fortin-type barometer, the formulas are then given in a transformed arrangement which permits use of the latter tables. As will be explained, calibrations are necessary to determine the appropriate constants pertinent to each fixed-cistern barometer.

Since the level of the mercury in the cistern of the fixed-cistern barometer cannot be directly determined, and since the height of the meniscus in the tube above that level must be inferred from the single scale reading made at the top of the mercury in the tube, it is evident that the fixed-cistern barometer is not a primary instrument. It is owing to these reasons that the scale of the barometer must be graduated on a contracted basis (see sec. 2.6), and that at least several readings on the scale of the fixed-cistern barometer must be checked by calibration against a primary, "normal," or "standard" barometer. In the latter portion of this section a procedure is presented for calibrating fixed-cistern barometers with a view to securing some degree of improvement in the accuracy obtainable by means of this type of instrument. See also sec. A–2.4.

[A primary barometer is one which can be graduated from first principles, and does not require a calibration. As examples of such an instrument we may cite the normal barometer at the National Physical Laboratory, Teddington, England,[1] and the normal barometer at the National Bureau of Standards, Washington, D. C. In both instruments tubes of large bore exceeding one inch are used to keep the capillary effects small. Effectively, the arrangement of the apparatus is that of a U-tube manometer with the lower, open end serving as the cistern. The vacuum above the meniscus in the upper, closed end of the tube is established by means of a diffusion pump. Direct observation of the height of the column of mercury between the two meniscuses is made by means of a double cathetometer. The latter is an instrument for measuring lengths on a scale very accurately, based on the use of two micrometer microscopes which ride on a vertical column and permit alternate viewing of the two meniscuses and of a standard scale of length mounted parallel to the column.[2] It is essential for the cross sections of the cistern and tube of the primary barometer to be alike in order to secure close balancing of capillary effects at the two meniscuses. See sec. A–2.5.]

A characteristic of the fixed-cistern barometer which hampers the obtainment of good qualities of repeatability is the uncertainty of the capillary depression in the cistern. This may vary from time to time, e.g. when the surface tension of the mercury changes as impurities are accumulated; when the height of the meniscus in the cistern falls (or rises) as an accommodation to the rise (or fall) of pressure; or when the line of contact between mercury surface and cistern wall deviates from a perfect ring of uniform contact as a result of irregular adhesion of the mercury to the wall. The capillary depression may eventually undergo a permanent shift, especially if the surface of the mercury in the cistern acquires a cover of sediment, which alters the shape of the meniscus. Owing to this latter situation, recalibration of the fixed-cistern barometer is necessary at intervals of time.

The principal reasons leading to the necessity for a temperature correction in the case of a fixed-cistern barometer are partly the same as those pertinent to the case of a Fortin-type barometer and partly different. In regard to both instruments it must be borne in mind that the standard temperature for mercury is 0° C. (32° F.). With reference to scales, some barometers have scales which read accurately in accordance with their labels at this same temperature, but some read accurately at a different temperature. In conjunction with these considerations we have the fact that the coefficient of cubical thermal expansion of mercury is different than the coefficient of linear thermal expansion of the scale. All of the foregoing leads to the conclusion that a certain correction term is required for both kinds of mercurial barometers, this term being already given in the available tables of temperature correction. However, the fixed-cistern barometer requires an additional correction. The reason for this is that an increase of temperature of the instrument causes an increase both in the volume of the mercury and in the cross-sectional areas of the (iron) cistern and of the (glass) tube. Owing to these area changes, the apparent rise of the mercury resulting from temperature increase is less than would be the case if the areas remained constant, because some

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[1] Sears, J. E., Jr., and J. S. Clark, Proc. Roy. Soc., London, Ser. A., vol. 139, pp. 130–146 (1933).

[2] Glazebrook, Sir R. "A Dictionary of Applied Physics," vol. III, London (1923), p. 152, 167–168.

of the mercury goes to occupy the increment of capacity produced by the expansion of the cistern and tube. From these considerations it follows that the additional correction required for the fixed-cistern barometer depends upon a factor V/A representing the ratio of the volume of mercury in the barometer (V) to the effective cross-sectional area of the cistern (A). (The effective area, A, may be defined as the actual internal cross-sectional area of the cistern *minus* the external cross-sectional area of the glass tailpiece of the barometer tube which dips into the mercury in the cistern.)

Theoretical analyses have been made by various investigators[3] [4] [5] to determine the total temperature correction for the fixed-cistern barometer. The complete results of the analyses are very involved; hence for the sake of simplicity the investigators dispose of terms which are small in comparison to the dominant terms, thereby securing an approximation. On this basis the correction for instrumental error (K_i) combined with the total temperature correction for the fixed-cistern barometer is obtained in the forms (I and II) shown below, where the symbols used are defined as follows:

DEFINITIONS OF SYMBOLS

B = observed reading of the barometer;

B_{ct} = reading of the fixed-cistern barometer corrected for instrumental error and for temperature (but not for gravity), where the correction for temperature includes reduction to standard temperature of the mercury (0° C.);

K_i = correction for instrumental error (index or scale error, including error due to capillarity);

V = total volume of mercury in the fixed-cistern barometer at the temperature 0° C.;

A = effective cross-sectional area of the cistern at the temperature 0° C.;

m = coefficient of cubical (voluminal) thermal expansion of mercury, for volume measured relative to that at 0° C.;

l = coefficient of linear thermal expansion of the metal of which the scale of the barometer is composed, for length measured relative to that at 0° C.;

l_a = coefficient of linear thermal expansion of the metal of which the scale of the barometer is composed, for length measured relative to that at a temperature t_a, at which the scale is accurate; $l_a = \dfrac{l}{(1+lt_a)}$;

t_a = temperature at which the scale is accurate (standard), in accordance with the label associated with the graduations of the scale; this signifying that when a scale is at the temperature t_a it would agree with a standard scale which is accurate regardless of its temperature or is corrected for temperature, allowance being made for the contraction of the original scale;

t = attached thermometer reading;

n = composite mean coefficient of linear thermal expansion of the materials of which the (iron) cistern and glass barometer tube are composed;

(*Note:* The value of n depends somewhat upon ratio of the volume of mercury in the tube above the meniscus level of the cistern to the total volume of mercury, V, and upon the ratio of the volume of the tailpiece immersed in the mercury to V.)

Theoretical Formulas for Temperature Correction of Fixed-Cistern Barometer

I. Metric Measure Barometer (graduated in millimeters or millibars)

Scale accurate at temperature t_a
(Temperature in °C.)

$$(B_{ct} - B) = -(B + K_i)\left[\frac{(m - l_a)t + l_a t_a}{(1 + mt)}\right] - \frac{V}{A}(m - 3n)t + K_i \qquad \text{(I)}$$

where B_{ct}, B, K_i and V/A are expressed in consistent units, with graduations either in

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[3] Glazebrook, R., "A Dictionary of Applied Physics," vol. III, London, Macmillan and Co., (1923). Article on "Barometers and Manometers," by F. A. Gould, on pp. 140–192.

[4] Irgens, K., Meteorologische Zeitschrift, vol. 45, pp. 441–444 (1928), and vol. 50, pp. 507–508 (1933). See also: E. Kleinschmidt, Meteorologische Zeitschrift, vol. 51, pp. 194–195 (1934).

[5] Sneyers, R., "De la correction thermique du baromètre à cuvette et à échelle fixes," Belgium, Institut Royal Météorologique; Miscellanées, Fasc. No. 37, (1951).

millimeters or in "millibars" on a contracted scale. (See sec. 2.6.)

Note: The general practice has been to graduate the scale of millimeter barometers so that $t_a = 0°$ C. This condition may not have been precisely satisfied in all of these instruments. The scales of barometers graduated in "millibars" have been such that t_a was 0° C. in some cases, and in other cases such that t_a was a different value.[6] After the International Barometer Conventions (see Appendix 1.4.1) are put into effect, it will be the common practice to make $t_a = 0°$ C. for barometers manufactured accordingly.

II. English Measure Barometer (graduated in inches)

Scale accurate at temperature t_a
(Temperatures in °F.)

$$(B_{ct} - \mathrm{B}) = -\,(B + K_i) \times \left[\frac{(m - l_a)\ (t - 32°) + l_a\ (t_a - 32°)}{1 + m\ (t - 32°)}\right] - \frac{V}{A}(m - 3n)\ (t - 32°) + K_i \qquad \text{(II)}$$

Note: Prior to the taking effect of the International Barometer Conventions (see Appendix 1.4.1), the value of t_a was supposed to be 62° F. However, this may not have been the case for all makes of barometers. When scales are graduated in accordance with the International Barometer Conventions, the value of t_a will be 32° F.

As previously pointed out, equations (I) and (II) are approximations. It is difficult to make accurate determinations of the unknown quantity $(V/A)(m - 3n)$ by direct measurements. However, if precise comparative readings of the fixed-cistern barometer are made against a "normal" or "standard" barometer at several different temperatures covering a sufficiently wide range, it is possible to calculate effective values of the quantities $(V/A)(m - 3n)$ and K_i with the aid of the calibration data, provided the temperature t_a is known. Usually the manufacturer of the barometer can supply the value of the temperature (t_a) at which the scale is accurate; otherwise t_a can be determined by measuring the scale by means of a cathetometer at a known temperature, and calculating t_a, assuming the coefficient of linear thermal expansion to be known.

In order to compute the desired quantities $(V/A)(m - 3n)$ and K_i from the calibration data, the foregoing equations must be transformed into new equations which are linear in these two unknown quantities. Thus, the tests at a fixed temperature yield a single linear equation in terms of the two unknowns. Tests at two widely separated temperatures yield two such equations, which can be solved simultaneously for $(V/A)(m - 3n)$ and K_i. By making tests at additional temperatures, the results of the calculations may be improved.

After the values of $(V/A)(m - 3n)$ and K_i are known, special tables may be prepared giving the correction $(B_{ct} - B)$ as a function of B and t, in accordance with equations (I) or (II). Under this procedure such a table must be computed especially for each barometer, since the table would yield the combined correction for instrumental error (scale error) and temperature pertaining to the given instrument.

The procedure outlined below for expressing the combination of corrections for instrumental (scale) error and temperature is recommended, owing to the fact that by means of a special technique it permits use of the temperature correction tables for Fortin-type barometers to give results applicable to fixed-cistern barometers, and yields a satisfactory degree of precision, in the case of observations over limited ranges of pressure and barometer temperature.

In the following, the temperature at which the scale is accurate, t_a, is assumed to be known; and if it is unknown, it should be determined in the manner previously explained. The particular value of t_a for a given barometer will generally depend upon the make and specifications of the instrument. (See Appendix 1.4.1).

Use will be made of the following functions of temperature, which will be recognized as the coefficient of B or $(B + K_i)$ in the expressions for the temperature correction of the Fortin-type barometers (see Appendix 1.4.2 and sec. 5.1):

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[6] Great Britain Air Ministry, Meteorological Office, "Meteorological Observer's Handbook," 1942 Edition (Reprinted 1947).

(a) *For Metric Measure Barometers* (t in °C.)

$$f(t, t_a) = \frac{(m - l_a)t + l_a t_a}{(1 + mt)}$$

(b) *For English Measure Barometers* (t in °F.)

$$f(t, t_a) = \frac{(m - l_a)\ (t - 32) + l_a(t_a - 32)}{1 + m(t - 32)}$$

For each fixed-cistern barometer operating over a limited range of pressure it is possible to determine a "reference temperature," denoted by t_r, and a "barometer constant," denoted by b, which satisfy the following equation:

$$(B_{ct} - B) = (B + K_i + b) \times [-f(t, t_a) + f(t_r, t_a)] + K_i \qquad \text{(III)}$$

For operations outside of the limited range of pressure, corrections of a residual character may be found necessary, above and beyond the correction given by the equation.

In order to determine the unknown quantities, K_i, b, and t_r for a given fixed-cistern barometer, it is necessary to perform calibration tests at two or more temperatures, making observations at the same definite set of barometer readings (B) under each temperature condition. For comparison with these values of B, one must have observations made at equal pressures by means of a standardizing ("normal" or primary) barometer, where the readings of the latter are corrected for instrumental error and temperature.

Let

B_{ct} = reading of the standardizing barometer, corrected for instrumental error and temperature (reduced to 0° C.);
B = observed reading of the fixed-cistern barometer;
K_i = instrumental correction of the fixed-cistern barometer;
b = the "barometer constant" of the fixed-cistern barometer;
t = attached thermometer reading;
t_a = temperature at which the scale of the fixed-cistern barometer is accurate;
t_r = "reference temperature" for the fixed-cistern barometer; and
C_r = residual correction for the fixed-cistern barometer (this being necessary only for operations outside of the limited range of pressure covered in normal practice on the basis of which the quantities K_i, b, and t_r are determined). (See equation VIII.)

Equation (III) may be rewritten in the following two forms:

$$[B_{ct} - B + B \cdot f(t, t_a)] = -(K_i + b) \cdot f(t, t_a) + [(B + K_i + b) \cdot f(t_r, t_a) + K_i] \qquad \text{(IV)}$$

and

$$[B_{ct} - B + (B + K_i + b) \cdot f(t, t_a)] = [(B + K_i + b) \cdot f(t_r, t_a) + K_i] \qquad \text{(V)}$$

Denoting,

(1) $Y_1 \equiv [B_{ct} - B + B \cdot f(t, t_a)]$
(2) $X_1 \equiv f(t, t_a)$
(3) $Y_{10} \equiv [(B + K_i + b) \cdot f(t_r, t_a) + K_i]$
(4) $Y_2 \equiv [B_{ct} - B + (B + K_i + b) \cdot f\ (t, t_a)]$
(5) $X_2 \equiv (B + K_i + b)$
(6) $Y_{20} \equiv K_i$

then eqs. (IV) and (V) may be written

$$Y_1 = -(K_i + b)X_1 + Y_{10} \qquad \text{(VI)}$$

and

$$Y_2 = f(t_r, t_a)X_2 + Y_{20} \qquad \text{(VII)}$$

Eq. (VI) shows that Y_1 is linearly related to X_1; and eq. (VII) indicates that Y_2 is linearly related to X_2. In eq. (VI) the slope of the line is $-(K_i + b)$, and the intercept of the line on the Y_1 axis is Y_{10} (that is, the value of Y_1 when $X_1 = 0$). In eq. (VII) the slope of the line is $f(t_r, t_a)$ and the intercept of the line on the Y_2 axis is Y_{20} (that is, the value of Y_2 when $X_2 = 0$).

The procedure for determining K_i, b, and t_r for a particular fixed-cistern barometer is outlined below, assuming that comparative observations of this instrument with a standardizing barometer have been made at two or more constant temperatures (t), provided the same series of readings B is made in each case. An example of the computations regarding K_i, b, and t_r is shown in Tables 5.3.1 (a), (b), (c), and (d). These tables are contained in this chapter immediately after the following instructions.

(1) Corresponding to every value of B in the series chosen, determine B_{ct} from the data yielded by the standardizing barometer, corrected for instrumental error and temperature.

(2) For each temperature (t) at which the tests were conducted, calculate $f(t, t_a)$ according to equations (a) or (b), for "Metric Measure Barometers," or "English Meas-

ure Barometers," respectively, whichever is appropriate. This yields X_1. (See headings of Table 5.3.1 (a) and (b).)

(3) Calculate Y_1 for each comparative observation, according to equation (1) above, noting the value of B pertinent to each case. (See sample computations in Table 5.3.1 (a) and (b).)

(4) On a piece of graph paper with uniform rulings in perpendicular directions, mark a point representing Y_1, (as ordinate) plotted against the corresponding value of X_1 (as abscissa), and at the point make a notation of the value of B on which Y_1 was based. This should be done for all pairs of values (X_1, Y_1); examples are shown in fig. 5.3.1 below.

(5) Connect by straight-line segments all consecutive points pertaining to a constant value of B. This will yield as many lines as there are values of B (see fig. 5.3.1). The lines should be nearly parallel.

(6) Determine the slope of the line pertaining to each constant value of B, where slope based on two points is defined as equal to difference in ordinates (Y_1) divided by the corresponding difference in abscissas (X_1). The value of the slope represents $-(K_i + b)$, according to equation (VI). It is usually advantageous to give preference to the thus-obtained value of the slope pertinent to the value of B nearest which the barometer will normally be read. The *negative* of the slope so found is $(K_i + b)$, and this should be used in subsequent calculations. (See sample computation of slope in Table 5.3.1 (c).)

(7) Refer to equations (4), (5) and (VII). Using the values of $(K_i + b)$ found from the negative of the slope last referred to in paragraph (6) above, calculate X_2 on the basis of equation (5) and the corresponding Y_2 on the basis of equation (4), for each of the comparative observations obtained during the calibrations. (See sample computations of X_2 and Y_2 in Table 5.3.1 (a) and (b).)

(8) On a piece of graph paper similar to

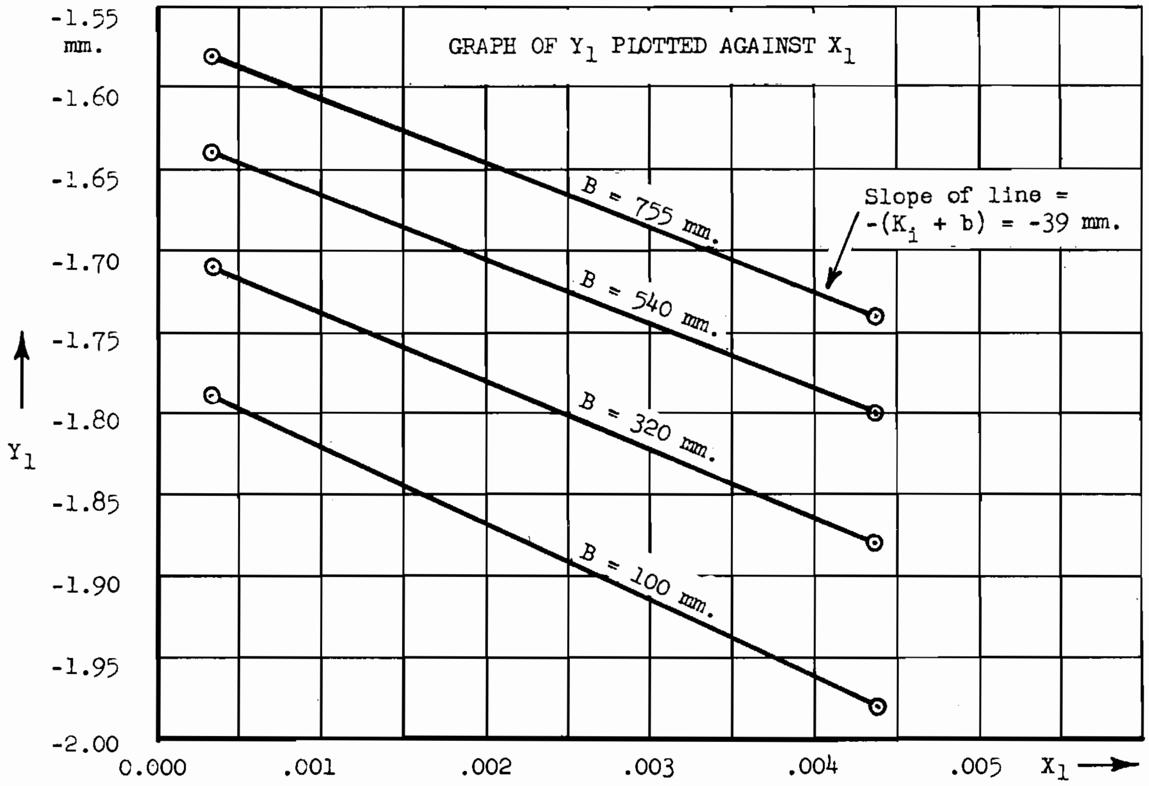

FIGURE 5.3.1. Results of comparative barometer tests at two different temperatures to determine $(K_i + b)$ for fixed-cistern barometer number 378.

that described in paragraph (4), mark points representing Y_2 (as ordinate) plotted against the corresponding X_2 (as abscissa), for all of the data referred to in paragraph (7). (See fig. 5.3.2).

(9) Construct the straight line of best fit for the points plotted on the (X_2, Y_2) graph referred to in paragraph (8), and extend the line to the Y_2 axis (that is, the vertical line for $X_2 = 0$). In deciding on the line of best fit, it is desirable to give more weight to the points based on the more reliable readings, and on the points for conditions of pressure and temperature most nearly similar to those under which the fixed-cistern barometer will be used (see fig. 5.3.2).

(10) In accordance with equations (6) and (VII), K_i is given by the value of Y_2 where the straight line of best fit intersects the Y_2 axis. Therefore, read off the value of the ordinate at the point at which the straight line in question cuts the Y_2 axis, and regard this value as K_i. (See fig. 5.3.2).

(11) In accordance with equation (VII), the slope of the line of best fit on the (X_2, Y_2) graph represents the value of $f(t_r, t_a)$. Determine this slope. (See fig. 5.3.2). (Slope based on two points is defined as equal to difference in ordinates (Y_2) divided by the corresponding difference in abscissas (X_2).) (See sample computations of slope in Table 5.3.1 (d).)

(12) Making use of this value for $f(t_r, t_a)$ in the formula given by equation (a) or (b), whichever is appropriate, calculate by algebraic solution the corresponding value of t_r. A simpler method of determining t_r is to refer to the temperature-correction tables for Fortin-type barometers, and to ascertain t_r by inverse interpolation, under a convenient selected barometer reading (B). Thus, B multiplied by the slope referred to in paragraph (11) is found in the body of the table, and t_r is the corresponding side argument. (See sample computations in Table 5.3.1 (d).) When use is made of equation (a) or (b), as outlined above, the symbol t must be replaced by t_r.

(13) Calculate the "barometer constant," b, for the particular barometer on the basis of the identity $b = (K_i + b) - K_i$, making use of the value of $(K_i + b)$ found in accordance with instructions in paragraph (6), and the value of K_i found in accordance with the instructions in paragraph (10). (See sample computations in Table 5.3.1 (d).)

When the values of K_i, b, and t_r have been determined for each fixed-cistern barometer on the basis of the methods outlined in the preceding paragraphs, (1)—(13), the residual corrections C_r may be calculated for the comparative observations in order to check

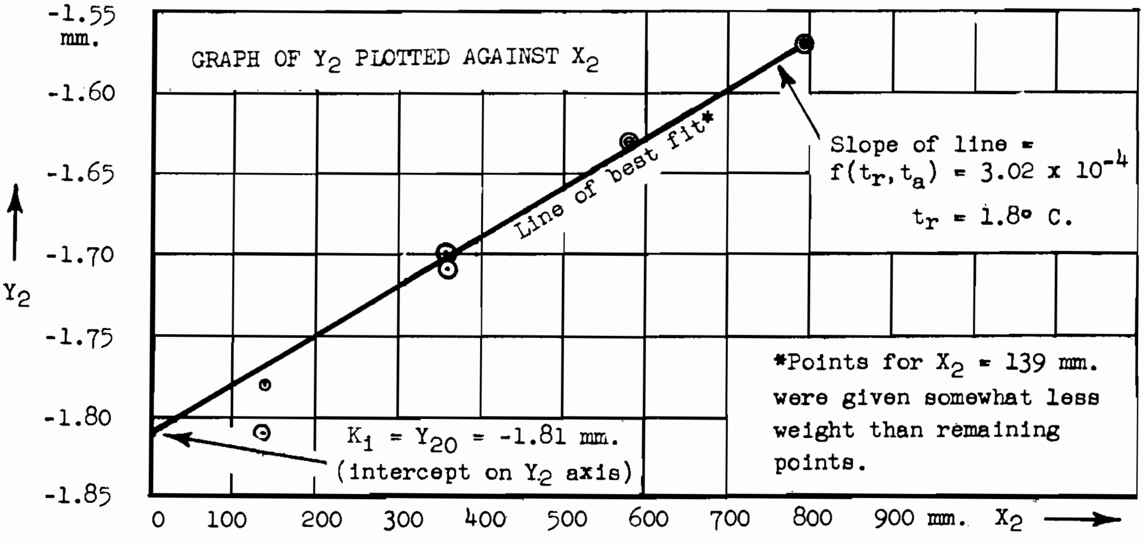

FIGURE 5.3.2. Results of comparative barometer tests at two different temperatures to determine K_i and $f(t_r, t_a)$ for fixed-cistern barometer number 378.

the results and to ascertain whether the residual corrections are sufficiently large to justify their application in observational practice, above and beyond the normal instrumental corrections. Results of sample computations of C_r are shown in Table 5.3.1 (a) and (b). The equation representing C_r is given below:

$$C_r = (B_{ct} - B) - (B + K_i + b) \times [-f(t, t_a) + f(t_r, t_a)] - K_i \qquad \text{(VIII)}$$

It may be inferred from the sample data in Table 5.3.1 (a) and (b) that for readings (B) of the given barometer at, or exceeding 320 mm., calculated values of the combined correction for instrumental error and temperature based on equation (III) will yield results accurate within ± 0.01 mm. Hg. At lower readings the deviations become significantly larger (for example, 0.04 mm. at $B = 100$ mm.); but B in these cases is well outside of the normal range of operation of the barometer.

Table 5.3.1 (a)

Computations of data for (X_1, Y_1) and (X_2, Y_2) graphs, to permit determination of K_i, b, $f(t_r, t_a)$ and t_r for barometer No. 378, for which $t_a = 0°$ C.

Temperature of test, $t = 27°$ C.; $f(t, t_a) = X_1 = 0.004390$

B	B_{ct}	$B \times f(t, t_a)$	Y_1	X_2	$(K_i+b) \times f(t, t_a)$	Y_2	C_r*
mm.	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
755.00..........	749.95	3.31	−1.74	794	0.17	−1.57	0.00
540.00..........	535.83	2.37	−1.80	579	0.17	−1.63	+0.01
320.00..........	316.72	1.40	−1.88	359	0.17	−1.71	0.00
100.00..........	97.58	0.44	−1.98	139	0.17	−1.81	−0.04

Table 5.3.1 (b)

Computations of data for (X_1, Y_1) and (X_2, Y_2) graphs, to permit determination of K_i, b, $f(t_r, t_a)$ and t_r for barometer No. 378, for which $t_a = 0°$ C.

Temperature of test, $t = 2°$ C.; $f(t, t_a) = X_1 = 0.0003267$

B	B_{ct}	$B \times f(t, t_a)$	Y_1	X_2	$(K_i+b) \times f(t, t_a)$	Y_2	C_r*
mm.	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
755.00.	753.17	0.25	−1.58	794	0.01	−1.57	0.00
540.00..........	538.18	0.18	−1.64	579	0.01	−1.63	0.00
320.00..........	318.19	0.10	−1.71	359	0.01	−1.70	−0.01
100.00..........	98.18	0.03	−1.79	139	0.01	−1.78	−0.01

*See equation VIII

Table 5.3.1 (c)

Computation to Determine ($K_i + b$)

Referring to the graph of Y_1 plotted against X_1 (see fig. 5.3.1), find the slope of the line corresponding to the value of B which is most nearly equal to the average of the barometer readings expected to be observed at the station where the instrument will be located (for example, $B = 755$ mm.).

$$\text{(Slope of line)} = \frac{(Y_1 \text{ at point 2}) - (Y_1 \text{ at point 1})}{(X_1 \text{ at point 2}) - (X_1 \text{ at point 1})}$$

Taking point 2 as that corresponding to the maximum of X_1 and point 1 as minimum value, we find

$$\text{(Slope of line)} = -(K_i + b) = \frac{[-1.74 - (-1.58)] \text{ mm.}}{0.004390 - 0.0003267} = -39 \text{ mm.}$$

Therefore $(K_i + b) = 39$ mm.

Table 5.3.1 (d)

Computations to Determine K_i, b, $f(t_r, t_a)$ and t_r

Referring to graph of Y_2 plotted against X_2, (see fig. 5.3.2), construct the line of best fit; and extend it to intersect the Y_2 axis.

(1) Read the value of Y_{20} (Y_2 intercept), which is the ordinate Y_2 at the point where the line of best fit intersects the Y_2 axis. We thus find $Y_{20} = K_i = -1.81$ mm.

(2) In order to calculate b, make use of results found in Table 5.3.1 (c) and in (1) above. Thus we obtain $b = (K_i + b) - K_i = (39 \text{ mm.}) - (-1.81 \text{ mm.}) = 40.8$ mm.

(3) Referring again to the graph of Y_2 plotted against X_2, find the slope of the line of best fit. This yields $f(t_r, t_a)$.

$$(\text{Slope of line}) = \frac{(Y_2 \text{ at point 2}) - (Y_2 \text{ at point 1})}{(X_2 \text{ at point 2}) - (X_2 \text{ at point 1})}$$

Taking point 2 as that corresponding to the maximum value of X_2 and point 1 as that corresponding to $X_2 = 0$, we obtain

$$(\text{Slope of line}) = f(t_r, t_a) = \frac{[-1.57 - (-1.81)] \text{ mm.}}{[794 - 0] \text{ mm.}} = 3.02 \times 10^{-4}$$

(4) In order to determine t_r, we make use of the appropriate equation for $f(t, t_a)$; in this case the equation pertaining to barometers reading in metric measures, where $t_a = 0°$ C. (See equation in sec. 5.1, and equation (a) in sec. 5.3.) Thus, in view of the result found under (3) above.

$$3.02 \times 10^{-4} = f(t_r, t_a) = \frac{(m - l)t_r}{1 + mt_r} = \frac{(0.0001818 - 0.0000184)\, t_r}{(1 + 0.0001818\, t_r)}$$

When this equation is solved for t_r, we find $t_r = 1.8°$ C.

After K_i, b, and t_r are known, the combined correction for instrumental error and temperature may be found with the aid of the temperature correction tables pertinent to Fortin-type barometers. An example is shown below:

Fixed-Cistern Barometer No. 378

Graduated to read in millibars.
Scale accurate at temperature $t_a = 0°$ C.
Instrumental correction, K_i = −2.4 mb.
Barometer constant, b = 50.4 mb.
Reference temperature, t_r = 1.8° C.
Observed reading of barometer, B = 1006.6 mb.
Attached thermometer reading, t = 27.0° C.

According to equation (III), the barometer reading corrected for instrumental error and temperature (B_{ct}) is given by

$$B_{ct} = B - (B + b + K_i) \cdot f(t, t_a) + (B + b + K_i) \cdot f(t_r, t_a) + K_i \quad \text{(IX)}$$

After comparing the terms of eq. (IX) with those given in sec. 5.1 for the Fortin-type barometer, it will be noted that $-(B + b + K_i) \cdot f(t, t_a)$ represents the correction for temperature pertinent to the Fortin-type barometer at the barometer reading $(B + b + K_i)$ and at attached thermometer reading t; whereas $+ (B + b + K_i) \cdot f(t_r, t_a)$ represents the *negative* of the correction for temperature pertinent to the Fortin-type barometer at the barometer reading $(B + b + K_i)$ and an attached thermometer reading t_r.

The temperature correction tables for Fortin-type barometers in metric measures are designed for a brass scale accurate at temperature 0° C.; that is, $t_a = 0°$ C.

The foregoing facts provide the basis for the procedure illustrated below for the computation of the barometer reading corrected for instrumental error and temperature (B_{ct}).

Sample Calculation of B_{ct}

$(B + b + K_i) = (1006.6 + 50.4 - 2.4)$ mb.	= 1054.6 mb.
(1) Observed barometer reading, B	= 1006.6 mb.
(2) Temperature correction from Table 5.2.2 corresponding to reading $(B + b + K_i) = 1054.6$ mb. and temperature 27°C.	= −4.63 mb.
(3) *Negative* of temperature correction from Table 5.2.2 corresponding to reading $(B + b + K_i)$ = 1054.6 mb. and temperature $t_r = 1.8°$	= +0.31 mb.
(4) Correction for instrumental error, K_i	= −2.4 mb.
(5) Barometer corrected for instrumental error and temperature, as given by algebraic sum of items (1), (2), (3), and (4); B_{ct}	= 999.9 mb.

Note: The value of B_{ct} must still be corrected for gravity in order to secure the absolute pressure in true millibars. As may be seen from equation (24) in Appendix 1.4.2, the absolute pressure (B_o), representing the barometer corrected for instrumental error, temperature and gravity is given by the expression

$$B_o = B_{ct} + B_{ct}\frac{g_l - g_o}{g_o}$$

Values of the second term in the right-hand member of this equation may be obtained by means of Table 3.3.2.

5.4 "TOTAL CORRECTION" TABLE FOR FORTIN-TYPE BAROMETERS

The "total correction" is defined as the algebraic total of all corrections which must be applied to the barometer reading in order to obtain the true station pressure under the existing conditions. In the case of the Fortin-type barometer, it may be considered that the "total correction" represents the result obtained by adding algebraically the appropriate correction of the instrument for temperature and the "sum of corrections," where the latter applies to the given barometer in accordance with the definition stated in sec. 5.1. (Note: It will be recalled, as illustrated in fig. 3.3.0, that the "sum of corrections" is the algebraic sum of the corrections for instrumental error, gravity, and removal correction, if any. Whenever necessary, a "residual correction" may be included, on the condition that the provisions of sec. 4.4 are in effect.)

If one considers the case of a Fortin-type barometer in a given situation for which the "sum of corrections" is a constant, it will be evident that the "total correction" is a function of the attached thermometer reading (t) and the observed barometer reading (B), based on the value obtained by algebraic addition of the "sum of corrections" and the temperature correction corresponding to the arguments t and B. Hence, these two arguments are sufficient to permit determination of the pertinent total correction, provided that the "sum of corrections" appropriate to the barometer is taken into account.

The "Total Correction Table," No. 5.4.1, published in full in Chapter 14, is designed to obviate the need for performing the algebraic addition for each observation, and to eliminate interpolation. Fig. 5.4.1 illustrates one page of Table 5.4.1, with data inserted for the "total correction" as an example under the assumption that the "sum of corrections" is —.023 in. Hg. In the copies of Table 5.4.1 published in Chapter 14 or as separate reprints, the column headed "Total Corr." will be blank. Authorized personnel at stations will fill in this total correction column each time that the "sum of corrections" pertaining to the station mercury barometer is changed. In accordance with the definition, the data which are to be entered under the column headed "Total Corr." will be obtained as the *algebraic sum* of the following two items: (1) the "sum of corrections" given on the Barometer Correction Card, Form WBAN 54–3.3.1; and (2) the temperature correction given under the first column of Table 5.4.1. Instructions regarding the entry of data in the total correction column of Table 5.4.1 are presented on the "Information Sheet" which forms the cover page of that table as contained in Chapter 14. On the same sheet will be found instructions and an example regarding the use of the "Total Correction Table."

IMPORTANT NOTE:

Whenever the "sum of corrections" pertaining to the station mercury barometer is revised or whenever the instrument is changed, it will be necessary to revise the data accordingly under the "total correction column."

At those stations which use a variable removal correction, the total correction column of Table 5.4.1 should be left blank. In these cases the temperature correction may be obtained from Table 5.4.1 to eliminate the need for interpolation. In this event the sum of corrections corresponding to the observed outdoor temperature should be obtained from the Barometer Correction Card. This sum of corrections should then be added algebraically to the temperature correction secured from Table 5.4.1 to obtain the total correction.

CAUTION: It should be noted that Table 5.4.1 is for use *only* with barometers having the scale reading true at 62° F. Table 5.2.3 should be used to obtain the temperature correction for barometers having the scale true at 32° F.

TABLE 5.4.1 - Page 11

BAROMETER TOTAL CORRECTION TABLE

(For Fortin Barometers, scale true at 62°F)

TEMP. 70.0 - 65.5°F

Barometer No. 990 Sum of Corrections -.023 Date 9/8/58

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	70.0°F										Total Corr. in.
-.118	-.141	31.668	69.5°F									-.141
-.117	-.140	31.401	- - -	69.0°F	- - -	- - -	- - -	- - -	- - -	- - -	- - -	-.140
-.116	-.139	31.133	31.513	- - -	68.5°F	- - -	- - -	- - -	- - -	- - -	- - -	-.139
-.115	-.138	30.866	31.242	31.627	- - -	- - -	- - -	- - -	- - -	- - -	- - -	-.138
-.114	-.137	30.599	30.972	31.354	31.745	68.0°F	- - -	- - -	- - -	- - -	- - -	-.137
-.113	-.136	30.332	30.701	31.080	31.468	- - -	67.5°F	- - -	- - -	- - -	- - -	-.136
-.112	-.135	30.064	30.431	30.806	31.191	31.585	- - -	- - -	- - -	- - -	- - -	-.135
-.111	-.134	29.797	30.160	30.532	30.914	31.304	31.706	67.0°F	- - -	- - -	- - -	-.134
-.110	-.133	29.530	29.890	30.258	30.636	31.024	31.421	- - -	66.5°F	- - -	- - -	-.133
-.109	-.132	29.263	29.619	29.984	30.359	30.743	31.137	31.541	- - -	66.0°F	- - -	-.132
-.108	-.131	28.995	29.349	29.711	30.082	30.462	30.853	31.253	31.664	- - -	- - -	-.131
-.107	-.130	28.728	29.078	29.437	29.805	30.181	30.568	30.965	31.372	31.790	65.5°F	-.130
-.106	-.129	28.461	28.808	29.163	29.527	29.901	30.284	30.677	31.081	31.495	- - -	-.129
-.105	-.128	28.194	28.537	28.889	29.250	29.620	30.000	30.389	30.789	31.199	31.621	-.128
-.104	-.127	27.926	28.267	28.615	28.973	29.339	29.715	30.101	30.497	30.903	31.321	-.127
-.103	-.126	27.659	27.996	28.341	28.695	29.058	29.431	29.813	30.205	30.607	31.021	-.126
-.102	-.125	27.392	27.726	28.068	28.418	28.778	29.147	29.525	29.913	30.312	30.721	-.125
-.101	-.124	27.125	27.455	27.794	28.141	28.497	28.862	29.237	29.621	30.016	30.422	-.124
-.100	-.123	26.858	27.185	27.520	27.864	28.216	28.578	28.949	29.330	29.720	30.122	-.123
-.099	-.122	26.590	26.914	27.246	27.586	27.935	28.293	28.661	29.038	29.425	29.822	-.122
-.098	-.121	26.323	26.644	26.972	27.309	27.655	28.009	28.373	28.746	29.129	29.523	-.121
-.097	-.120	26.056	26.373	26.698	27.032	27.374	27.725	28.084	28.454	28.833	29.223	-.120
-.096	-.119	25.789	26.103	26.425	26.755	27.093	27.440	27.796	28.162	28.537	28.923	-.119
-.095	-.118	25.521	25.832	26.151	26.477	26.812	27.156	27.508	27.870	28.242	28.623	-.118
-.094	-.117	25.254	25.562	25.877	26.200	26.532	26.872	27.220	27.578	27.946	28.324	-.117
-.093	-.116	24.987	25.291	25.603	25.923	26.251	26.587	26.932	27.287	27.650	28.024	-.116
-.092	-.115	24.720	25.021	25.329	25.646	25.970	26.303	26.644	26.995	27.354	27.724	-.115
-.091	-.114	24.452	24.750	25.055	25.368	25.689	26.019	26.356	26.703	27.059	27.424	-.114
-.090	-.113	24.185	24.480	24.782	25.091	25.408	25.734	26.068	26.411	26.763	27.125	-.113
-.089	-.112	23.918	24.209	24.508	24.814	25.128	25.450	25.780	26.119	26.467	26.825	-.112
-.088	-.111	23.651	23.939	24.234	24.537	24.847	25.165	25.492	25.827	26.172	26.525	-.111
-.087	-.110	23.383	23.668	23.960	24.259	24.566	24.881	25.204	25.536	25.876	26.226	-.110
-.086	-.109	23.116	23.398	23.686	23.982	24.285	24.597	24.916	25.244	25.580	25.926	-.109
-.085	-.108	22.849	23.127	23.412	23.705	24.005	24.312	24.628	24.952	25.284	25.626	-.108
-.084	-.107	22.582	22.857	23.139	23.428	23.724	24.028	24.340	24.660	24.989	25.326	-.107
-.083	-.106	22.314	22.586	22.865	23.150	23.443	23.744	24.052	24.368	24.693	25.027	-.106
-.082	-.105	22.047	22.316	22.591	22.873	23.162	23.459	23.764	24.076	24.397	24.727	-.105
-.081	-.104	21.780	22.045	22.317	22.596	22.882	23.175	23.476	23.785	24.101	24.427	-.104
-.080	-.103	21.513	21.775	22.043	22.319	22.601	22.891	23.188	23.493	23.806	24.127	-.103
-.079	-.102	21.245	21.504	21.769	22.041	22.320	22.606	22.900	23.201	23.510	23.828	-.102
-.078	-.101	20.978	21.234	21.496	21.764	22.039	22.322	22.612	22.909	23.214	23.528	-.101
-.077	-.100	20.711	20.963	21.222	21.487	21.759	22.037	22.323	22.617	22.918	23.228	-.100
-.076	-.099	- - -	20.693	20.948	21.210	21.478	21.753	22.035	22.325	22.623	22.929	-.099
-.075	-.098	- - -	- - -	20.674	20.932	21.197	21.469	21.747	22.033	22.327	22.629	-.098
-.074	-.097	- - -	- - -	- - -	20.655	20.916	21.184	21.459	21.742	22.031	22.329	-.097
-.073	-.096	- - -	- - -	- - -	- - -	20.636	20.900	21.171	21.450	21.736	22.029	-.096
-.072	-.095	- - -	- - -	- - -	- - -	- - -	20.616	20.883	21.158	21.440	21.730	-.095
-.071	-.094	- - -	- - -	- - -	- - -	- - -	- - -	- - -	20.866	21.144	21.430	-.094
-.070	-.093	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	20.848	21.130	-.093
		70.0°F	69.5°F	69.0°F	68.5°F	68.0°F	67.5°F	67.0°F	66.5°F	66.0°F	65.5°F	

FIGURE 5.4.1. Illustration of a "Total Correction Table" for a Fortin barometer whose "Sum of Corrections" = −0.023 in. Hg.

CHAPTER 6. STANDARDIZATION AND COMPARISON OF BAROMETERS

6.0 INTRODUCTION

This chapter is concerned with the establishment and maintenance of satisfactory standards in regard to the absolute accuracy of barometers. The objective is to secure a system of barometric measurements which yields pressure data conforming to accepted international and national tolerances. Without such a system, pressure gradients shown on the synoptic weather chart and altimeter setting differences used for various important aviation purposes would be unreliable.

Consistency in the basis of the data is essential in order to avoid conflicting data and discontinuous results originating from different sources. The best method of attaining absolute accuracy and consistency is by the conformity of barometric data in each region of the globe with the standards yielded by a primary (normal) barometer in the vicinity. Instruments of this latter character are maintained by such organizations as the National Bureau of Standards, Washington, D.C.; the National Physical Laboratory, Teddington, England; and the like. The primary barometers serve as the ultimate standards for all other pressure measuring instruments, including altimeters.

In this chapter procedures are recommended concerning comparison of barometers at various stages as in a ladder from top to bottom. At these respective stages, we have barometers in various classes that serve different functions or are characterized by different degrees of accuracy. In order to facilitate the discussion, each class of barometer in the ladder is assigned a letter, as explained in sec. 6.1.

The material concerning "International Comparison of Barometers," included as an Annex to this chapter, was adopted by the Commission for Instruments and Methods of Observation (CIMO) of the World Meteorological Organization (WMO) at its first meeting, held in Toronto, Canada, 10th August—4th September, 1953. The material in the Annex was approved by the Executive Committee of WMO at its Fourth Session held in Geneva, Switzerland, 6th–26th October, 1953.

In view of the scrupulous care involved under the procedures described in the Annex, the instructions therein may serve as a model and guide for comparisons of barometers at the various stages. The reader is therefore referred to the Annex on "International Comparison of Barometers" for basic information.

Every mercury barometer intended for field use must be inspected and tested before it is issued to a field station. The work of inspection and testing is generally done at an instrument laboratory or maintenance shop operated by the organization responsible for the equipment. A calibration is performed by comparison of the readings of the instrument with those of a standard barometer in the laboratory. On this basis a determination is made of the instrument correction (or correction for scale error and capillarity). The correction thus ascertained is generally recorded on a tag which is tied to the pertinent instrument. A sample of a tag designed for this purpose is illustrated by Form WBAN 54–6.0, headed "Certificate of Inspection of Instrument." (Sample tag is shown in fig. 13.6.1.) Filling out of the tag after the instrument is inspected and tested will be subsequently considered as a certification that the barometer has satisfied the usual laboratory inspection criteria and that the recorded correction was determined at the date and place indicated.

Under some conditions two or more barometric instruments must be compared when they are in different locations. It is desirable for the sake of accuracy that the two barometric instruments which are compared for standardization purposes be located in the same room at the same elevation. If, however, they are located at different elevations, a "removal correction" for the difference in elevation should be applied. When the difference in elevation exceeds 100 feet, or the horizontal distance between the two instruments exceeds 1 mile, serious questions may arise concerning the validity of the results of the comparisons. Wherever such extreme differences exist, the results must be viewed with reservations. (See sec. 6.6.2.) In that case it will be essential to have a greater number of comparative observations than usual, taken over longer periods of time, preferably when the winds are light, the pressure gradient is weak, and little or no marked barometric disturbance exists. When the terrain is hilly or mountainous, significant differences in local pressure may occur even over relatively short distances, owing to the effects of air drainage, wind, turbulence, etc. Under these conditions, highly accurate corrections to the readings of any instrument based on comparisons with another instrument at a distance are difficult to secure.

6.1 SYMBOLS AND TERMINOLOGY REGARDING DIFFERENT CLASSES OF BAROMETER

The following system of symbols and terminology is used throughout this chapter with reference to the various classes of barometer, where the subscript *r* indicates "region" in the international meteorological sense:[1]

"*A*"	denotes an absolute standard barometer capable of independent determination of pressure to an accuracy of at least ±0.05 millibars. Barometers of this class are maintained at the National Bureau of Standards, Washington, D. C.; the National Physical Laboratory, Teddington, England; and at other similar standardizing institutions.
"A_r"	denotes a barometer of category "*A*" which has been selected by regional agreement as a reference standard for barometers of that region.
"*B*"	denotes a working standard barometer of a national Meteorological Service of a design suitable for routine pressure comparisons and with known errors which have been established by comparison with a regional standard.[2]
"B_r"	denotes a barometer of category "*B*" in a region, which the national Meteorological Services of the Region agree to use as the reference standard barometer for the Region, in the event that a barometer of category "*A*" is unavailable in the Region.
"*C*"	denotes the fixed sub-standard barometer used for comparative purposes at field supervising stations of a national Meteorological Service.[2]
"*M*"	denotes a portable microbarograph of good quality and accuracy.
"*N*"	denotes two or more portable precision aneroid barometers of excellent quality. (It is found desirable to have each aneroid barometer mounted in a box which may be sealed and pumped up to a fixed fiducial pressure that will be maintained until the box seal is broken. Shock mounting of the instrument would be desirable as a means of preventing damage in transit.)
"*P*"	denotes a traveling mercurial barometer of good quality and accuracy which may be carried by an observer from one country to another, or one continent to another, and still retain its calibration.
"*S*"	denotes a mercurial barometer located at an ordinary station.
"*V*"	denotes an altimeter-setting indicator.
"*W*"	denotes a pressure-sensitive altimeter.

In the following, the abbreviations like "A_r", "*B*", "*C*", "*S*", etc., will often be used to represent a particular barometer of the category specified by the letter. The reader should find the meaning clear from the context in each case.

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[1] The system here employed is consistent with that contained in the Annex. Categories "*V*" and "*W*" have been added.

[2] All agencies involved may use these symbols for barometers of suitable quality serving the functions described.

Comparative barometer readings relating to two or more barometers are entered on appropriate forms such as Forms WBAN 54–6.3, –6.5, –6.6, –6.9.1, –6.9.2 (WB Forms 455–6, 455–7, 455–8, 455–9 and 455–11). In every case the designation of the categories of the barometers involved should be indicated by the pertinent symbols.

6.2 ABSOLUTE STANDARD (PRIMARY) BAROMETER FOR THE UNITED STATES *("A")*

Standards of pressure in the United States are established by reference to the absolute standard, primary barometer (category "A_r") maintained at the National Bureau of Standards, Washington, D.C. Information concerning this instrument is outlined in sec. A-2.5.5.

6.3 STANDARDIZATION OF WORKING STANDARD BAROMETERS *("B")*

The working standard barometers (category "*B*") of the U. S. Weather Bureau and of the various components of the U. S. military establishment located in North America will be standardized by comparisons with the barometer of category "A_r" referred to in sec. 6.2. Procedures for accomplishing the standardization are described in the Annex, especially under the caption "Recommended Practices Regarding First-Order International Comparison of Barometers." Comparisons which agree closely, based on at least two trips between "*B*" and "A_r" are necessary to establish sound results. As a consequence of the standardizations, corrections should be determined for each barometer in category "*B*", so that when these are applied to the readings of the working standard barometer ("*B*") corrected for gravity and temperature they will cause the results to agree with the absolute pressures obtained from the primary barometer ("A_r"). The corrections should be checked at least every two years by repetition of the comparisons.

At the instrument laboratories of the Weather Bureau and of the Military Services there are maintained several barometers that are of the same quality as the working standard barometer ("*B*"), or better. These instruments should, if practicable, be installed in an underground room where the temperature changes are very slight, the humidity is low or moderate, and the air relatively clean or unpolluted. All of these barometers should be standardized simultaneously, in the manner explained above. Form WBAN 54–6.3 should be used for entry of the comparative barometer readings and related data.

The readings of all of these instruments, properly corrected for temperature and for instrumental error (based on comparisons with "A_r"), should be compared periodically, at least every month. Records of the results should be carefully maintained in a historical file of comparative pressure data. Study of the comparative records, plotted on a continuing graph, should readily reveal any tendency of the corrections of the respective barometers to drift relative to one another or to the primary standard. A marked, sudden change in difference between them should disclose a possible impairment of one of the instruments.

6.4 STANDARDIZATION OF SUB-STANDARD BAROMETERS *("C")*

Each Agency maintains fixed, good quality sub-standard barometers (category "*C*") of large bore (0.5 to 0.6 inch) at regional offices, depots or selected field stations. These are used for comparative purposes in the field. They permit determination of control or check readings on the accuracy of barometers located at other stations of the Agency in the region or area served by the office or depot.

Barometers of category "*C*" should be standardized at least every two years by comparisons with the barometer of category "*B*" of the Service involved. Station barometers (category "*S*") installed near "*C*" are to be compared concurrently. Procedures outlined in the Annex should be followed, giving cognizance insofar as practicable to "Recommended Practices Regarding First-Order International Comparison of Barometers."

Corrections should be determined for the barometer in category "*C*." These corrections are to be applied to barometer "*C*" in order to make it agree with barometer "A_r", through the intermediary of barometer "*B*", which is itself corrected to agree with "A_r".

Periodic comparisons should be made every month of barometers in categories "*C*" and "*S*", maintained side by side. Records of the results should be kept indefinitely. Careful watch should be kept for the development of any marked shift or drift of the difference between them. Should such a marked change occur, new standardization comparisons with respect to "*B*" are necessary.

In the case of U. S. barometers in category "*C*" which are located overseas in or near countries where some foreign establishment maintains a primary barometer ("*A*" or "A_r"), arrangements should be made, if practicable, to carry out a series of comparisons between the two instruments. The procedures outlined in the Annex should be followed, and the results should be transmitted to headquarters for referral to the main instrument laboratory of the Agency in the states.

6.5 COMPARISON OF STATION BAROMETERS ("*S*", "*N*", AND "*V*") WITH REGIONAL OFFICE OR HEADQUARTERS SUB-STANDARD BAROMETER ("*C*")

6.5.0 General Features of Comparison Program

Field inspectors or field aides will conduct a continuing program of making comparative barometer readings between the substandard barometer ("*C*") at the regional office or headquarters and the mercurial barometers ("*S*") at the stations under the supervision of the office or headquarters. This program is carried out by these personnel through the use of portable barometers which are compared in sequence with "*C*" before departure for a visit to the stations, with "*S*" during the visit, and again with "*C*" after the return. Preference should be given to such sequences of comparisons at intervals not exceeding one year. In station areas where there is considerable atmospheric pollution, dust, sand, etc., comparisons of "*S*" at more frequent intervals are desirable. The procedure outlined in paragraph (2) under "Recommends," in the Annex, may be followed; although it is preferable to carry out, if practicable, some of the provisions covered in the Annex under the caption "Recommended Practices Regarding First-Order International Comparison of Barometers." In particular, a recommended practice is that joint use be made of portable precision aneroid barometers ("*N*") and the traveling mercurial barometer ("*P*") for transport by the field inspectors or field aides in order to make the comparisons.

6.5.1 Limit Regarding Variation of Inspection Barometer

At the office of point-of-departure (origin) of the field inspectors or field aides, prior to their leaving for an inspection trip, the personnel should undertake the making of a set of comparative readings of the portable barometers ("*P*" and/or "*N*") with the substandard barometer ("*C*"). Similar comparisons should be made upon return to the origin, but after at least two hours time have elapsed, preferably with a fan blowing on the instruments, in order to allow temperature equilibrium to be established between the instruments and their environment. Agreement between past and current comparative results should be checked in each case. If changes exceeding 0.005 inch of mercury (0.17 mb.) are revealed between averages of past and current comparative data (that is, when the corrections to reduce to the standard barometer appear to undergo marked shifts), the results should be checked, and the comparisons repeated if necessary. Any evidence that the portable instruments have become impaired during transit or from use should lead to invalidation of the data obtained with their aid. (It is intended that the reader should interpret the term "past" in connection with comparative results or data, referred to above, as pertaining to the set of comparative values obtained just previous to the current set.)

6.5.2 Basic Procedures for Comparisons at Stations

When an inspector or field aide transports a portable mercurial barometer to a station for the purpose of making comparative readings at the latter place, the barometer should usually be allowed to hang beside the station barometric instruments for at least two hours before readings are begun. However, the time interval may be shortened; thus, if available, an electric fan should be used to ventilate the instruments and the surrounding space in the room in order to quickly attain temperature equilibrium between them. In this event, it should be noted that by observing the attached thermometer and plotting results versus time as a curve the establishment of equilibrium can be determined as the curve levels off. At least five (5) comparative sets of barometer readings are required, and the readings should include those from all pressure measuring instruments at the station. Time intervals between readings should be at least 15 minutes.

If practicable, the period during which the readings are made should be selected on the basis of the occurrence of favorable meteorological conditions which are "barometrically quiet." For present purposes these may be considered as conditions (a) with little or no significant pressure fluctuations as shown on the microbarograph; (b) with a flat trace on the latter instrument, or at most a fairly steady, slow rate of fall or rise of pressure. Thus, periods with conditions involving frontal passages, strong or gusty winds, thunderstorms, hurricanes, etc., should be avoided for the making of comparative barometer readings, because these are usually attended by large and rapid fluctuations of pressure, often with rapid rates of fall or rise.

If, under emergency conditions, it is necessary to make the comparative readings when a rapid rate of fall or rise in pressure is occurring, the order in which the readings are made from the different instruments should be alternated (that is, reversed in order of readings for each comparison). If practicable, a copy of the trace of the microbarograph for the given period should be secured later on when convenient; and the copy, with times carefully indicated, should be attached to the form containing the "Comparative Barometer Readings." Under these conditions, the exact time of reading of each instrument should be entered on the form. If time permits, a second set of comparisons should be made and reported on the appropriate form.

6.5.3 Forms for "Comparative Barometer Readings"

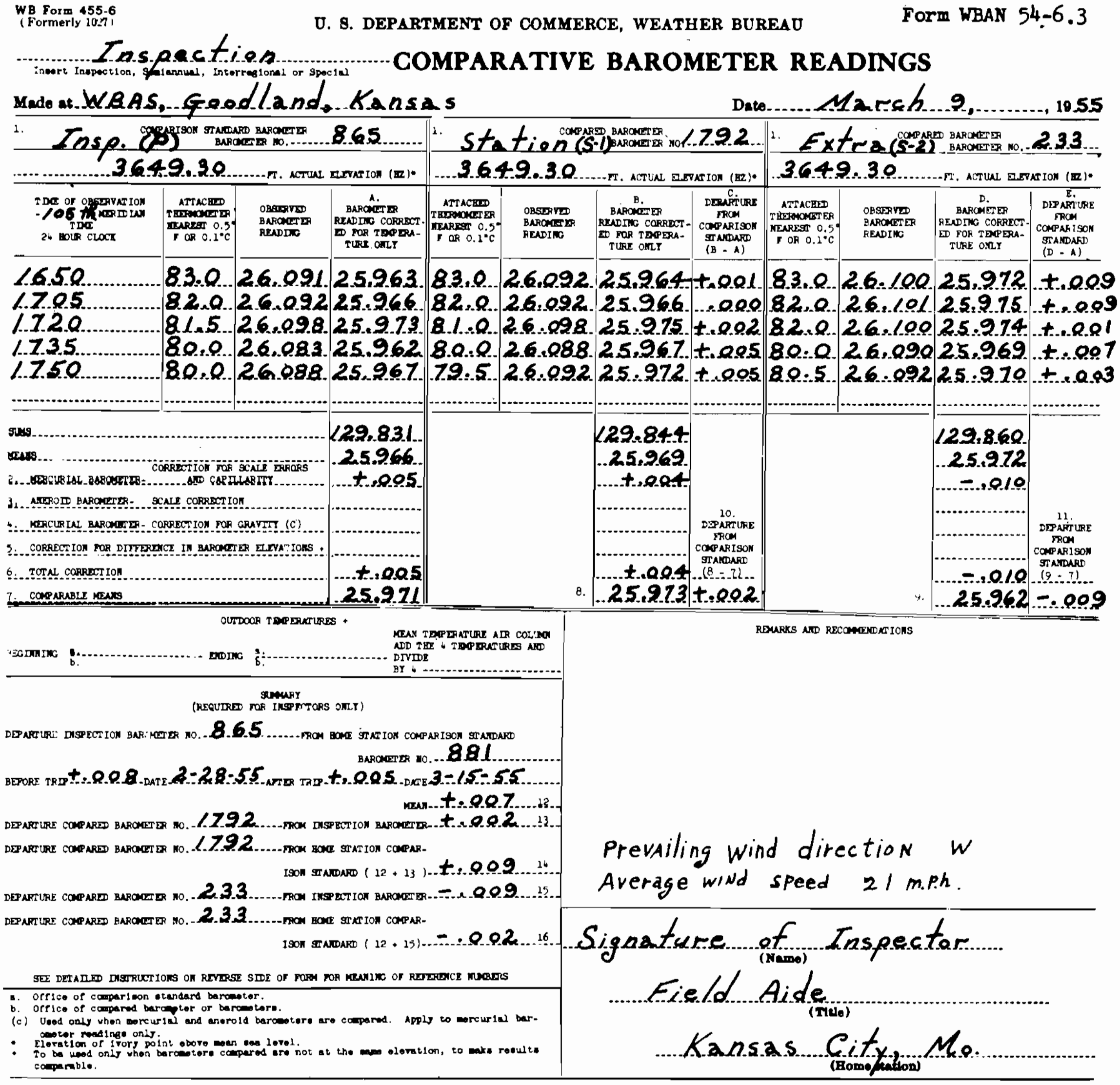
All data pertaining to comparative barometer readings should be entered on an appropriate form. In the case of the data obtained at land stations, the form to be used is Form WBAN 54–6.3 or the equivalent WB Form 455–6, "Comparative Barometer Readings."

Fig. 6.5.1 shows a completed copy of the face of Form WBAN 54–6.3 (WB Form 455–6), involving the comparison of an inspector's portable mercurial barometer with two mercurial barometers located at a station which the inspector visited. Fig. 6.5.2 shows the reverse side of Form WBAN 54–6.3 (WB Form 455–6) where instructions are given regarding its preparation.

On the form last referred to, certain terms are used in a technical sense, and these terms are now explained. Thus, "Home Station" signifies the name and location of the inspector's headquarters. Hence, the term "Home Station Standard" used on the form refers to the sub-standard barometer (*"C"*) located at the headquarters of the inspector, or to the station barometer at the headquarters of the inspector if an instrument of category *"C"* is not available there. The terms "Comparison Standard" and "Compared Barometers" are purely relative; the former term referring to the barometer taken as the standard (or reference basis) for the immediate comparison, and the latter term referring to the barometer being compared with the instrument mentioned in the preceding clause.

Fig. 6.5.3 presents a completed copy of Form WBAN 54–6.3 (WB Form 455–6) pertaining to a case in which an inspector's mercurial barometer is compared with two different instruments, one being the station mercurial barometer and the other being a precision aneroid barometer.

Fig. 6.5.4 illustrates a completed copy of Form WBAN 54–6.3 (WB Form 455–6) relating to a situation in which the inspec-



WB Form 455-6
(Formerly 1027)

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

Form WBAN 54-6.3

Inspection (Insert Inspection, Semiannual, Interregional or Special) COMPARATIVE BAROMETER READINGS

Made at WBAS, Goodland, Kansas Date March 9, 1955

1. Insp. (P) COMPARISON STANDARD BAROMETER BAROMETER NO. 865 — 3649.30 FT. ACTUAL ELEVATION (HZ)*

1. Station (S-1) COMPARED BAROMETER BAROMETER NO. 1792 — 3649.30 FT. ACTUAL ELEVATION (HZ)*

1. Extra (S-2) COMPARED BAROMETER BAROMETER NO. 233 — 3649.30 FT. ACTUAL ELEVATION (HZ)*

TIME OF OBSERVATION -105 th MERIDIAN TIME 24 HOUR CLOCK	ATTACHED THERMOMETER NEAREST 0.5° F OR 0.1°C	OBSERVED BAROMETER READING	A. BAROMETER READING CORRECTED FOR TEMPERATURE ONLY	ATTACHED THERMOMETER NEAREST 0.5° F OR 0.1°C	OBSERVED BAROMETER READING	B. BAROMETER READING CORRECTED FOR TEMPERATURE ONLY	C. DEPARTURE FROM COMPARISON STANDARD (B - A)	ATTACHED THERMOMETER NEAREST 0.5° F OR 0.1°C	OBSERVED BAROMETER READING	D. BAROMETER READING CORRECTED FOR TEMPERATURE ONLY	E. DEPARTURE FROM COMPARISON STANDARD (D - A)
1650	83.0	26.091	25.963	83.0	26.092	25.964	+.001	83.0	26.100	25.972	+.009
1705	82.0	26.092	25.966	82.0	26.092	25.966	.000	82.0	26.101	25.975	+.009
1720	81.5	26.098	25.973	81.0	26.098	25.975	+.002	82.0	26.100	25.974	+.001
1735	80.0	26.083	25.962	80.0	26.088	25.967	+.005	80.0	26.090	25.969	+.007
1750	80.0	26.088	25.967	79.5	26.092	25.972	+.005	80.5	26.092	25.970	+.003

	A	B	10. DEPARTURE FROM COMPARISON STANDARD (8 - 7)	D	11. DEPARTURE FROM COMPARISON STANDARD (9 - 7)
SUMS	129.831	129.844		129.860	
MEANS	25.966	25.969		25.972	
2. MERCURIAL BAROMETER - CORRECTION FOR SCALE ERRORS AND CAPILLARITY	+.005	+.004		-.010	
3. ANEROID BAROMETER - SCALE CORRECTION					
4. MERCURIAL BAROMETER - CORRECTION FOR GRAVITY (C)					
5. CORRECTION FOR DIFFERENCE IN BAROMETER ELEVATIONS +					
6. TOTAL CORRECTION	+.005	+.004		-.010	
7. COMPARABLE MEANS	25.971	8. 25.973	+.002	9. 25.962	-.009

OUTDOOR TEMPERATURES +

BEGINNING a. b. ENDING a. b. MEAN TEMPERATURE AIR COLUMN ADD THE 4 TEMPERATURES AND DIVIDE BY 4

SUMMARY
(REQUIRED FOR INSPECTORS ONLY)

DEPARTURE INSPECTION BAROMETER NO. 865 FROM HOME STATION COMPARISON STANDARD BAROMETER NO. 881

BEFORE TRIP +.008 DATE 2-28-55 AFTER TRIP +.005 DATE 3-15-55

MEAN +.007 12

DEPARTURE COMPARED BAROMETER NO. 1792 FROM INSPECTION BAROMETER +.002 13

DEPARTURE COMPARED BAROMETER NO. 1792 FROM HOME STATION COMPARISON STANDARD (12 + 13) +.009 14

DEPARTURE COMPARED BAROMETER NO. 233 FROM INSPECTION BAROMETER -.009 15

DEPARTURE COMPARED BAROMETER NO. 233 FROM HOME STATION COMPARISON STANDARD (12 + 15) -.002 16

SEE DETAILED INSTRUCTIONS ON REVERSE SIDE OF FORM FOR MEANING OF REFERENCE NUMBERS

a. Office of comparison standard barometer.
b. Office of compared barometer or barometers.
(c) Used only when mercurial and aneroid barometers are compared. Apply to mercurial barometer readings only.
* Elevation of ivory point above mean sea level.
\+ To be used only when barometers compared are not at the same elevation, to make results comparable.

REMARKS AND RECOMMENDATIONS

Prevailing wind direction W
Average wind speed 21 m.p.h.

Signature of Inspector (Name)

Field Aide (Title)

Kansas City, Mo. (Home Station)

FIGURE 6.5.1. Comparative barometer readings: portable inspection Fortin-type mercurial barometer (*P*) compared with the station and extra mercurial barometers (*S*–1 and *S*–2) during an inspector's visit.

tor's Fortin-type instrument is compared with the station mercurial barometer and an altimeter-setting indicator. Slightly different details in procedure are involved in the respective cases illustrated in figs. 6.5.1, 6.5.3, and 6.5.4.

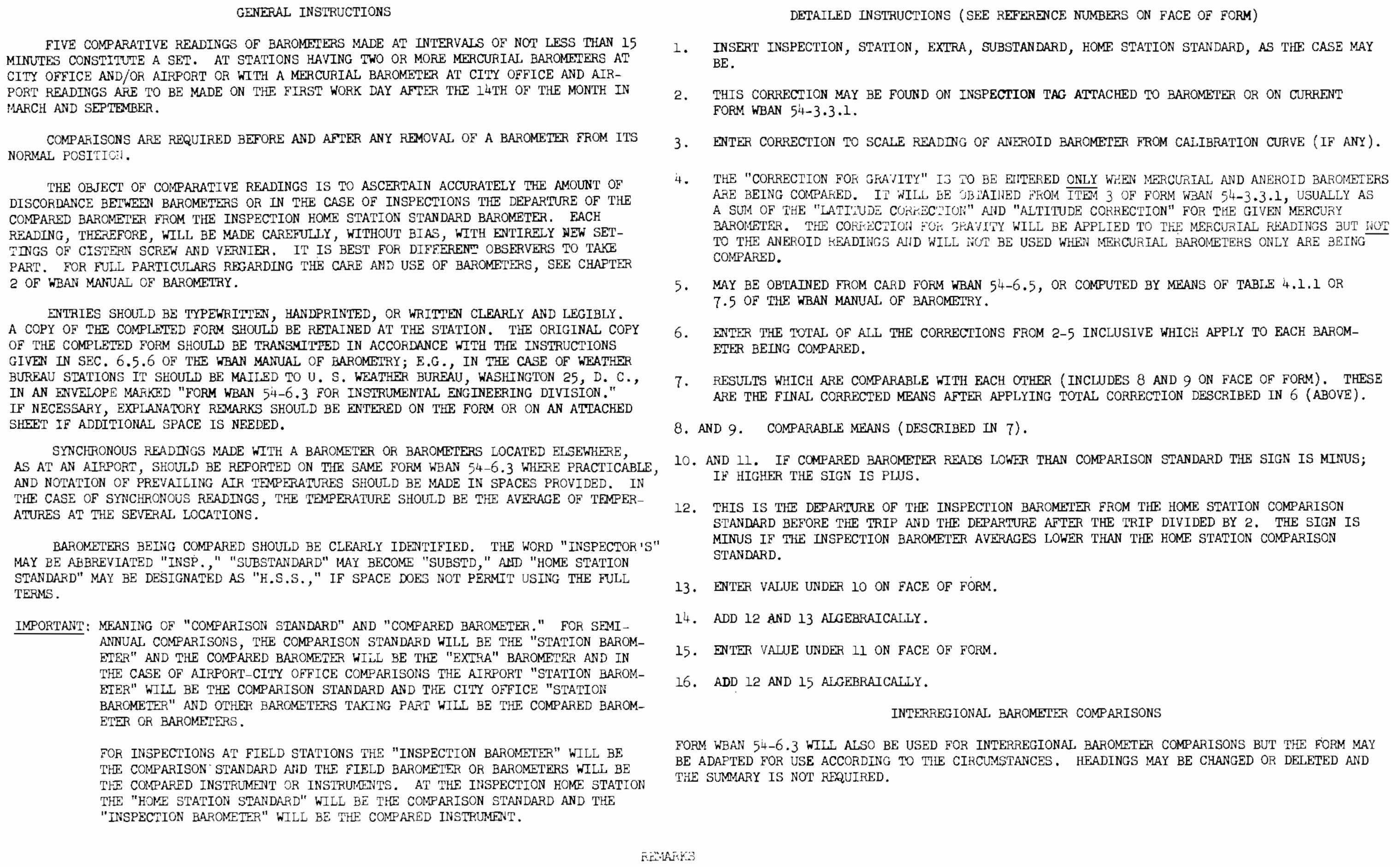
6.5.4 Criteria for Deciding Upon Need for Barometer Comparisons

When stations are visited by inspectors, the latter shall use the following criteria in deciding whether barometer comparisons are to be made and the appropriate forms rendered:

(a) Whenever an inspection comparison has not been made in the last six months.

(b) Whenever recent station comparisons between station mercurial barometer and precision aneroid instruments on Form WBAN 54–6.3 or –6.6 (WB Form 455–6 or 455–7), or other evidence, indicates questionable or unsatisfactory performance.

(c) Whenever a mercurial barometer is cleaned, relocated, replaced or otherwise disturbed; at which time, comparisons will be made both before and after the disturbance; if pos-



GENERAL INSTRUCTIONS

FIVE COMPARATIVE READINGS OF BAROMETERS MADE AT INTERVALS OF NOT LESS THAN 15 MINUTES CONSTITUTE A SET. AT STATIONS HAVING TWO OR MORE MERCURIAL BAROMETERS AT CITY OFFICE AND/OR AIRPORT OR WITH A MERCURIAL BAROMETER AT CITY OFFICE AND AIRPORT READINGS ARE TO BE MADE ON THE FIRST WORK DAY AFTER THE 14TH OF THE MONTH IN MARCH AND SEPTEMBER.

COMPARISONS ARE REQUIRED BEFORE AND AFTER ANY REMOVAL OF A BAROMETER FROM ITS NORMAL POSITION.

THE OBJECT OF COMPARATIVE READINGS IS TO ASCERTAIN ACCURATELY THE AMOUNT OF DISCORDANCE BETWEEN BAROMETERS OR IN THE CASE OF INSPECTIONS THE DEPARTURE OF THE COMPARED BAROMETER FROM THE INSPECTION HOME STATION STANDARD BAROMETER. EACH READING, THEREFORE, WILL BE MADE CAREFULLY, WITHOUT BIAS, WITH ENTIRELY NEW SETTINGS OF CISTERN SCREW AND VERNIER. IT IS BEST FOR DIFFERENT OBSERVERS TO TAKE PART. FOR FULL PARTICULARS REGARDING THE CARE AND USE OF BAROMETERS, SEE CHAPTER 2 OF WBAN MANUAL OF BAROMETRY.

ENTRIES SHOULD BE TYPEWRITTEN, HANDPRINTED, OR WRITTEN CLEARLY AND LEGIBLY. A COPY OF THE COMPLETED FORM SHOULD BE RETAINED AT THE STATION. THE ORIGINAL COPY OF THE COMPLETED FORM SHOULD BE TRANSMITTED IN ACCORDANCE WITH THE INSTRUCTIONS GIVEN IN SEC. 6.5.6 OF THE WBAN MANUAL OF BAROMETRY; E.G., IN THE CASE OF WEATHER BUREAU STATIONS IT SHOULD BE MAILED TO U. S. WEATHER BUREAU, WASHINGTON 25, D. C., IN AN ENVELOPE MARKED "FORM WBAN 54-6.3 FOR INSTRUMENTAL ENGINEERING DIVISION." IF NECESSARY, EXPLANATORY REMARKS SHOULD BE ENTERED ON THE FORM OR ON AN ATTACHED SHEET IF ADDITIONAL SPACE IS NEEDED.

SYNCHRONOUS READINGS MADE WITH A BAROMETER OR BAROMETERS LOCATED ELSEWHERE, AS AT AN AIRPORT, SHOULD BE REPORTED ON THE SAME FORM WBAN 54-6.3 WHERE PRACTICABLE, AND NOTATION OF PREVAILING AIR TEMPERATURES SHOULD BE MADE IN SPACES PROVIDED. IN THE CASE OF SYNCHRONOUS READINGS, THE TEMPERATURE SHOULD BE THE AVERAGE OF TEMPERATURES AT THE SEVERAL LOCATIONS.

BAROMETERS BEING COMPARED SHOULD BE CLEARLY IDENTIFIED. THE WORD "INSPECTOR'S" MAY BE ABBREVIATED "INSP.," "SUBSTANDARD" MAY BECOME "SUBSTD," AND "HOME STATION STANDARD" MAY BE DESIGNATED AS "H.S.S.," IF SPACE DOES NOT PERMIT USING THE FULL TERMS.

IMPORTANT: MEANING OF "COMPARISON STANDARD" AND "COMPARED BAROMETER." FOR SEMI-ANNUAL COMPARISONS, THE COMPARISON STANDARD WILL BE THE "STATION BAROMETER" AND THE COMPARED BAROMETER WILL BE THE "EXTRA" BAROMETER AND IN THE CASE OF AIRPORT-CITY OFFICE COMPARISONS THE AIRPORT "STATION BAROMETER" WILL BE THE COMPARISON STANDARD AND THE CITY OFFICE "STATION BAROMETER" AND OTHER BAROMETERS TAKING PART WILL BE THE COMPARED BAROMETER OR BAROMETERS.

FOR INSPECTIONS AT FIELD STATIONS THE "INSPECTION BAROMETER" WILL BE THE COMPARISON STANDARD AND THE FIELD BAROMETER OR BAROMETERS WILL BE THE COMPARED INSTRUMENT OR INSTRUMENTS. AT THE INSPECTION HOME STATION THE "HOME STATION STANDARD" WILL BE THE COMPARISON STANDARD AND THE "INSPECTION BAROMETER" WILL BE THE COMPARED INSTRUMENT.

DETAILED INSTRUCTIONS (SEE REFERENCE NUMBERS ON FACE OF FORM)

1. INSERT INSPECTION, STATION, EXTRA, SUBSTANDARD, HOME STATION STANDARD, AS THE CASE MAY BE.

2. THIS CORRECTION MAY BE FOUND ON INSPECTION TAG ATTACHED TO BAROMETER OR ON CURRENT FORM WBAN 54-3.3.1.

3. ENTER CORRECTION TO SCALE READING OF ANEROID BAROMETER FROM CALIBRATION CURVE (IF ANY).

4. THE "CORRECTION FOR GRAVITY" IS TO BE ENTERED ONLY WHEN MERCURIAL AND ANEROID BAROMETERS ARE BEING COMPARED. IT WILL BE OBTAINED FROM ITEM 3 OF FORM WBAN 54-3.3.1, USUALLY AS A SUM OF THE "LATITUDE CORRECTION" AND "ALTITUDE CORRECTION" FOR THE GIVEN MERCURY BAROMETER. THE CORRECTION FOR GRAVITY WILL BE APPLIED TO THE MERCURIAL READINGS BUT NOT TO THE ANEROID READINGS AND WILL NOT BE USED WHEN MERCURIAL BAROMETERS ONLY ARE BEING COMPARED.

5. MAY BE OBTAINED FROM CARD FORM WBAN 54-6.5, OR COMPUTED BY MEANS OF TABLE 4.1.1 OR 7.5 OF THE WBAN MANUAL OF BAROMETRY.

6. ENTER THE TOTAL OF ALL THE CORRECTIONS FROM 2-5 INCLUSIVE WHICH APPLY TO EACH BAROMETER BEING COMPARED.

7. RESULTS WHICH ARE COMPARABLE WITH EACH OTHER (INCLUDES 8 AND 9 ON FACE OF FORM). THESE ARE THE FINAL CORRECTED MEANS AFTER APPLYING TOTAL CORRECTION DESCRIBED IN 6 (ABOVE).

8. AND 9. COMPARABLE MEANS (DESCRIBED IN 7).

10. AND 11. IF COMPARED BAROMETER READS LOWER THAN COMPARISON STANDARD THE SIGN IS MINUS; IF HIGHER THE SIGN IS PLUS.

12. THIS IS THE DEPARTURE OF THE INSPECTION BAROMETER FROM THE HOME STATION COMPARISON STANDARD BEFORE THE TRIP AND THE DEPARTURE AFTER THE TRIP DIVIDED BY 2. THE SIGN IS MINUS IF THE INSPECTION BAROMETER AVERAGES LOWER THAN THE HOME STATION COMPARISON STANDARD.

13. ENTER VALUE UNDER 10 ON FACE OF FORM.

14. ADD 12 AND 13 ALGEBRAICALLY.

15. ENTER VALUE UNDER 11 ON FACE OF FORM.

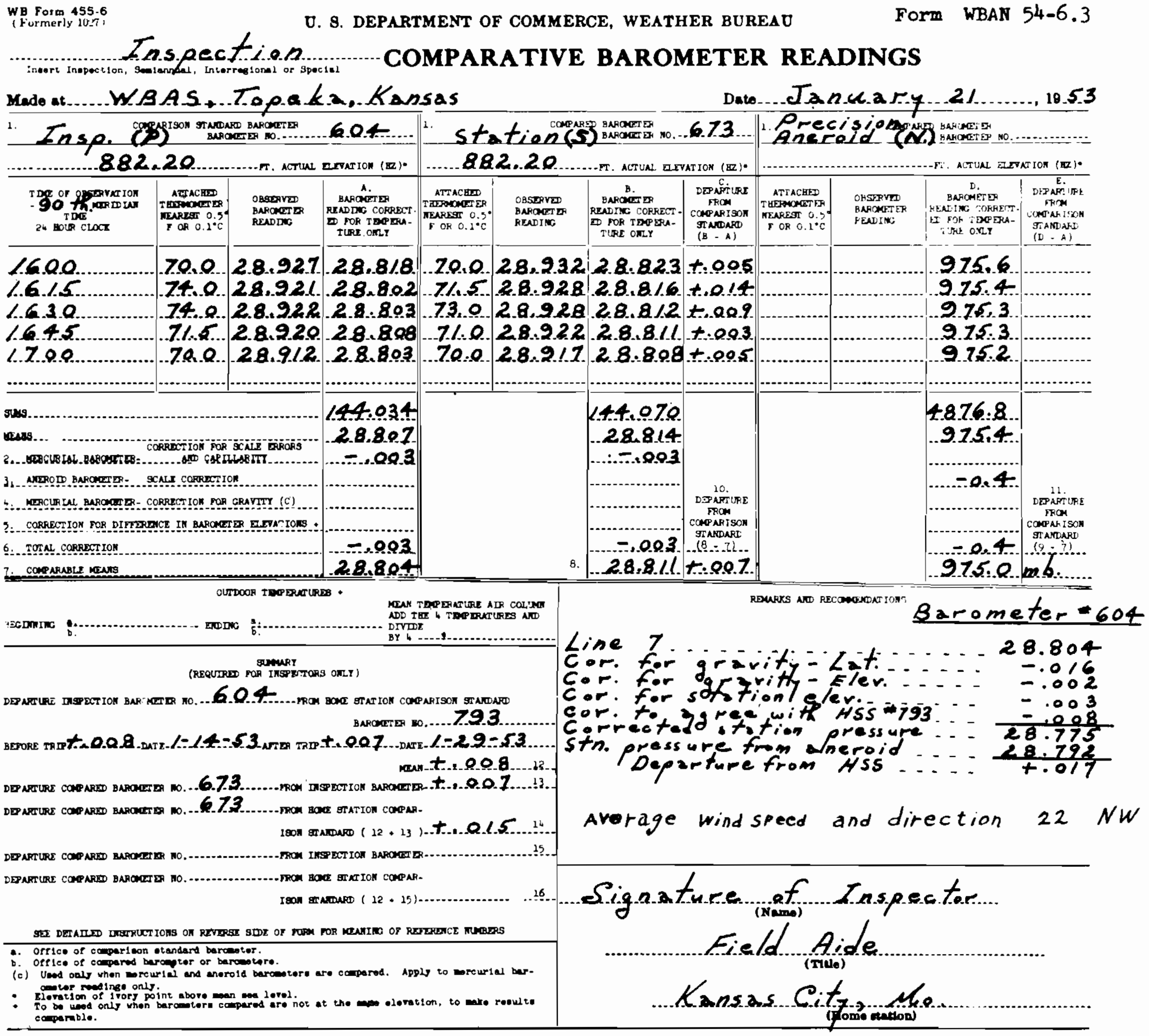
16. ADD 12 AND 15 ALGEBRAICALLY.

INTERREGIONAL BAROMETER COMPARISONS

FORM WBAN 54-6.3 WILL ALSO BE USED FOR INTERREGIONAL BAROMETER COMPARISONS BUT THE FORM MAY BE ADAPTED FOR USE ACCORDING TO THE CIRCUMSTANCES. HEADINGS MAY BE CHANGED OR DELETED AND THE SUMMARY IS NOT REQUIRED.

REMARKS

FIGURE 6.5.2. Comparative barometer readings: illustration of the reverse side of Form WBAN 54-6.3 where instructions are given for its preparation.



WB Form 455-6
(Formerly 1027)

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

Form WBAN 54-6.3

Inspection COMPARATIVE BAROMETER READINGS
Insert Inspection, Semiannual, Interregional or Special

Made at WBAS, Topaka, Kansas Date January 21, 1953

1. Insp. (P) COMPARISON STANDARD BAROMETER BAROMETER NO. 604				1. Station (S) COMPARED BAROMETER BAROMETER NO. 673				1. Precision Aneroid (N) COMPARED BAROMETER BAROMETER NO.			
882.20 FT. ACTUAL ELEVATION (HZ)*				882.20 FT. ACTUAL ELEVATION (HZ)*				FT. ACTUAL ELEVATION (HZ)*			
TIME OF OBSERVATION 90 th MERIDIAN TIME 24 HOUR CLOCK	ATTACHED THERMOMETER NEAREST 0.5° F OR 0.1°C	OBSERVED BAROMETER READING	A. BAROMETER READING CORRECTED FOR TEMPERATURE ONLY	ATTACHED THERMOMETER NEAREST 0.5° F OR 0.1°C	OBSERVED BAROMETER READING	B. BAROMETER READING CORRECTED FOR TEMPERATURE ONLY	C. DEPARTURE FROM COMPARISON STANDARD (B - A)	ATTACHED THERMOMETER NEAREST 0.5° F OR 0.1°C	OBSERVED BAROMETER READING	D. BAROMETER READING CORRECTED FOR TEMPERATURE ONLY	E. DEPARTURE FROM COMPARISON STANDARD (D - A)
1600	70.0	28.927	28.818	70.0	28.932	28.823	+.005			975.6	
1615	74.0	28.921	28.802	71.5	28.928	28.816	+.014			975.4	
1630	74.0	28.922	28.803	73.0	28.928	28.812	+.009			975.3	
1645	71.5	28.920	28.808	71.0	28.922	28.811	+.003			975.3	
1700	70.0	28.912	28.803	70.0	28.917	28.808	+.005			975.2	

	A	B	10. DEPARTURE FROM COMPARISON STANDARD (8 - 7)	D	11. DEPARTURE FROM COMPARISON STANDARD (9 - 7)
SUMS	144.034	144.070		4876.8	
MEANS	28.807	28.814		975.4	
2. MERCURIAL BAROMETER: CORRECTION FOR SCALE ERRORS AND CAPILLARITY	-.003	-.003			
3. ANEROID BAROMETER- SCALE CORRECTION				-0.4	
4. MERCURIAL BAROMETER- CORRECTION FOR GRAVITY (C)					
5. CORRECTION FOR DIFFERENCE IN BAROMETER ELEVATIONS ◆					
6. TOTAL CORRECTION	-.003	-.003		-0.4	
7. COMPARABLE MEANS	28.804	8. 28.811	+.007	975.0 mb.	

OUTDOOR TEMPERATURES ◆

BEGINNING a. b. ENDING a. b. MEAN TEMPERATURE AIR COLUMN ADD THE 4 TEMPERATURES AND DIVIDE BY 4 9

SUMMARY
(REQUIRED FOR INSPECTORS ONLY)

DEPARTURE INSPECTION BAROMETER NO. 604 FROM HOME STATION COMPARISON STANDARD BAROMETER NO. 793

BEFORE TRIP +.008 DATE 1-14-53 AFTER TRIP +.007 DATE 1-29-53

MEAN +.008 12

DEPARTURE COMPARED BAROMETER NO. 673 FROM INSPECTION BAROMETER +.007 13

DEPARTURE COMPARED BAROMETER NO. 673 FROM HOME STATION COMPARISON STANDARD (12 + 13) +.015 14

DEPARTURE COMPARED BAROMETER NO. FROM INSPECTION BAROMETER 15

DEPARTURE COMPARED BAROMETER NO. FROM HOME STATION COMPARISON STANDARD (12 + 15) 16

SEE DETAILED INSTRUCTIONS ON REVERSE SIDE OF FORM FOR MEANING OF REFERENCE NUMBERS

a. Office of comparison standard barometer.
b. Office of compared barometer or barometers.
(c) Used only when mercurial and aneroid barometers are compared. Apply to mercurial barometer readings only.
* Elevation of ivory point above mean sea level.
◆ To be used only when barometers compared are not at the same elevation, to make results comparable.

REMARKS AND RECOMMENDATIONS

Barometer #604

Line 7	28.804
Cor. for gravity - Lat.	-.016
Cor. for gravity - Elev.	-.002
Cor. for station elev.	-.003
cor. to agree with HSS #793	-.008
Corrected station pressure	28.775
Stn. pressure from aneroid	28.792
Departure from HSS	+.017

Average wind speed and direction 22 NW

Signature of Inspector
(Name)

Field Aide
(Title)

Kansas City, Mo.
(Home station)

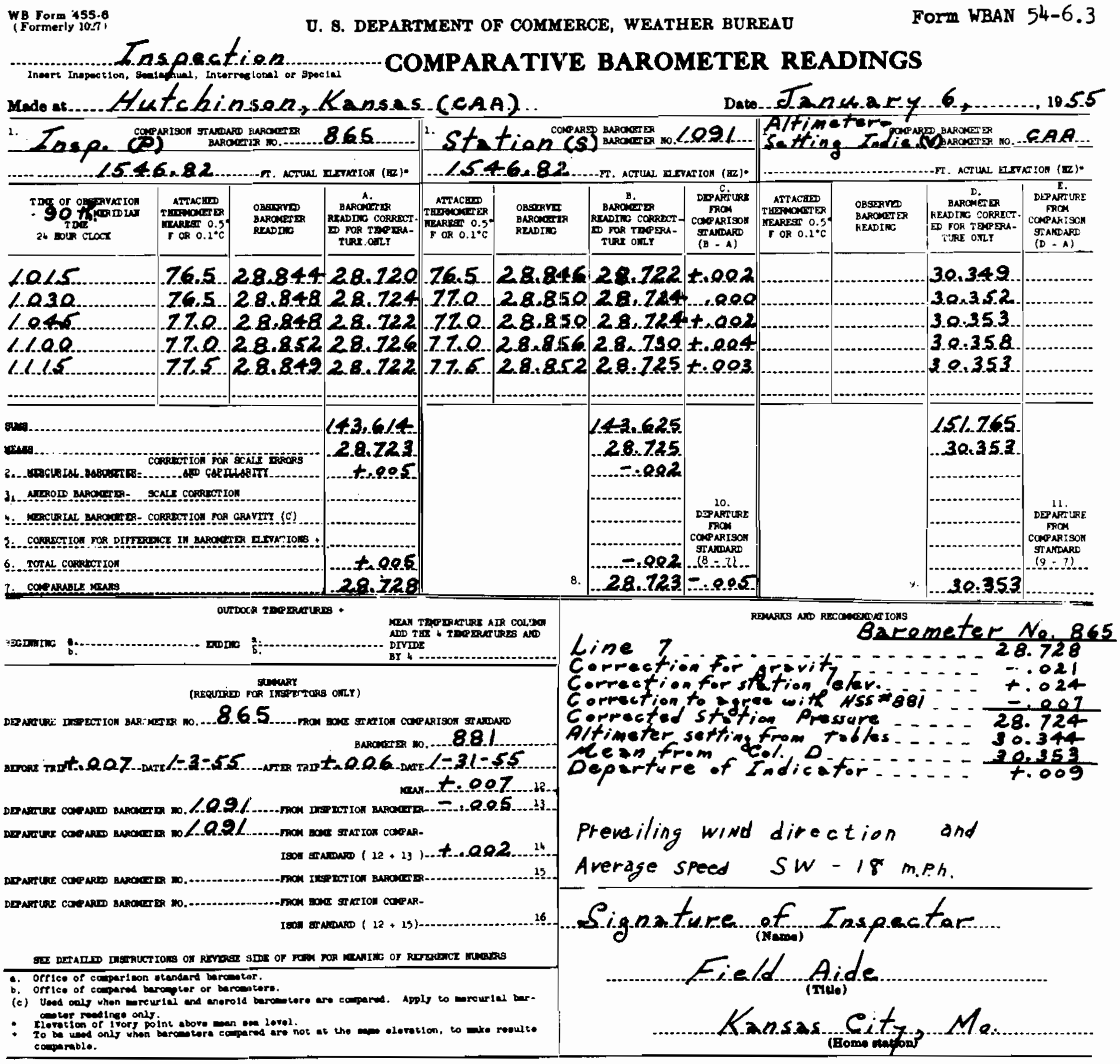
FIGURE 6.5.3. Comparative barometer readings: portable inspection Fortin-type mercurial barometer (*P*) compared with station mercurial (*S*) and precision aneroid (*N*) barometers during an inspector's visit.

sible, at least two hours after the disturbance.

In case a station barometer ("*S*") is to be cleaned, comparative barometer readings between "*P*" (and/or "*N*") and "*S*" should be made both before and several hours after the cleaning operation. When the results of these comparisons are such as to imply that the vacuum has been rendered defective (as when a marked algebraic increase occurs in the difference "*P*" — "*S*") the instrument "*S*" should be taken out of service and replaced.

Similarly, in case a mercurial barometer at a station is moved from one place to another, comparative barometer readings should be made before and after the move. If time is available, it is preferable to allow several hours to elapse after the move before making the second set of readings, as this may permit the instrument to become better stabilized (for example, if small bubbles of air on the inside of the glass tube have been dislodged by the move and work their way up for a time).

If it has been less than six months since the last set of comparisons was made and none of the criteria listed in paragraphs (a) —(e), above, are satisfied, comparative barometer readings need not be made by the



WB Form 455-6
(Formerly 1027)

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

Form WBAN 54-6.3

Inspection COMPARATIVE BAROMETER READINGS
Insert Inspection, Semiannual, Interregional or Special

Made at Hutchinson, Kansas (CAA)
Date January 6, 1955

1. Insp. (P) COMPARISON STANDARD BAROMETER BAROMETER NO. 865
1546.82 FT. ACTUAL ELEVATION (HZ)*

1. Station (S) COMPARED BAROMETER BAROMETER NO. 1091
1546.82 FT. ACTUAL ELEVATION (HZ)*

1. Altimeter-Setting Indic. (V) COMPARED BAROMETER BAROMETER NO. CAA
FT. ACTUAL ELEVATION (HZ)*

TIME OF OBSERVATION - 90th MERIDIAN TIME 24 HOUR CLOCK	ATTACHED THERMOMETER NEAREST 0.5° F OR 0.1°C	OBSERVED BAROMETER READING	A. BAROMETER READING CORRECTED FOR TEMPERATURE ONLY	ATTACHED THERMOMETER NEAREST 0.5° F OR 0.1°C	OBSERVED BAROMETER READING	B. BAROMETER READING CORRECTED FOR TEMPERATURE ONLY	C. DEPARTURE FROM COMPARISON STANDARD (B - A)	ATTACHED THERMOMETER NEAREST 0.5° F OR 0.1°C	OBSERVED BAROMETER READING	D. BAROMETER READING CORRECTED FOR TEMPERATURE ONLY	E. DEPARTURE FROM COMPARISON STANDARD (D - A)
1015	76.5	28.844	28.720	76.5	28.846	28.722	+.002			30.349	
1030	76.5	28.848	28.724	77.0	28.850	28.724	.000			30.352	
1045	77.0	28.848	28.722	77.0	28.850	28.724	+.002			30.353	
1100	77.0	28.852	28.726	77.0	28.856	28.730	+.004			30.358	
1115	77.5	28.849	28.722	77.6	28.852	28.725	+.003			30.353	
SUMS			143.614			143.625				151.765	
MEANS			28.723			28.725				30.353	
2. MERCURIAL BAROMETER- CORRECTION FOR SCALE ERRORS AND CAPILLARITY			+.005			-.002					
3. ANEROID BAROMETER- SCALE CORRECTION											
4. MERCURIAL BAROMETER- CORRECTION FOR GRAVITY (C)							10. DEPARTURE FROM COMPARISON STANDARD (8 - 7)				11. DEPARTURE FROM COMPARISON STANDARD (9 - 7)
5. CORRECTION FOR DIFFERENCE IN BAROMETER ELEVATIONS +											
6. TOTAL CORRECTION			+.005			-.002					
7. COMPARABLE MEANS			28.728		8.	28.723	-.005		9.	30.353	

OUTDOOR TEMPERATURES +

BEGINNING a. b. ENDING a. b.

MEAN TEMPERATURE AIR COLUMN ADD THE 4 TEMPERATURES AND DIVIDE BY 4

SUMMARY
(REQUIRED FOR INSPECTORS ONLY)

DEPARTURE INSPECTION BAROMETER NO. 865 FROM HOME STATION COMPARISON STANDARD BAROMETER NO. 881

BEFORE TRIP +.007 DATE 1-3-55 AFTER TRIP +.006 DATE 1-31-55

MEAN +.007 12

DEPARTURE COMPARED BAROMETER NO. 1091 FROM INSPECTION BAROMETER -.005 13

DEPARTURE COMPARED BAROMETER NO 1091 FROM HOME STATION COMPARISON STANDARD (12 + 13) +.002 14

DEPARTURE COMPARED BAROMETER NO. FROM INSPECTION BAROMETER 15

DEPARTURE COMPARED BAROMETER NO. FROM HOME STATION COMPARISON STANDARD (12 + 15) 16

SEE DETAILED INSTRUCTIONS ON REVERSE SIDE OF FORM FOR MEANING OF REFERENCE NUMBERS

a. Office of comparison standard barometer.
b. Office of compared barometer or barometers.
(c) Used only when mercurial and aneroid barometers are compared. Apply to mercurial barometer readings only.
* Elevation of ivory point above mean sea level.
\+ To be used only when barometers compared are not at the same elevation, to make results comparable.

REMARKS AND RECOMMENDATIONS

Barometer No. 865

Line 7	28.728
Correction for gravity	-.021
Correction for station elev.	+.024
Correction to agree with HSS #881	-.007
Corrected Station Pressure	28.724
Altimeter setting from tables	30.344
Mean from Col. D	30.353
Departure of Indicator	+.009

Prevailing wind direction and
Average speed SW - 18 m.p.h.

Signature of Inspector
(Name)

Field Aide
(Title)

Kansas City, Mo.
(Home station)

FIGURE 6.5.4. Comparative barometer readings: portable inspection Fortin-type mercurial barometer (*P*) compared with station mercurial (*S*) barometer and altimeter-setting indicator (*V*) during an inspector's visit.

inspector unless, in his judgment, some other circumstance not covered here warrants the making of a special set of comparisons.

6.5.5 Tapping of the Barometer

In order to secure normal effects due to capillarity at the meniscus in the cistern and barometer tube, respectively, and in order to obtain reproducible results under all conditions, it is necessary to tap the barometer in accordance with an approved, standardized procedure as described below. Thus, in the case of Fortin barometers, the metal portion of the cistern should be tapped lightly when the surface of the mercury in the cistern reaches a level of about 1/16th of an inch below the ivory point during the course of the adjustment, but it is undesirable to tap the cistern *after* this stage is reached in raising the mercury; instead, the mercury must be raised by means of the adjusting screw above this level *without tapping* until the mercury surface in the cistern just perceptibly makes contact with the ivory point as indicated by a dimple. The metal sheath surrounding the barometer tube should be tapped lightly in the vicinity of the meniscus in the tube just after the cistern is tapped and *also* immediately before setting the vernier for the purpose of making a reading. In the case of fixed-cistern barometers, the cistern should be tapped just before setting the vernier as described in the previous sentence. Observers should bear in mind the fact that failure to carry out the foregoing procedure in a standard manner can yield discrepancies.

The result may be understood by virtue of the fact that accommodation of the meniscus to the rising or falling motions of the mercury will ordinarily govern the final height, contact angle, and form which the meniscus will assume under the given conditions if a standard tapping procedure is not employed. The height, contact angle, and form will then differ from those which were obtained in the laboratory where a standard tapping procedure was used at the time of the calibration for the purpose of determining the correction for scale error and capillarity. In that event, an inconsistency will exist and readings will suffer from some unknown error since the value of the correction will not strictly apply under these conditions. (See sec. 2.7.1.)

6.5.6 Preparation and Disposition of Form WBAN 54–6.3

Form WBAN 54–6.3 entitled "Comparative Barometer Readings" should be prepared in accordance with the instructions given on the reverse side of the form (see fig. 6.5.2 for instructions, and figs. 6.5.1, 6.5.3, and 6.5.4 for examples of entries on the face of the form). The form may be prepared either on a typewriter, or by longhand, provided care is taken to make all entries on the form clearly legible.

Disposition of copies of the completed Form WBAN 54–6.3 should be made in accordance with the following instructions:

(1) *Weather Bureau.*—The original completed form is to be promptly mailed to the Central Office in an envelope marked "Form WBAN 54–6.3 for Instrumental Engineering Division," and one copy is to be retained for the station file.

(2) *Air Force.*—The original completed copy is to be filed at the regional maintenance shop, and one copy is to be retained at the station.

(3) *Navy.*—The original completed copy is to be filed at the facility responsible for the supervision and calibration of the equipment, and one copy is to be retained at the station.

6.5.7 Action Dependent Upon Variation in Inspection Barometer

Comparison of the portable inspector's barometers with the home station standard barometer (usually category "*C*") is necessary both before he leaves on a field trip and after his return. The same precautions must be taken for these comparisons as for those made at field stations. If the departure of the inspector's barometer from the home station standard barometer is consistent within 0.005 inch of mercury for the comparisons made before and after the trip, the average of the two departures will be used as the mean, representative departure for the trip; for example, see entry item 12 on Form WBAN 54–6.3 (WB Form 455–6).

However, when the difference between the departures before and after the trip falls outside the 0.005 inch Hg limit, a second set of comparisons should be made under favorable conditions at least a day after the first set which was made immediately following the completion of the trip. The purpose of the second set is to determine whether the first set will be confirmed, within a few thousandths of an inch Hg. If it is confirmed, suitable special notations should be made on the form, pointing out emphatically and clearly the relatively large discrepancy found between the departures observed before and after the trip. On the other hand, if the second set does not confirm the first set, the matter should be explored further to determine which set is most nearly correct, by further comparisons if necessary. The results thus found should be explained under "Remarks" and on a memorandum with related forms, attached.

6.5.8 Tolerance Regarding Departure of "*S*" from "A_r"

The departure of a compared barometer (category '*S*'") at a station from the home station comparison standard barometer (see item 16 on Form WBAN 54–6.3, WB Form

455–6) gives an indication of the closeness with which the two instruments agree. When account is taken of the deviation of the home station comparison standard barometer from the absolute standard (primary) barometer of the United States (category "A_r") it is possible to determine the departure of "S" from "A_r". A tolerance regarding the permissible maximum departure of "S" from "A_r" is established, namely 0.020 inch of mercury (0.68 mb.). As a rule, when "S" deviates from "A_r" by more than 0.020 inch of mercury, it is considered that the barometer is defective, possibly owing to imperfect vacuum above the meniscus in the barometer tube, or pollution of the mercury in the cistern with resultant change of capillarity and adhesion of foreign material to the ivory point.

If two or more comparisons made on different trips within a few years yield values of the departure of "S" from "A_r" which agree within 0.005 inch of mercury and are within the tolerance (0.020 in. Hg), this permits determination of a fairly reliable mean departure. The "residual correction" will be determined on such a basis (see sec. 4.4).

6.5.9 Action When Tolerance Is Exceeded

When "S" deviates from "A_r" by more than 0.020 inch of mercury, consideration should be given to regarding "S" as defective and to replacing it with a mercurial barometer which will yield agreement within the acceptable tolerance. Field inspectors should make recommendations regarding replacement when the deviation of "S" from "A_r" appears to exceed the tolerance; but final decision and action on the matter rests with the central instrument laboratory of the agency at whose station the barometer "S" is located. Appropriate notes regarding recommendations and action taken by field inspectors should be written on the form giving the "Comparative Barometer Readings" and on any other pertinent report sheets concerning the field trip.

6.5.10 Detailed Rules for Completion of Forms

6.5.10.1 General.—The form for "Comparative Barometer Readings" should be used for entering data pertinent to comparisons of all types of pressure-measuring instruments, including the mercurial barometer, the aneroid barometer, and the altimeter-setting indicator, as illustrated by figs. 6.5.1, 6.5.3 and 6.5.4. Those preparing the form should carefully observe the following principles or guiding rules:

(A) Precision of comparative readings should be to the nearest 0.001 inch of mercury; or barring this, to the last estimated decimal figure of the instrument scale (for example, to the nearest 0.05 mb.).

(B) With regard to the comparative readings of mercurial barometers, these should first be corrected for temperature, and resultant sums and means taken. (See columns headed A, B, and D on fig. 6.5.1 and the two lines marked "Sums" and "Means" immediately under the block of five readings.)

(C) In those columns pertaining to mercurial barometer data the "Correction for Scale Error and Capillarity" should be entered next (see line marked 2 on figs. 6.5.1, 6.5.3, and 6.5.4, the line marked 3 being blank); but in those columns pertaining to aneroid barometers, the scale correction should be entered (see line marked 3 on fig. 6.5.3, the line marked 2 being blank). In the first case the "Correction for Scale Error and Capillarity" will be found recorded on the "Barometer Correction Card"; and in the second case the aneroid barometer "Scale Correction" is usually given on the calibration curve. When no calibration curve is available, no entry is made in the space labeled "Aneroid Barometer-Scale Correction."

(D) Omit an entry in the space labeled "Mercurial Barometer-Correction for Gravity" in case all of the barometers being compared are mercurial. Fill in the space appropriately under the mercurial barometer data in case a single mercurial barometer is compared with one or more aneroid barometers or altimeter-setting indicators; and in that case do *not* fill in the space under the data for aneroid barometers and altimeter-setting indicators. (See line marked 4 on figs. 6.5.1, 6.5.3, and 6.5.4; and note Detailed Instructions under item 4 on fig. 6.5.2). Also, if comparative data for *two* mercurial barometers together with one aneroid barometer or one altimeter-setting indicator are presented on the form, do *not* fill in the space labeled "Mercurial Barometer-Correction for Gravity" under any column. However, as indicated in figs. 6.5.3 and 6.5.4, special computations are entered under "Remarks and Recommendations" in these cases.

(E) A "Correction for Difference in Barometer Elevations" (see line marked 5 on figs. 6.5.1, 6.5.3, and 6.5.4) is only entered if "Comparison Standard Barometer" is at a different elevation than the "Compared Barometer." When the two instruments are at different elevations, the correction referred to represents a "removal correction." This can be calculated by use of the data given in Table 4.1.1. In order to compute the correction one must know the difference in elevation between the two barometers, and the mean temperature of the intervening air column. (See sec. 6.5.11 for more details; also see Chapter 4; especially sec. 4.3, sample computation of "removal correction.")

(F) The term "Total Correction" pertinent to the form is explained in item 6 under "Detailed Instructions" on the reverse side of the form (see fig. 6.5.2).

(G) The term "Comparable Means" referred to on the form (see items 7, 8, and 9 of figs. 6.5.1, 6.5.2, 6.5.3, and 6.5.4) represents the algebraic sum of the "Means" (second line) and the "Total Correction" (item 6).

(H) Departures of the "Compared Barometer" from the "Comparison Standard Barometer" are next entered only if both instruments are of mercurial type (see entry items 10 and 11, fig. 6.5.1). The entry is *not* made in the columns pertaining to aneroid barometers and altimeter setting indicators (see figs. 6.5.3 and 6.5.4).

(I) The "Summary" (Required for Inspectors Only) on the form is limited to data pertaining only to mercurial barometers. (See figs. 6.5.1, 6.5.3, and 6.5.4.)

6.5.10.2 Aneroid Barometers.—When an aneroid barometer is compared with the "Inspection Barometer," the special computations under "Remarks and Recommendations" will contain the following data (see fig. 6.5.3), including appropriate algebraic signs:

(a–1) The "Comparable Means" (line 7) for the "Inspection Barometer."

(b–1) The correction for gravity. (If the "Barometer Correction Card" shows it in two components, as a term for latitude and a term for elevation, these terms may be given separately. The correction for gravity is pertinent only if the barometer is mercurial.)

(c–1) The "removal correction," or correction to allow for the difference in elevation between the zero point of the Inspection Barometer and the station elevation (H_p).

(d–1) The correction which must be applied to the Inspection Barometer in order to make it agree with the "Home Station Comparison Standard Barometer" (*HSS*). (It should be noted that this correction has the opposite algebraic sign to that of the mean departure of the Inspection Barometer from the "Home Station Comparison Standard." See entry item 12 on fig. 6.5.3.)

(e–1) The corrected station pressure, based on the algebraic sum of the items listed above under paragraphs (a–1) to (d–1).

(f–1) The station pressure as obtained from the mean of the five comparative aneroid barometer readings with the appropriate "scale correction" applied. In this case the "scale correction" represents the total correction which has been applied in daily practice to the aneroid barometer readings at the station in order to obtain the station pressure.

(g–1) The departure of the thus-obtained "station pressure" from the "Home Station Comparison Standard Barometer" ("*HSS*").

The central instrument laboratory of the agency involved is responsible for determining the departure of "*HSS*" from "A_r". After this has been done, the algebraic addition of item (g–1) to the departure of "*HSS*" from "A_r" will give the departure of the "station pressure" from "A_r", where "station pressure" here denotes the values based on *corrected* aneroid readings, as explained under paragraph (f–1) above. Thus, if the departure of "station pressure" from "A_r" has been found, it could be applied with the *opposite* algebraic sign to the "station pressure" data in order to obtain results compatible with the readings of the primary barometer. (See sec. 6.7.)

6.5.10.3 Altimeter-Setting Indicators.—Comparative Barometer Readings pertaining to Altimeter-Setting Indicators are evaluated in the manner shown in fig. 6.5.4. The following entries will be made in the space under "Remarks and Recommendations" in this case:

(a–2) The "comparable means" based on the comparative barometer readings obtained from the Inspection Barometer (line 7).

(b–2) The correction for gravity pertaining to the station mercurial barometer. (See relevant comments under paragraph (b–1), above.)

(c–2) The "removal correction". (See pertinent comments under paragraph (c–1), above.)

(d–2) The correction which must be applied to the Inspection Barometer in order to make it agree with the "Home Station Comparison Standard Barometer." (See comments under paragraph (d–1) above.)

(e–2) The corrected station pressure based on the algebraic sum of the items listed above under paragraphs (a–2) to (d–2), inclusive.

(f–2) The proper altimeter setting which corresponds to the corrected station pressure described in paragraph (e–2). (It is possible to obtain the proper altimeter setting here intended by referring to the pressure-reduction computer or altimeter-setting tables. These yield the altimeter setting as a function of corrected station pressure. Another alternative is to calculate the altimeter setting in the manner described in sec. 8.1.)

(g–2) The mean of the comparative readings of the altimeter-setting indicator.

(h–2) The departure of the entry described in paragraph (g–2) from the entry described in paragraph (f–2); this representing the departure of the altimeter-setting indicator ("*V*") from "*HSS*"; that is, the departure here involved is item (g–2) *minus* item (f–2).

Assuming that the responsible central instrument laboratory has determined the departure of "*HSS*" from "A_r", the algebraic application of this result to the departure described in paragraph (h–2) will yield the departure of "*V*" from "A_r". When the latter departure is applied with *opposite* algebraic sign to the readings of "*V*" it will give results in harmony with those of the primary barometer "A_r". (See sec. 6.8.)

6.5.11 Barometer Comparisons Involving Airport Station and City Office

Consider the case in which a field inspector visits an Airport Station in an area where there is also located a Weather Bureau City Office, or other meteorological installation. In this case it is desirable that simultaneous comparative barometer readings be obtained at both places while the Inspection Barometer is being compared with the pressure measuring instruments located at the Airport Station.

Arrangements can be made by telephone to have the readings made simultaneously at the two stations in accordance with a predetermined schedule of observations, say at 15 minute intervals by synchronized clocks.

Since the actual barometer elevations at the two stations are generally different, a suitable correction for difference in elevation must be taken into account to render the results comparable. The correction for difference in elevation is contained on Form WBAN 54–6.5 (see for example, WB Form 455–11; formerly WB Form 1060).

Effectively, the correction for difference in elevation is a variable "removal correction" which is a function of the mean outdoor temperature at the two locations; the normal annual mean pressure at the level midway between the points; and the difference between the actual barometer elevations at the Airport Station and City Office (or other meteorological installation), respectively. The data shown on Form WBAN 54–6.5 are calculated with the aid of Table 4.1.1. Thus, if H_{za} denotes the actual barometer elevation at Airport Station and H_{zc} denotes the actual barometer elevation at the City Office (or other meteorological installation), it is first necessary to ascertain the difference $(H_{za} - H_{zc})$ in order to calculate the correction. The correction is computed in the same manner as the "variable removal correction" discussed in sec. 4.2 and 4.3, except that for present purposes H_{za} and H_{zc} are used in place of H_z and H_p, respectively, referred to in sec. 4.2 and 4.3. Note should be made of the proper algebraic sign, which is the same as the sign of the difference $(H_{za} - H_{zc})$, since the correction is designed to be applied algebraically to the readings at the Airport Station in order to obtain data comparable to the readings made at the City Office (or other meteorological installation).

Fig. 6.5.5 illustrates two cases involving opposite signs of the corrections. The users should take careful note that if either H_{za} or H_{zc} is changed, the corrections must be revised, and a new Form WBAN 54–6.5 must be issued.

Two other precautions should be kept in mind: (a) if there is a considerable horizontal distance between the two stations, the existence of a horizontal gradient of pressure may make the calculated correction unrepresentative; and (b) if there is a considerable vertical distance between the stations, the effect of variable pressure which is neglected may introduce an error.

In case (a), the results could be improved if the horizontal gradient of pressure at the mean elevation between H_{za} and H_{zc} under the given meteorological situation were known, and proper allowance taken for the effect of the gradient. In case (b), it is possible to make some improvement in the corrections by preparing a special table for reduction of pressure between the levels H_{za} and H_{zc}, where pressure at H_{za} and mean temperature of the air column are the arguments. Such a special table may be prepared with the aid of the material presented in conjunction with sec. 7.3. However, a note of caution is necessary where great precision and accuracy are desired, especially in regions having rugged terrain, marked temperature discontinuities between air masses, and strong winds.

6.5.12 Comparisons at Headquarters Station

The headquarters station for the field inspector shall have either a large bore (category "*C*") or, lacking this, a station-type mercurial barometer of good quality to be used for comparative purposes at the station. This instrument is identified as the "Home Station Comparison Standard" (*HSS*). It shall be considered a permanent installation and is not to be used for field trips under any circumstances.

Inspection barometers shall be subjected to comparative readings with the "Home Station Standard" (*HSS*) within a day or two of the beginning and end of field trips.

In conjunction with these comparisons, simultaneous readings should also be taken of the regular station mercurial barometer and extra mercurial barometer, if any, at intervals not to exceed one month. The data thus obtained will serve as a control on the performance of the "Home Station Standard."

6.5.13 Rendition of Forms

Forms WBAN 54–6.3 relating to Comparative Barometer Readings should be carried or forwarded promptly to immediate higher headquarters as soon as there is no longer any need for the data in making entries under "Summary" on the forms for the trip immediately following or preceding the latest comparisons with the "Home Station Comparison Standard Barometer." The forms being forwarded should be arranged in chronological order with the most recent comparisons at the bottom.

6.5.14 Determination of "Residual Corrections"

The central instrument laboratory of the agency involved, as the case may be, will review the results of the barometer comparisons and determine whether a "residual correction" should be applied to the station barometer readings (see sec. 4.4).

6.6 COMPARISON OF STATION BAROMETERS

6.6.0 General Instructions

Intercomparisons of all pressure-measuring instruments is required on a regular schedule at half-yearly intervals. The intent of this is to include comparisons between the instruments at single stations, and simultaneously at stations in pairs or larger groups in a given locality, wherever practicable. (See sec. 6.5.11.) Data obtained from such periodic checks will permit maintaining a control on the internal consistency of the pressure readings for the various units involved. Other comparisons are also required under the following circumstances (see sec. 6.5.4):

(a) When any of the pressure-measuring instruments show unsatisfactory performance, or their accuracy is questioned;
(b) When any of the instruments are relocated, or there is a new installation;
(c) When any of the instruments have been subjected to a serious disturbance, shock, unusual movement, or other adverse condition or treatment.

6.6.1 Dates, Times, and Conditions for Regular Comparisons

Regular barometer comparisons should be scheduled semi-annually on the first workday after March 14 and September 14. The dates may be deferred from one to several days if unfavorable conditions exist on the regularly scheduled day. In this case the readings should be made on the next day yielding favorable conditions. The times of day selected for the readings should be arranged for the mutual convenience of the parties involved, provided that the conditions are then suitable for the obtainment of reliable results. Favorable conditions are regarded as those characterized by "barometrically quiet" traces on the microbarograph; that is, periods of steady pressure, or change of pressure at a fairly steady, slow rate, not exceeding 0.05 inch of mercury per hour, with no abrupt discontinuities in rate of change leading to marked, sudden variations of pressure ("jumps"). Periods with severe storms or winds over 20 miles per hour are considered unfavorable (see secs. 2.11 and 6.5.2), since stormy conditions and gusty winds produce significant fluctuations of pressure as measured within buildings. The attendant "jumps" of pressure yield inconsistent data for readings taken in different rooms or buildings, and at different moments of time.

It is important that the readings on the different instruments which are compared should be as nearly simultaneous as practicable, usually within about one minute. Clocks and watches should be synchronized.

If air-conditioning equipment is used in either or both buildings where the barometers are installed, it is desirable to have a door or window open, if practicable, in each building involved, at the time of the comparative observations.

6.6.2 Correction for Difference in Barometer Elevations

When the barometers at two or more stations in a given locality are to be compared simultaneously, it is an established practice to apply a "correction for the difference in elevation" to the results obtained at the Airport Station in order to obtain data directly comparable to those secured from the readings at the City Office or other meteorological installation. The "correction for the difference in elevation" pertinent to comparative barometer readings must be based upon the difference between the actual elevations of the barometers (H_z) at the stations involved. Form WBAN 54–6.5 containing the appropriate "corrections for difference in elevation" as a function of temperature should be on hand before the comparisons are made. Examples of the correction are shown in sec. 6.5.11 (fig. 6.5.5). Instructions contained in that section should be carefully observed under the circumstances outlined.

Case I

Actual barometer elevation at Airport Station; H_{za} = 148 gpft.

Actual barometer elevation at City Office; H_{zc} = 182 gpft.

Mean of outdoor temperatures at two stations	Correction *
°F	(inches of mercury)$_n$
-20°	-0.043
-10°	-0.042
0°	-0.041
+10°	-0.040
20°	-0.039
30°	-0.039
40°	-0.038
50°	-0.037
60°	-0.036
70°	-0.036
80°	-0.035
90°	-0.034
100°	-0.034

Case II

Actual barometer elevation at Airport Station; H_{za} = 963 gpft.

Actual barometer elevation at City Office; H_{zc} = 880 gpft.

Mean of outdoor temperatures at two stations	Correction *
°F	(inches of mercury)$_n$
-20°	+0.102
-10°	+0.100
0°	+0.098
+10°	+0.096
20°	+0.094
30°	+0.092
40°	+0.090
50°	+0.088
60°	+0.087
70°	+0.085
80°	+0.083
90°	+0.082
100°	+0.080

* Correction to be applied to corrected mean (actual pressure) given on WB FORM 455-6 for Airport Station at ________ (name) ________ H_z __________ feet to secure value directly comparable with similar simultaneous pressure datum for City Office at ________ (name) ________ H_z __________ feet.

FIGURE 6.5.5. Correction of pressure readings for difference of elevation.

The "mean temperature of the air column" to be used in referring to the correction table on Form WBAN 54–6.5 is based on the outdoor temperatures at the two stations, evaluated as the mean at the time of the beginning and ending of the set of five comparative barometer readings for the two places (see block headed "Outdoor Temperatures" on Form WBAN 54–6.3). Data on Form WBAN 54–6.5 will normally be prepared and supplied by the appropriate headquarters. However, in an emergency the station personnel may compute the necessary data for temporary use (see sec. 6.5.11), provided that they submit the results to the appropriate headquarters for checking at the termination of the immediate emergency.

When the difference in actual elevation of the barometers at the two stations exceeds 100 feet, both *the existing station pressure at the Airport* and *the mean outdoor temperature* should be used as arguments in determining the "correction for difference in elevation." In that case, it is necessary to obtain the appropriate correction from a special table prepared for the purpose, since the data based only on the latter argument (as illustrated in fig. 6.5.5) are then inadequate. Under normal procedures the special table will be prepared and supplied by appropriate headquarters, but in an emergency the station personnel may compute the table of corrections for difference in elevation, provided that the official in charge submits the table to the headquarters for verification at the end of the immediate emergency. The special table will be calculated with the aid of data contained in Table 7.5, provided that the actual barometer elevations (H_z) for the two stations are first converted to geopotentials by means of the procedures outlined in sec. 1.3, and the difference between these geopotentials is taken as the argument for geopotential in referring to Table 7.5. In addition, the "mean virtual temperature of the air column, T_{mv}" will include a correction for humidity derived from Tables 7.6.1 and 7.6.2; that is, this correction will be added to the mean outdoor temperature to obtain T_{mv}. Further details will be found in Chapter 7 under sec. 7.3 headed "Reduction of Pressure Downward or Upward to any Level in General."

6.6.3 Detailed Instructions for the Comparisons

The procedures outlined in sec. 6.5 should be followed in so far as relevant to the situation at hand.

For each reading with the Fortin-type barometer, the thumbscrew at the bottom of the instrument must be adjusted until the surface of the mercury in the cistern just touches the tip of the ivory point (see "Manual of Surface Observations," paragraph 7110, and sec. 2.4.2 of this manual for further details). Tapping of the barometer should be performed in accordance with instructions in sec. 6.5.5. The observer should make the readings carefully and methodically, followed by entry of data on the record form. Every reading and entry should be checked by re-scrutiny of the meniscus settings, scale and vernier readings, and entries. (*Note:* As a test in regard to the repeatability of barometer adjustments, meniscus settings, and readings, it is a worth-while experiment to have several observers perform the operations separately in rapid succession and to compare results. This is especially desirable when new observers come to the station. Repetitions of the test under convenient, favorable conditions will tend to promote the obtainment of consistent results. An important source of error has been found to be the failure of some observers to set the base of the vernier precisely tangent to the top of the meniscus in the barometer tube when the line of sight is level.)

Data obtained from the readings should be entered on Form WBAN 54–6.3 "Comparative Barometer Readings," in accordance with the pertinent instructions in sec. 6.5. Figs. 6.5.1, 6.5.3, and 6.5.4 may be regarded as samples of the form prepared for the semi-annual comparisons, except that the data relating to the inspection barometer may be replaced by those pertinent to the station mercurial barometer. Information on the reverse side of Form WBAN 54–6.3 (see fig. 6.5.2) explains the nomenclature of the compared barometers.

When "residual corrections" are available as entered on Form WBAN 54–3.3.1 "Barometer Correction Card," for the given mercurial barometer and are included in the "Sum of Corrections" for regular observational use (see Section 4.4), the "residual correction" should be added algebraically to the "correction for scale error and capillarity," and the result should be entered on the line numbered as item 2 on Form WBAN 54–6.3, "Comparative Barometer Readings," in the column pertaining to the given barometer. An appropriate footnote should be written on the form to indicate the content of the item entry.

Precise times of all readings should be recorded. Wind speed and direction should be recorded under "Remarks," with notations in regard to gustiness, storms, etc., if necessary. In the case of comparisons made when inspection barometers are not involved, the "Summary (Required for Inspectors Only)" on Form WBAN 54–6.3 will be left blank.

When simultaneous observations are made at two or more stations in a given locality, the personnel at the City Office or other meteorological installation should fill in the appropriate columns on copies of Form WBAN 54–6.3, thus providing a compilation of the readings made with the barometers at their location. The original copy of the form thus prepared should then be forwarded to the Airport Station. At the latter place, data pertinent to the barometer at the City Office (or other meteorological installation) will be copied on the Form WBAN 54–6.3 containing the original, comparative barometer data secured simultaneously at the Airport Station, and the form will be completed. The forms for the readings made at the two or more stations involved in connection with Form WBAN 54–6.3 should be checked independently by different personnel, if practicable.

Copies of all the completed forms should be signed by the responsible official, and prompt disposition of the forms should be made as indicated in sec. 6.5.6.

6.7 STANDARDIZATION OF PRECISION ANEROID BAROMETERS

6.7.0 General Information Concerning Aneroid Barometers

Meteorological station aneroid barometers of modern times are constructed to satisfy very stringent specifications. These instruments are designed to indicate changes or departures in pressure with considerable precision. In order to obtain accurate results in terms of pressure on an absolute basis, the precision aneroid barometer must itself be compared with a standardized mercurial barometer in order to ascertain suitable corrections to be applied to the readings of the aneroid instrument. After the corrections have been determined, they must be properly applied to each observed reading of the aneroid barometer, and the corrected reading will be considered as representative of station pressure (P).

With regard to the comparative readings mentioned above it should be understood that the station pressure (P) derived from the mercurial barometer for purposes of comparison with the readings of the aneroid barometer will include all appropriate corrections to the former instrument; that is, corrections for temperature, scale error and capillarity, gravity, and removal, (provided H_z differs from H_p); also the "residual correction" if known. (See Chapters 2–5.) Thus, as a matter of definition, P denotes absolute pressure at the station elevation (H_p) based on an instrument standardized by means of established procedures to bring it into accord with the national primary barometer "A_r".

Extreme care and considerable effort are necessary to establish the quality of the accuracy capable of being yielded by an aneroid barometer and to determine the necessary corrections to the readings, in compliance with stringent meterological standards.

The general information contained in sec. 2.8 and 2.10 is intended to help those who use aneroid barometers to understand the method of operation, the characteristics, and the limitations of this type of instrument. Only by a full grasp of the inherent sources of error and the precautions necessary to minimize or overcome the possible discrepancies can the user apply the device to obtain results of a satisfactory degree of reliability. The procedures for standardizing aneroid barometers described in sec. 6.7.2 are based on these considerations.

6.7.1 Definitions of Correction, C_a, of Aneroid Barometer

6.7.1.0 General Information.—The following notation is used:

P = station pressure (that is, pressure at the level of the station elevation, H_p);

P_z = pressure at the level of the actual elevation of the barometer (H_z);

R_a = reading of aneroid barometer (before correction is applied);

C_{vr} = "variable removal correction" (see Chapter 4);

C_a = correction of aneroid barometer.

All of the foregoing quantities are assumed to be in consistent units.

The definition of C_a depends upon the character of the removal correction, whether constant or variable (see secs. 6.7.1.1 and 6.7.1.2, below, respectively). The constant removal correction if any, is included in Form WBAN 54–3.3.1 as line 4, "Reduction: H_z to Station Elev. (H_p)". The "variable removal correction", if any, is included on the reverse side of that form. Sec. 6.7.1.3, below, briefly explains the significance of C_a.

The aneroid barometer is provided with a zero-setting screw or device for adjusting the position of the pointer with respect to the scale. This permits adjustment of the correction (C_a) if desired. It is considered advisable that the correction C_a always have a small positive (+) value rather than a zero or a small negative value. The reason for this is that the correction will then be applied with a consistently positive sign. The objection to the correction being zero at some particular time is that it might subsequently fluctuate in sign, leading to possible application of the erroneous sign at other times.

6.7.1.1 Definition of C_a in Case Where Removal Correction is Constant.[3]—When the removal correction is constant, the definition of C_a is given by the expression

$$C_a = (P - R_a); \qquad (1)$$

that is, the station pressure *minus* the actual reading of the aneroid barometer.

In this case the application of C_a is in accord with the relationship

$$P = (R_a + C_a); \qquad (2)$$

that is, the station pressure is the algebraic sum of the actual reading of the aneroid barometer and the correction.

6.7.1.2 Definition of C_a in Case Where the Removal Correction is Variable.—Where the removal correction is variable, the definition of C_a is given by the expression

$$C_a = (P_z - R_a); \qquad (3)$$

that is, C_a is the difference between the actual pressure at the level of the barometer (H_z) and the actual reading of the aneroid. We have the relationship

$$P = (P_z + C_{vr}); \text{ or } P_z = (P - C_{vr}); \quad (4)$$

that is, the station pressure at station elevation (H_p) is the algebraic sum of the actual pressure at the level of the barometer (H_z) and the "variable removal correction (C_{vr})". Thus, in practice P_z is the mercurial barometer reading corrected both for the "Sum of Corrections" on the face of Form WBAN 54–3.3.1 and for the temperature, provided that the variable removal correction is included on the reverse of the form. In this case the "Sum of Corrections" on the face of the form does not include a removal correction (line 4 is blank).

After the value of C_a has been established in accordance with the procedure described in sec. 6.7.2, its application is in accord with the following relationship:

$$P = (R_a + C_a + C_{vr}); \qquad (5)$$

that is, the station pressure is equal to the algebraic sum of the actual reading of the aneroid barometer, the correction C_a and the variable removal correction corresponding to the current outdoor temperature (see reverse of Form WBAN 54–3.3.1).

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[3] Cases in which no removal correction is used are regarded as cases of constant removal correction; actually zero in amount.

6.7.1.3 Significance of C_a for Aneroid Barometers.—In accordance with the foregoing two definitions of C_a the reader may readily see in both cases that while C_a includes a correction to allow for the discrepancy between the pressure measurements yielded by the two instruments being compared, it also includes an amount which may be considered to represent a "removal correction." Thus, in the case of the definition $C_a = (P - R_a)$, the value of C_a embodies a "removal correction" which reduces the pressure from the level of the aneroid barometer to the level of the station elevation (H_p). Also, in the case of the definition $C_a = (P_z - R_a)$, the value of C_a embodies a "removal correction" which reduces the pressure from the level of the aneroid barometer to the actual elevation of the zero point in the cistern of the mercury barometer (H_z). In the following we let C_{am} denote the mean correction, namely, the mean value of C_a based on ten comparative observations as outlined in sec. 6.7.2.7. By virtue of the inherent significance of C_a, as explained above, the quantity C_{am} has a similar significance, except that it is statistically more stable. It follows that in cases where a constant "removal correction" is employed, the sum $(R_a + C_{am}) = P$, the pressure at the station elevation, H_p; whereas in cases where a variable removal correction is used, the sum $(R_a + C_{am}) = P_z$, the pressure at the actual elevation of the zero point of the mercury barometer, H_z.

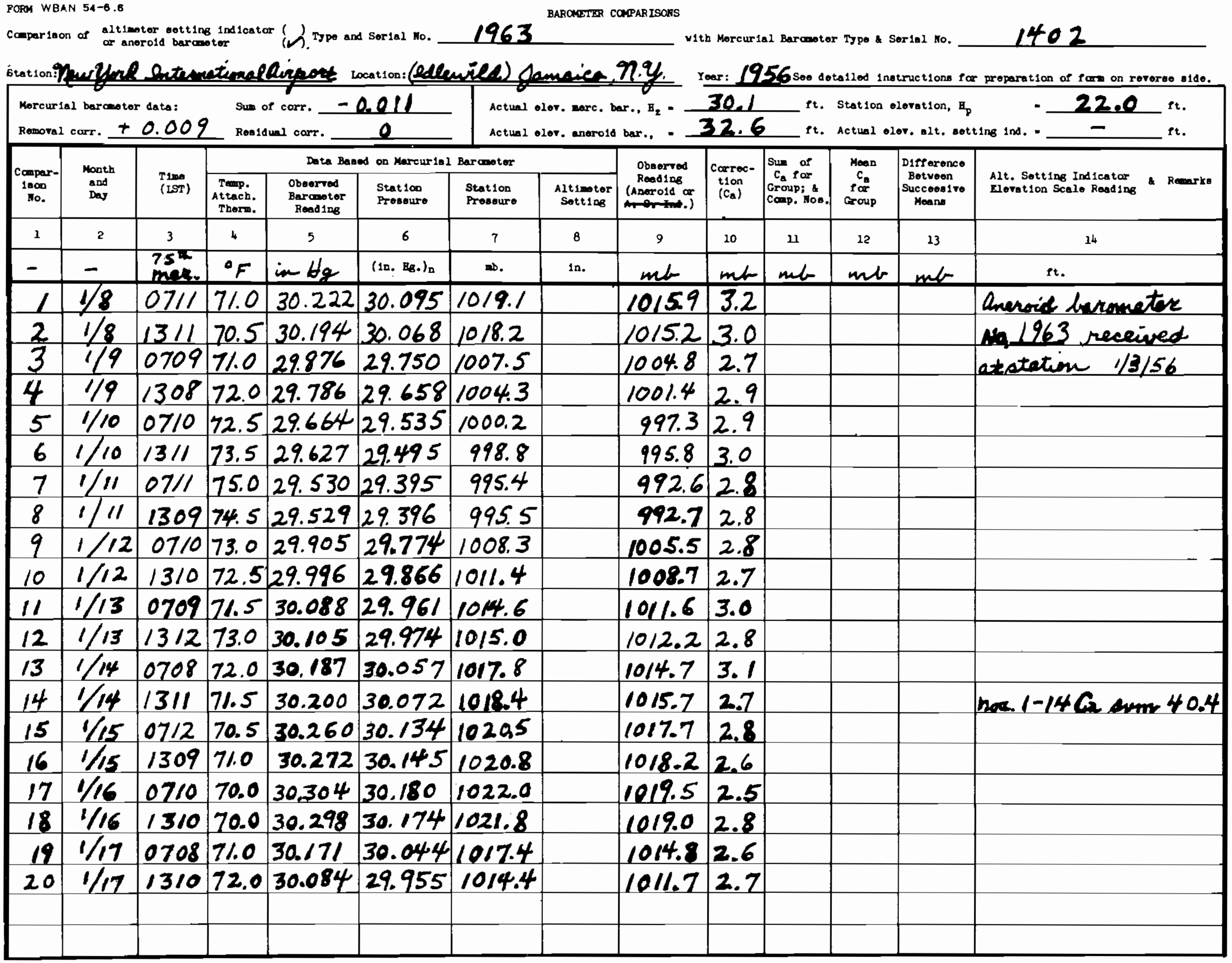
Consequently, if it is desired to determine the barometric pressure at some elevation (say H) other than H_p or H_z in either of the two cases mentioned above, where C_{am} is applied as indicated in the previous sentence, the pressure allowance for the difference in elevation must be based on consistent height data; that is $(H_p - H)$ where P is the datum in case the "removal correction" is constant; and $(H_z - H)$ where P_z is the datum in case the "removal correction" is variable. (See sec. 4.2.)

6.7.2 Basic Procedures for Standardizing Aneroid Barometers

6.7.2.0 General Information.—The following numbered secs. 6.7.2.1–6.7.2.8 give a brief summary of the procedures which are to be used in ascertaining whether the aneroid barometer gives satisfactory performance after its receipt at a field station, and in determining the mean correction applicable from time to time; additional details are given in sec. 6.7.2.9.

Exceptions are permitted with regard to certain of the provisions of the program of standardization of aneroid indicating instruments specified hereunder, when special conditions hold as stipulated in secs. A–2.16.2.5, A–2.16.2.6, and A–2.16.2.11. These sections deal, respectively, with the following three conditions: (1) when the instrument has been in good working order at a field station for at least six months, and its average correction checked on a weekly basis is consistent to within 0.2 mb.; (2) when the instrument has been reset by means of an adjusting screw; and (3) when it has been moved to a new location. The provisions of condition (1) must be satisfied before the exception is permitted in regard to conditions (2) and (3). In no case will the exceptions be permitted if there is any sign of malfunctioning of the instrument. If any of the foregoing three conditions apply at the station of the reader, he should refer to the pertinent sections (A–2.16.2.5, A–2.16.2.6, and A–2.16.2.11), and follow the special procedures indicated therein.

6.7.2.1 Comparative Observations to Determine C_a and General Plan.—Comparative observations will be made twice-daily at a 6-hour interval to obtain C_a values, and the data will be tabulated on Form WBAN 54–6.6 (see fig. 6.7.0 (a), (b), (c), (d), (e), and (f)) for at least 36 consecutive days at the beginning of the program (excluding the first four days after receipt of the aneroid barometer at the station). Continuation of the program will depend upon what is found from the data concerning the instrument performance. Before beginning the comparative observations, a selection should be made of the day of the week which will be best suited for the taking of the twice daily comparisons when these are subsequently taken only on one day per week. This selection may be based on the distribution of work load, scheduling of off-duty



FORM WBAN 54-6.6

BAROMETER COMPARISONS

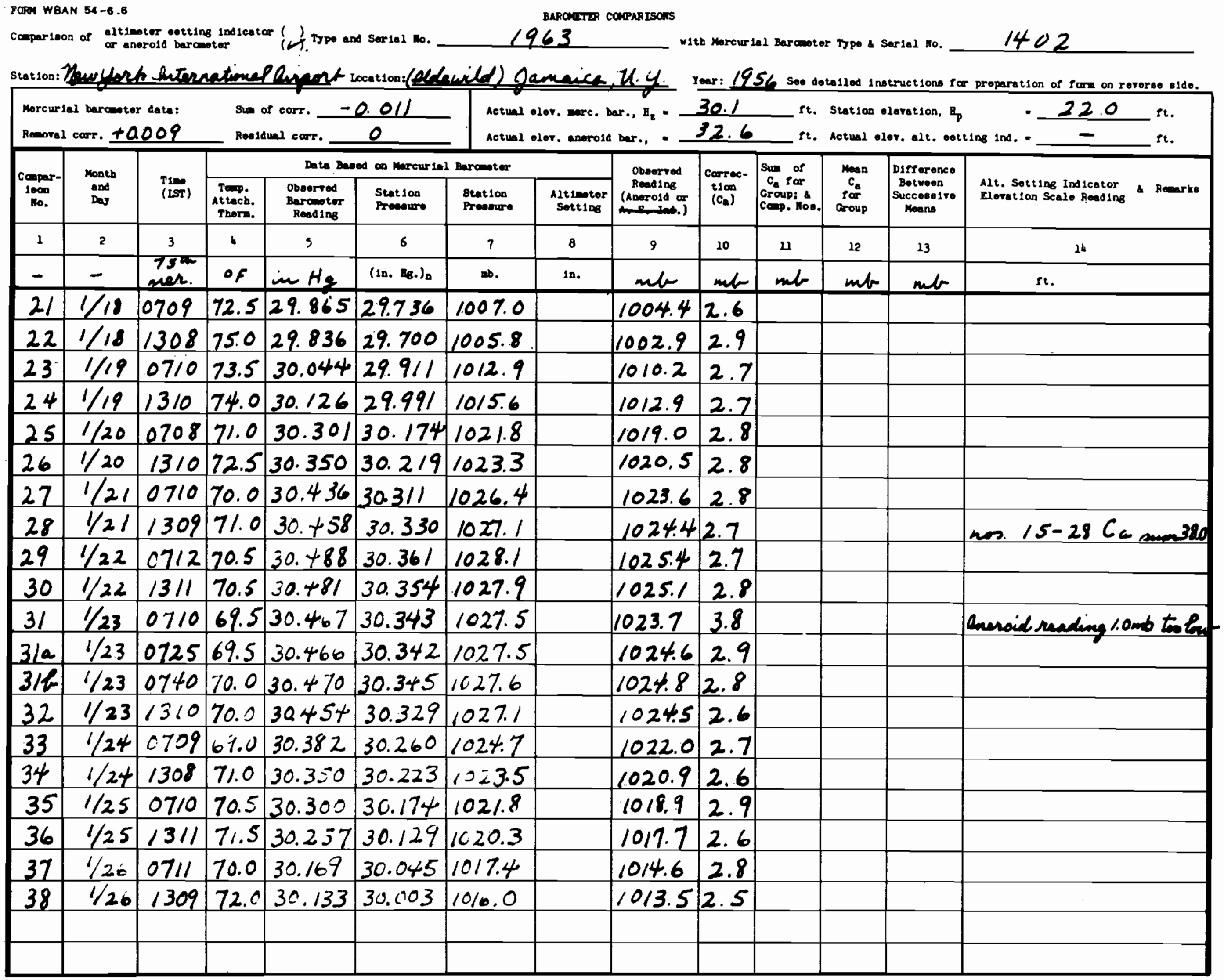
Comparison of altimeter setting indicator ( ) or aneroid barometer (✓). Type and Serial No. 1963 with Mercurial Barometer Type & Serial No. 1402

Station: New York International Airport Location: (Idlewild) Jamaica, N.Y. Year: 1956 See detailed instructions for preparation of form on reverse side.

Mercurial barometer data: Sum of corr. -0.011
Removal corr. + 0.009 Residual corr. 0
Actual elev. merc. bar., H_z = 30.1 ft. Station elevation, H_p = 22.0 ft.
Actual elev. aneroid bar., = 32.6 ft. Actual elev. alt. setting ind. = – ft.

Comparison No.	Month and Day	Time (LST)	Data Based on Mercurial Barometer					Observed Reading (Aneroid or ~~A. S. Ind.~~)	Correction (C_a)	Sum of C_a for Group; & Comp. Nos.	Mean C_a for Group	Difference Between Successive Means	Alt. Setting Indicator Elevation Scale Reading & Remarks
			Temp. Attach. Therm.	Observed Barometer Reading	Station Pressure	Station Pressure	Altimeter Setting						
1	2	3	4	5	6	7	8	9	10	11	12	13	14
–	–	75th mer.	°F	in Hg	(in. Hg.)$_n$	mb.	in.	mb	mb	mb	mb	mb	ft.
1	1/8	0711	71.0	30.222	30.095	1019.1		1015.9	3.2				Aneroid barometer
2	1/8	1311	70.5	30.194	30.068	1018.2		1015.2	3.0				No. 1963 received
3	1/9	0709	71.0	29.876	29.750	1007.5		1004.8	2.7				at station 1/3/56
4	1/9	1308	72.0	29.786	29.658	1004.3		1001.4	2.9				
5	1/10	0710	72.5	29.664	29.535	1000.2		997.3	2.9				
6	1/10	1311	73.5	29.627	29.495	998.8		995.8	3.0				
7	1/11	0711	75.0	29.530	29.395	995.4		992.6	2.8				
8	1/11	1309	74.5	29.529	29.396	995.5		992.7	2.8				
9	1/12	0710	73.0	29.905	29.774	1008.3		1005.5	2.8				
10	1/12	1310	72.5	29.996	29.866	1011.4		1008.7	2.7				
11	1/13	0709	71.5	30.088	29.961	1014.6		1011.6	3.0				
12	1/13	1312	73.0	30.105	29.974	1015.0		1012.2	2.8				
13	1/14	0708	72.0	30.187	30.057	1017.8		1014.7	3.1				
14	1/14	1311	71.5	30.200	30.072	1018.4		1015.7	2.7				nos. 1-14 C_a sum 40.4
15	1/15	0712	70.5	30.260	30.134	1020.5		1017.7	2.8				
16	1/15	1309	71.0	30.272	30.145	1020.8		1018.2	2.6				
17	1/16	0710	70.0	30.304	30.180	1022.0		1019.5	2.5				
18	1/16	1310	70.0	30.298	30.174	1021.8		1019.0	2.8				
19	1/17	0708	71.0	30.171	30.044	1017.4		1014.8	2.6				
20	1/17	1310	72.0	30.084	29.955	1014.4		1011.7	2.7				

FIGURE 6.7.0(a). Form WBAN 54-6.6 showing sample entries for comparison of aneroid barometer with mercurial barometer (continued on 6.7.0(b)).



FORM WBAN 54-6.6

BAROMETER COMPARISONS

Comparison of altimeter setting indicator ( ) or aneroid barometer (✓) Type and Serial No. 1963 with Mercurial Barometer Type & Serial No. 1402

Station: New York International Airport Location: (Idlewild) Jamaica, N.Y. Year: 1956 See detailed instructions for preparation of form on reverse side.

Mercurial barometer data: Sum of corr. -0.011

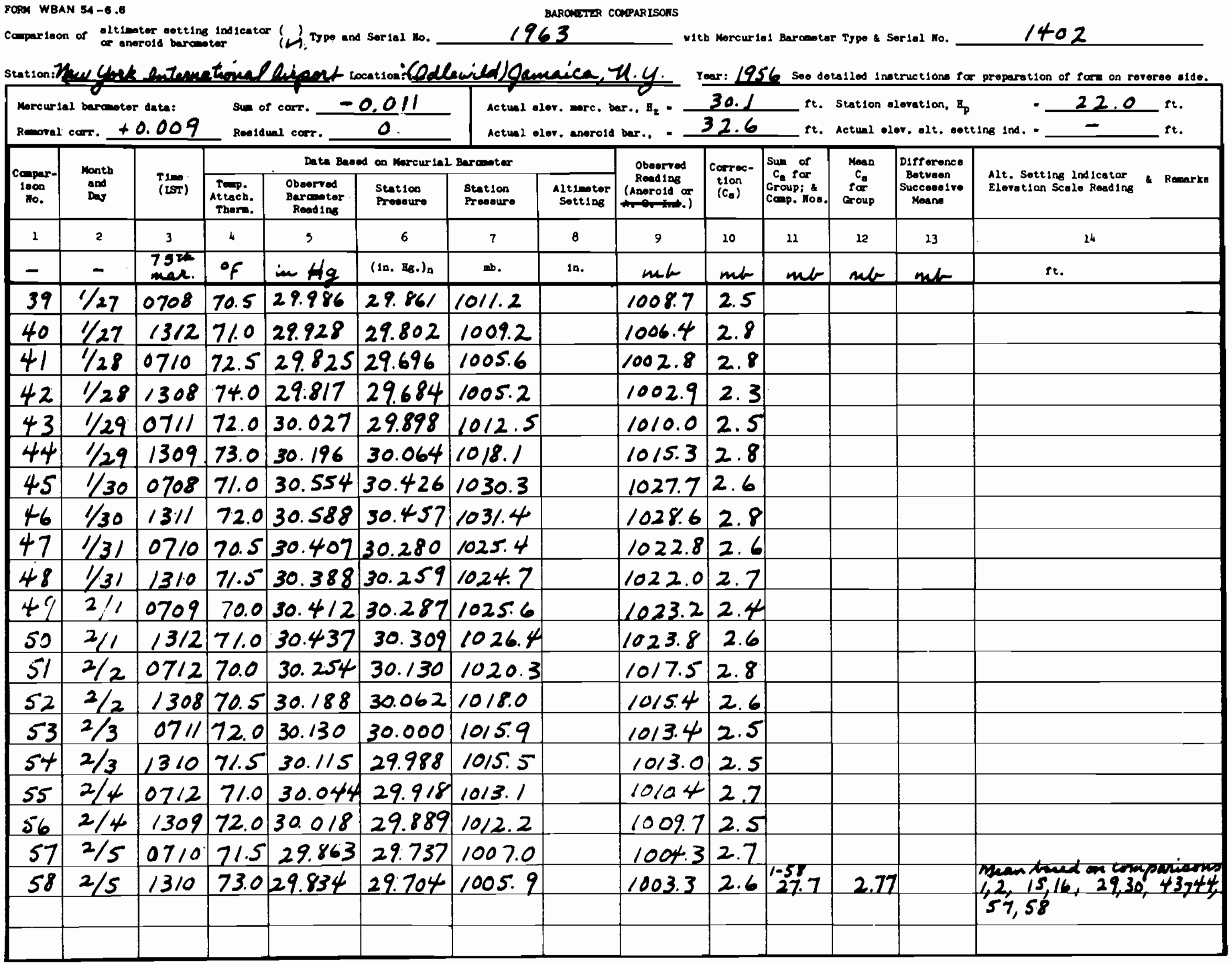
Removal corr. +0.009 Residual corr. 0

Actual elev. merc. bar., H_z = 30.1 ft. Station elevation, H_p = 22.0 ft.

Actual elev. aneroid bar., = 32.6 ft. Actual elev. alt. setting ind. = — ft.

Comparison No.	Month and Day	Time (LST)	Data Based on Mercurial Barometer					Observed Reading (Aneroid or ~~A. S. Ind.~~)	Correction (C_a)	Sum of C_a for Group; & Comp. Nos.	Mean C_a for Group	Difference Between Successive Means	Alt. Setting Indicator Elevation Scale Reading & Remarks
			Temp. Attach. Therm.	Observed Barometer Reading	Station Pressure	Station Pressure	Altimeter Setting						
1	2	3	4	5	6	7	8	9	10	11	12	13	14
—	—	75th mer.	°F	in Hg	(in. Hg.)$_n$	mb.	in.	mb	mb	mb	mb	mb	ft.
21	1/18	0709	72.5	29.865	29.736	1007.0		1004.4	2.6				
22	1/18	1308	75.0	29.836	29.700	1005.8		1002.9	2.9				
23	1/19	0710	73.5	30.044	29.911	1012.9		1010.2	2.7				
24	1/19	1310	74.0	30.126	29.991	1015.6		1012.9	2.7				
25	1/20	0708	71.0	30.301	30.174	1021.8		1019.0	2.8				
26	1/20	1310	72.5	30.350	30.219	1023.3		1020.5	2.8				
27	1/21	0710	70.0	30.436	30.311	1026.4		1023.6	2.8				
28	1/21	1309	71.0	30.458	30.330	1027.1		1024.4	2.7				nos. 15-28 Ca sum 38.0
29	1/22	0712	70.5	30.488	30.361	1028.1		1025.4	2.7				
30	1/22	1311	70.5	30.481	30.354	1027.9		1025.1	2.8				
31	1/23	0710	69.5	30.467	30.343	1027.5		1023.7	3.8				Aneroid reading 1.0mb too low
31a	1/23	0725	69.5	30.466	30.342	1027.5		1024.6	2.9				
31b	1/23	0740	70.0	30.470	30.345	1027.6		1024.8	2.8				
32	1/23	1310	70.0	30.454	30.329	1027.1		1024.5	2.6				
33	1/24	0709	69.0	30.382	30.260	1024.7		1022.0	2.7				
34	1/24	1308	71.0	30.350	30.223	1023.5		1020.9	2.6				
35	1/25	0710	70.5	30.300	30.174	1021.8		1018.9	2.9				
36	1/25	1311	71.5	30.257	30.129	1020.3		1017.7	2.6				
37	1/26	0711	70.0	30.169	30.045	1017.4		1014.6	2.8				
38	1/26	1309	72.0	30.133	30.003	1016.0		1013.5	2.5				

FIGURE 6.7.0(b). Form WBAN 54-6.6 showing sample entries for comparison of aneroid barometer with mercurial barometer (continued on 6.7.0(c)).



FORM WBAN 54-6.6

BAROMETER COMPARISONS

Comparison of altimeter setting indicator ( ) or aneroid barometer (✓) Type and Serial No. 1963 with Mercurial Barometer Type & Serial No. 1402

Station: New York International Airport Location: (Odlewild) Jamaica, N.Y. Year: 1956 See detailed instructions for preparation of form on reverse side.

Mercurial barometer data: Sum of corr. -0.011

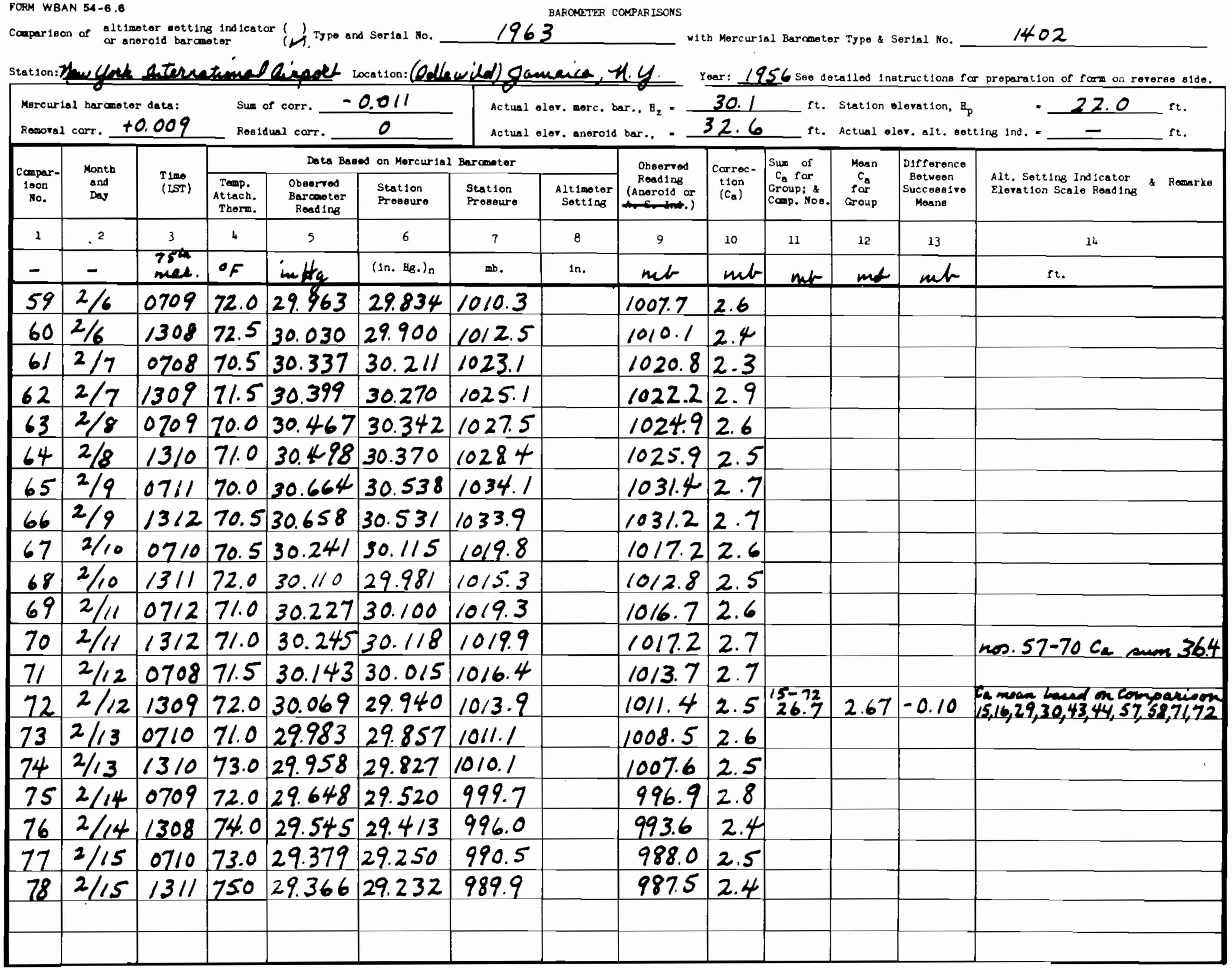
Removal corr. +0.009 Residual corr. 0.

Actual elev. merc. bar., H_z = 30.1 ft. Station elevation, H_p = 22.0 ft.

Actual elev. aneroid bar., = 32.6 ft. Actual elev. alt. setting ind. = – ft.

Comparison No.	Month and Day	Time (LST)	Data Based on Mercurial Barometer: Temp. Attach. Therm.	Observed Barometer Reading	Station Pressure	Station Pressure	Altimeter Setting	Observed Reading (Aneroid or ~~A. S. Ind.~~)	Correction (C_a)	Sum of C_a for Group; & Comp. Nos.	Mean C_a for Group	Difference Between Successive Means	Alt. Setting Indicator Elevation Scale Reading & Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14
–	–	75th mer.	°F	in Hg	(in. Hg.)n	mb.	in.	mb	mb	mb	mb	mb	ft.
39	1/27	0708	70.5	29.986	29.861	1011.2		1008.7	2.5				
40	1/27	1312	71.0	29.928	29.802	1009.2		1006.4	2.8				
41	1/28	0710	72.5	29.825	29.696	1005.6		1002.8	2.8				
42	1/28	1308	74.0	29.817	29.684	1005.2		1002.9	2.3				
43	1/29	0711	72.0	30.027	29.898	1012.5		1010.0	2.5				
44	1/29	1309	73.0	30.196	30.064	1018.1		1015.3	2.8				
45	1/30	0708	71.0	30.554	30.426	1030.3		1027.7	2.6				
46	1/30	1311	72.0	30.588	30.457	1031.4		1028.6	2.8				
47	1/31	0710	70.5	30.407	30.280	1025.4		1022.8	2.6				
48	1/31	1310	71.5	30.388	30.259	1024.7		1022.0	2.7				
49	2/1	0709	70.0	30.412	30.287	1025.6		1023.2	2.4				
50	2/1	1312	71.0	30.437	30.309	1026.4		1023.8	2.6				
51	2/2	0712	70.0	30.254	30.130	1020.3		1017.5	2.8				
52	2/2	1308	70.5	30.188	30.062	1018.0		1015.4	2.6				
53	2/3	0711	72.0	30.130	30.000	1015.9		1013.4	2.5				
54	2/3	1310	71.5	30.115	29.988	1015.5		1013.0	2.5				
55	2/4	0712	71.0	30.044	29.918	1013.1		1010.4	2.7				
56	2/4	1309	72.0	30.018	29.889	1012.2		1009.7	2.5				
57	2/5	0710	71.5	29.863	29.737	1007.0		1004.3	2.7				
58	2/5	1310	73.0	29.834	29.704	1005.9		1003.3	2.6	1-58 27.7	2.77		Mean based on comparisons 1,2, 15,16, 29,30, 43,44, 57,58

FIGURE 6.7.0(c). Form WBAN 54-6.6 showing sample entries for comparison of aneroid barometer with mercurial barometer (continued on 6.7.0(d)).



FORM WBAN 54-6.6

BAROMETER COMPARISONS

Comparison of altimeter setting indicator ( ) or aneroid barometer (✓) Type and Serial No. 1963 with Mercurial Barometer Type & Serial No. 1402

Station: New York International Airport Location: (Idlewild) Jamaica, N.Y. Year: 1956 See detailed instructions for preparation of form on reverse side.

Mercurial barometer data: Sum of corr. -0.011

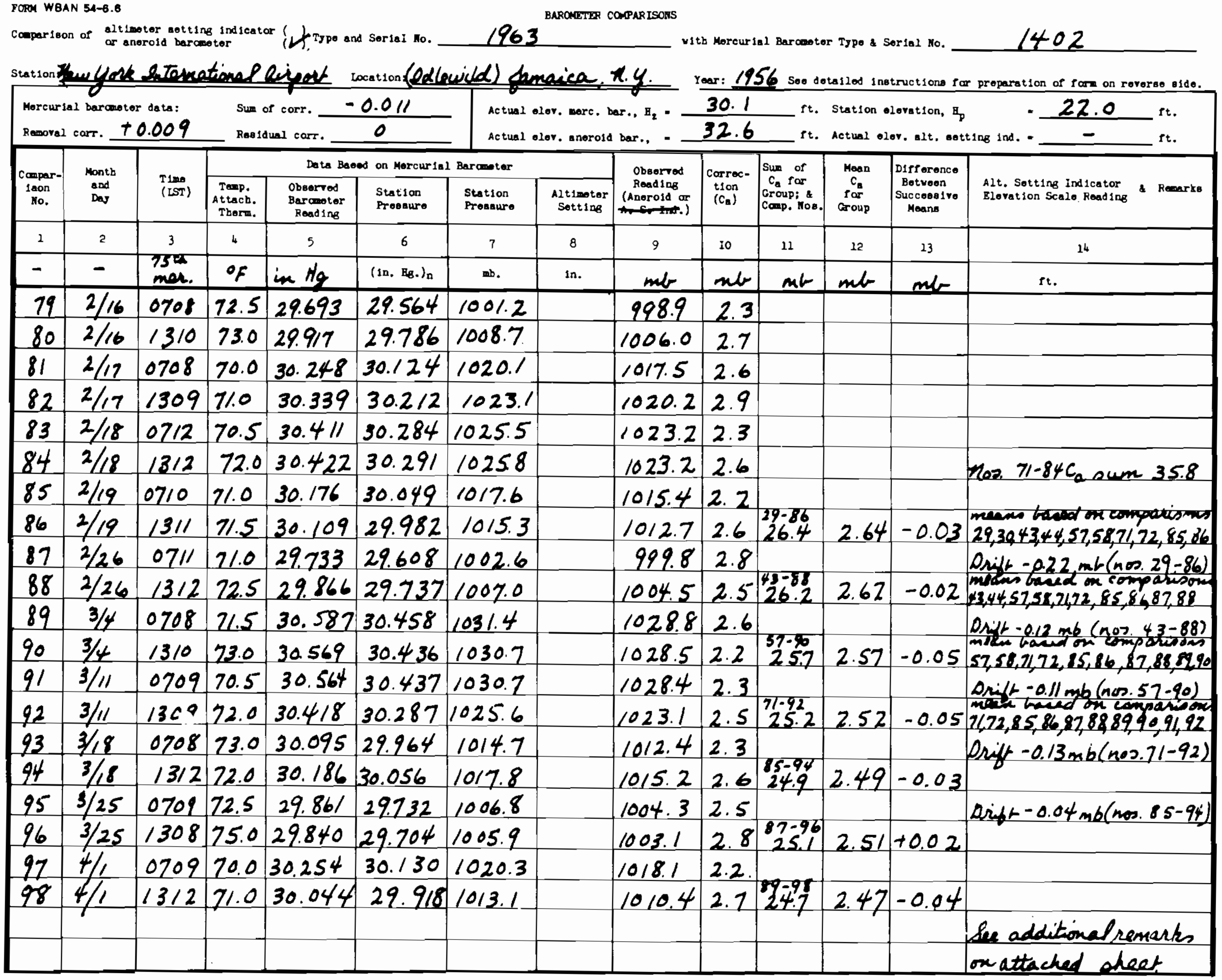
Removal corr. +0.009 Residual corr. 0

Actual elev. merc. bar., H_z = 30.1 ft. Station elevation, H_p = 22.0 ft.

Actual elev. aneroid bar., = 32.6 ft. Actual elev. alt. setting ind. = — ft.

Comparison No.	Month and Day	Time (LST)	Data Based on Mercurial Barometer					Observed Reading (Aneroid or ~~A. S. Ind.~~)	Correction (C_a)	Sum of C_a for Group; & Comp. Nos.	Mean C_a for Group	Difference Between Successive Means	Alt. Setting Indicator Elevation Scale Reading & Remarks
			Temp. Attach. Therm.	Observed Barometer Reading	Station Pressure	Station Pressure	Altimeter Setting						
1	2	3	4	5	6	7	8	9	10	11	12	13	14
—	—	75th mer.	°F	in Hg	(in. Hg.)n	mb.	in.	mb	mb	mb	mb	mb	ft.
59	2/6	0709	72.0	29.963	29.834	1010.3		1007.7	2.6				
60	2/6	1308	72.5	30.030	29.900	1012.5		1010.1	2.4				
61	2/7	0708	70.5	30.337	30.211	1023.1		1020.8	2.3				
62	2/7	1309	71.5	30.399	30.270	1025.1		1022.2	2.9				
63	2/8	0709	70.0	30.467	30.342	1027.5		1024.9	2.6				
64	2/8	1310	71.0	30.498	30.370	1028.4		1025.9	2.5				
65	2/9	0711	70.0	30.664	30.538	1034.1		1031.4	2.7				
66	2/9	1312	70.5	30.658	30.531	1033.9		1031.2	2.7				
67	2/10	0710	70.5	30.241	30.115	1019.8		1017.2	2.6				
68	2/10	1311	72.0	30.110	29.981	1015.3		1012.8	2.5				
69	2/11	0712	71.0	30.227	30.100	1019.3		1016.7	2.6				
70	2/11	1312	71.0	30.245	30.118	1019.9		1017.2	2.7				nos. 57-70 Ca sum 36.4
71	2/12	0708	71.5	30.143	30.015	1016.4		1013.7	2.7				
72	2/12	1309	72.0	30.069	29.940	1013.9		1011.4	2.5	15-72 26.7	2.67	-0.10	Ca mean based on Comparison 15,16,29,30,43,44,57,58,71,72
73	2/13	0710	71.0	29.983	29.857	1011.1		1008.5	2.6				
74	2/13	1310	73.0	29.958	29.827	1010.1		1007.6	2.5				
75	2/14	0709	72.0	29.648	29.520	999.7		996.9	2.8				
76	2/14	1308	74.0	29.545	29.413	996.0		993.6	2.4				
77	2/15	0710	73.0	29.379	29.250	990.5		988.0	2.5				
78	2/15	1311	750	29.366	29.232	989.9		987.5	2.4				

FIGURE 6.7.0(d). Form WBAN 54-6.6 showing sample entries for comparison of aneroid barometer with mercurial barometer (continued on 6.7.0(e)).



FORM WBAN 54-6.6

BAROMETER COMPARISONS

Comparison of altimeter setting indicator ( ) or aneroid barometer (✓) Type and Serial No. 1963 with Mercurial Barometer Type & Serial No. 1402

Station New York International Airport Location (Idlewild) Jamaica, N.Y. Year: 1956 See detailed instructions for preparation of form on reverse side.

Mercurial barometer data: Sum of corr. -0.011

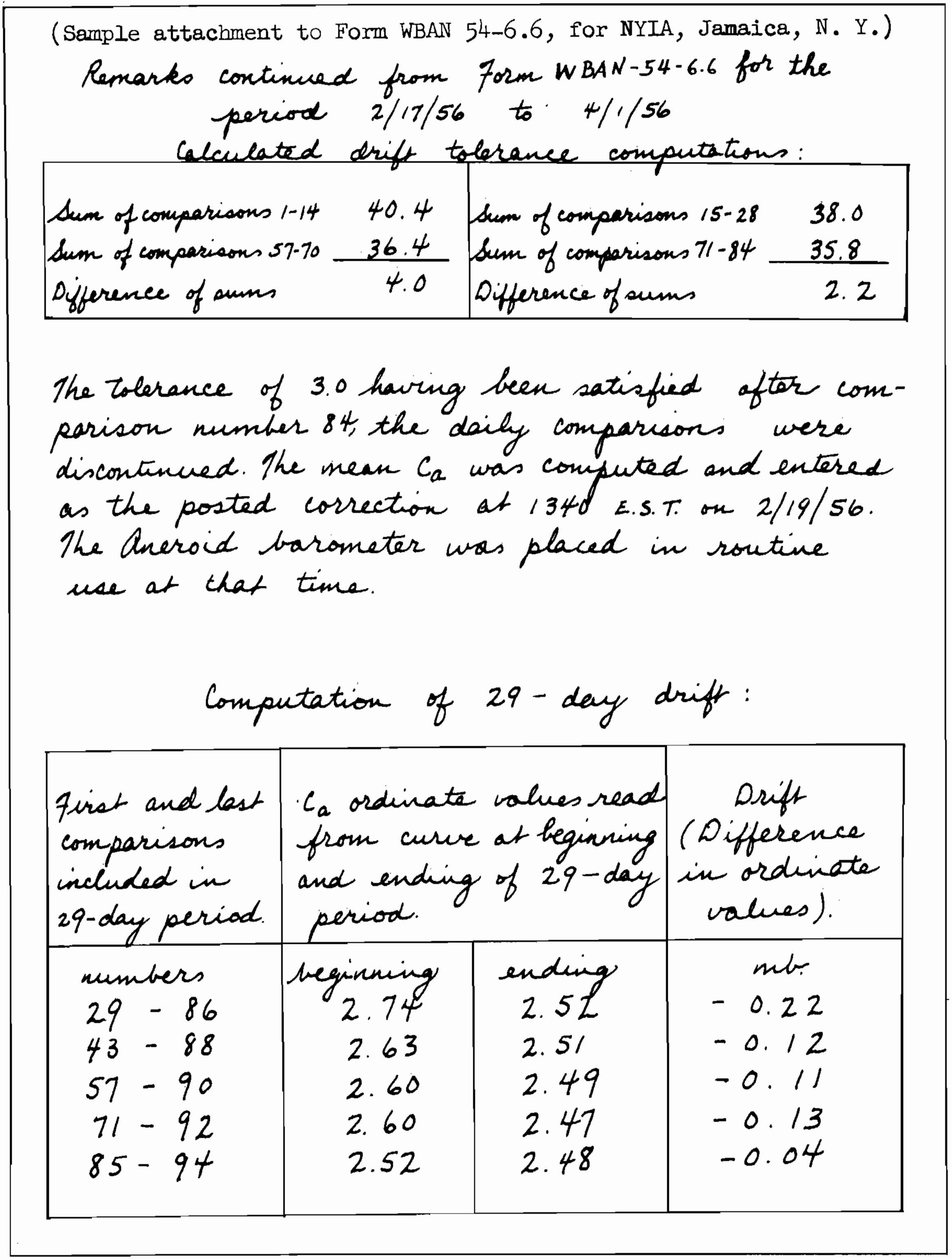
Removal corr. +0.009 Residual corr. 0

Actual elev. merc. bar., H_z = 30.1 ft. Station elevation, H_p = 22.0 ft.

Actual elev. aneroid bar., = 32.6 ft. Actual elev. alt. setting ind. = – ft.

Comparison No.	Month and Day	Time (LST)	Data Based on Mercurial Barometer					Observed Reading (Aneroid or ~~A. S. Ind.~~)	Correction (C_a)	Sum of C_a for Group; & Comp. Nos.	Mean C_a for Group	Difference Between Successive Means	Alt. Setting Indicator Elevation Scale Reading & Remarks
			Temp. Attach. Therm.	Observed Barometer Reading	Station Pressure	Station Pressure	Altimeter Setting						
1	2	3	4	5	6	7	8	9	10	11	12	13	14
–	–	75th mer.	°F	in Hg	(in. Hg.)n	mb.	in.	mb	mb	mb	mb	mb	ft.
79	2/16	0708	72.5	29.693	29.564	1001.2		998.9	2.3				
80	2/16	1310	73.0	29.917	29.786	1008.7		1006.0	2.7				
81	2/17	0708	70.0	30.248	30.124	1020.1		1017.5	2.6				
82	2/17	1309	71.0	30.339	30.212	1023.1		1020.2	2.9				
83	2/18	0712	70.5	30.411	30.284	1025.5		1023.2	2.3				
84	2/18	1312	72.0	30.422	30.291	1025.8		1023.2	2.6				Nos. 71-84 C_a sum 35.8
85	2/19	0710	71.0	30.176	30.049	1017.6		1015.4	2.2				
86	2/19	1311	71.5	30.109	29.982	1015.3		1012.7	2.6	29-86 26.4	2.64	-0.03	means based on comparisons 29,30,43,44,57,58,71,72,85,86
87	2/26	0711	71.0	29.733	29.608	1002.6		999.8	2.8				Drift -0.22 mb (nos. 29-86)
88	2/26	1312	72.5	29.866	29.737	1007.0		1004.5	2.5	43-88 26.2	2.67	-0.02	means based on comparisons 43,44,57,58,71,72,85,86,87,88
89	3/4	0708	71.5	30.587	30.458	1031.4		1028.8	2.6				Drift -0.12 mb (nos. 43-88)
90	3/4	1310	73.0	30.569	30.436	1030.7		1028.5	2.2	57-90 25.7	2.57	-0.05	mean based on comparisons 57,58,71,72,85,86,87,88,89,90
91	3/11	0709	70.5	30.564	30.437	1030.7		1028.4	2.3				Drift -0.11 mb (nos. 57-90)
92	3/11	1309	72.0	30.418	30.287	1025.6		1023.1	2.5	71-92 25.2	2.52	-0.05	mean based on comparisons 71,72,85,86,87,88,89,90,91,92
93	3/18	0708	73.0	30.095	29.964	1014.7		1012.4	2.3				Drift -0.13 mb (nos. 71-92)
94	3/18	1312	72.0	30.186	30.056	1017.8		1015.2	2.6	85-94 24.9	2.49	-0.03	
95	3/25	0709	72.5	29.861	29.732	1006.8		1004.3	2.5				Drift -0.04 mb (nos. 85-94)
96	3/25	1308	75.0	29.840	29.704	1005.9		1003.1	2.8	87-96 25.1	2.51	+0.02	
97	4/1	0709	70.0	30.254	30.130	1020.3		1018.1	2.2				
98	4/1	1312	71.0	30.044	29.918	1013.1		1010.4	2.7	89-98 24.7	2.47	-0.04	
													See additional remarks
													on attached sheet

FIGURE 6.7.0(e). Form WBAN 54-6.6 showing sample entries for comparison of aneroid barometer with mercurial barometer (continued on 6.7.0(f)).



(Sample attachment to Form WBAN 54-6.6, for NYIA, Jamaica, N. Y.)

Remarks continued from Form WBAN-54-6.6 for the period 2/17/56 to 4/1/56

Calculated drift tolerance computations:

Sum of comparisons 1-14	40.4	Sum of comparisons 15-28	38.0
Sum of comparisons 57-70	36.4	Sum of comparisons 71-84	35.8
Difference of sums	4.0	Difference of sums	2.2

The tolerance of 3.0 having been satisfied after comparison number 84, the daily comparisons were discontinued. The mean C_a was computed and entered as the posted correction at 1340 E.S.T. on 2/19/56. The Aneroid barometer was placed in routine use at that time.

Computation of 29-day drift:

First and last comparisons included in 29-day period.	C_a ordinate values read from curve at beginning and ending of 29-day period.		Drift (Difference in ordinate values).
numbers	beginning	ending	mb.
29 - 86	2.74	2.52	- 0.22
43 - 88	2.63	2.51	- 0.12
57 - 90	2.60	2.49	-0.11
71 - 92	2.60	2.47	- 0.13
85 - 94	2.52	2.48	-0.04

FIGURE 6.7.0 (f). Continuation of sample form WBAN 54–6.6.

days of personnel, and other local conditions. The instructions in secs. 6.7.2 and 6.7.3 are based on the assumption that the daily comparisons will begin on the same day of the week which has been selected for later continuation of the comparisons on the one day per week basis. At the completion of the 35th day of the period of data collection, an analysis of the information will be made in the manner outlined in secs. 6.7.2.3–6.7.2.6 below. If the performance satisfies certain criteria or tolerances laid down in those secs., the mean correction based on ten values of C_a will be determined on the 36th day, as explained in secs. 6.7.2.7, below. Subsequently, when and if the criteria are satisfied, the comparative observations will be only required on a weekly basis as outlined in secs. 6.7.2.7 and 6.7.2.9. Even on the weekly basis, two comparative observations will be made in a day, with a 6-hour interval between them.

In case the performance during the initial period should not satisfy the criteria or tolerances indicated in secs. 6.7.2.3–6.7.2.6, the twice-daily comparative observations will be continued each day for at least another week after the 36th day. Once more, at the termination of the latter week, the data will be examined to determine whether they fulfill the requirements given in those sections. If not, the same procedure will be continued week by week, until the requirements are fulfilled. Should there ever be a case in which the requirements are not fulfilled within 15 weeks, the facts should be reported to the next higher headquarters and the daily comparisons terminated.

6.7.2.2 Quality-Control Chart.—A Quality-Control Chart will be prepared and kept up to date. (See fig. 6.7.1.) This involves plotting of C_a against number of the comparison and week number in consecutive order. A smooth curve will be drawn to give a best fit to the plotted points. (See fig. 6.7.2 a, b, and c.) Slope of the curve is indicative of the drift of the aneroid barometer, and the deviations of plotted points from the curve shows the variability. (For further details see secs. 6.7.2.9.2–6.7.2.9.7.)

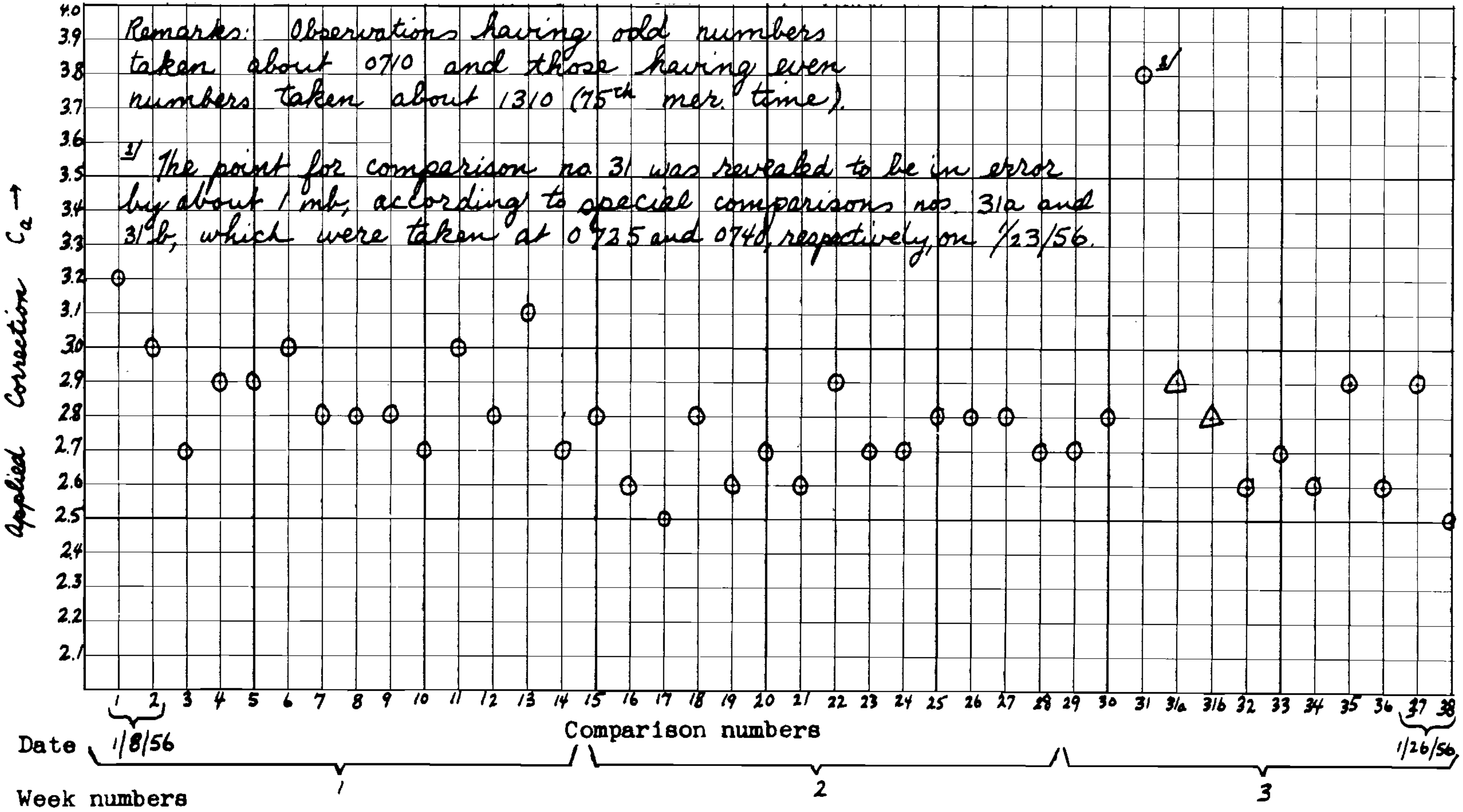
6.7.2.3 Calculations to Check Drift.—Two sums of C_a values will be compiled, comprising observations numbered 1–14, in one case, and numbered 57–70 in the other case (14 in each). (See fig. 6.7.3.) The difference between these sums will be taken; and if the absolute value of the difference (disregarding algebraic sign) is equal to or less than the "calculated drift tolerance" of 3.0 mb. (limited to this type of test), the drift will be considered satisfactory in this stage of the program. If the difference between the sums exceeds the specified drift tolerance, the twice-daily comparisons will be continued for another week and the test based on difference of sums will be repeated, using sums compiled from observations numbered 15–28 and 71–84, respectively. This procedure will be repeated if necessary, by weekly stages, until the "calculated drift tolerance" specified above is satisfied. After this tolerance has been satisfied, the daily comparisons will be abandoned and they will be superseded by a weekly schedule consisting of two comparisons made on just one day per week (such as every Sunday).

6.7.2.4 Drift Shown by "Curve of Best Fit" on Quality-Control Chart.—Values of C_a based on all comparative observations between aneroid and mercurial barometers should be plotted on the quality-control chart. The quality-control chart will serve to give a general indication of drift as shown by the trend of the plotted points. Accordingly the observers should review the chart from time to time at least once every week in order to determine whether the drift is excessive or holds within satisfactory limits. Uses of the chart to study "tail-end drift" and "variability" are discussed in succeeding secs. (see nos. 6.7.2.5 and 6.7.2.9.6; and nos. 6.7.2.6 and 6.7.2.9.7, respectively).

As outlined in sec. 6.7.2.1, a choice will have to be made in regard to a certain day of the week for taking a pair of comparative observations when operating on a weekly schedule (for example, every Sunday). The first pair of comparative observations will begin on that day of the week.

After the values of C_a for nine (9) such consecutive days (for example, 9 consecutive Sundays) have been plotted on the quality-control chart, the general drift will be determined from the curve constructed on

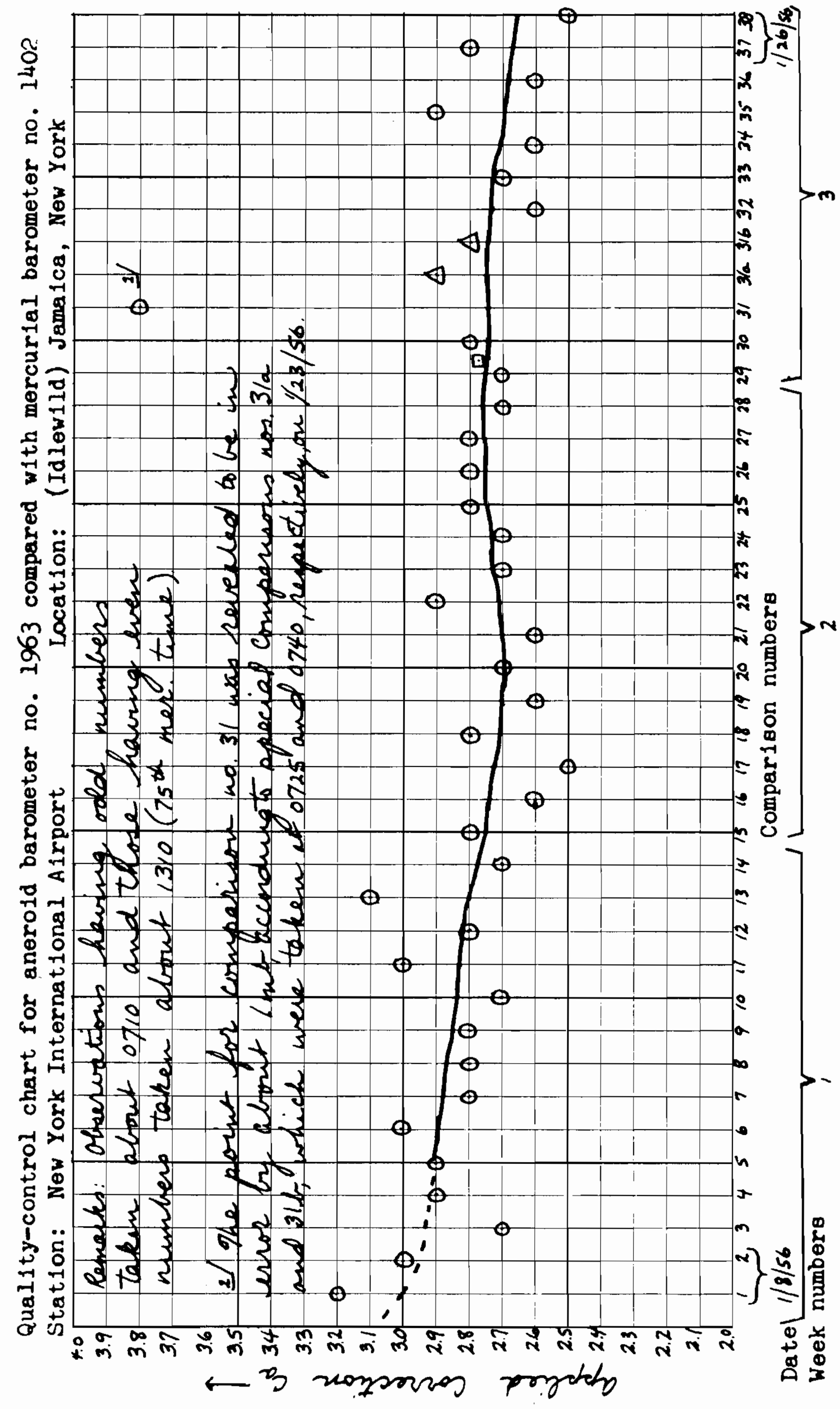
Quality—control chart for aneroid barometer no. 1963 compared with mercurial barometer no. 1402
Station: New York International Airport Location: (Idlewild) Jamaica, New York



Remarks: Observations having odd numbers taken about 0710 and those having even numbers taken about 1310 (75th mer. time).

1/ The point for comparison no 31 was revealed to be in error by about 1 mb, according to special comparisons no. 31a and 31b, which were taken at 0725 and 0740, respectively, on 1/23/56.

FIGURE 6.7.1. Illustration of a quality-control chart showing plotted points as they would appear before curve of best fit is drawn.



Quality-control chart for aneroid barometer no. 1963 compared with mercurial barometer no. 1402
Station: New York International Airport Location: (Idlewild) Jamaica, New York

Remarks: Observations having odd numbers taken about 0710 and those having even numbers taken about 1310 (75th mer. time)

1/ The point for comparison no. 31 was revealed to be in error by about (but according to special comparisons nos. 31a and 31b, which were taken at 0725 and 0740, respectively, on 1/23/56.

FIGURE 6.7.2.(a). Illustration of quality-control chart (continued on 6.7.2(b)).

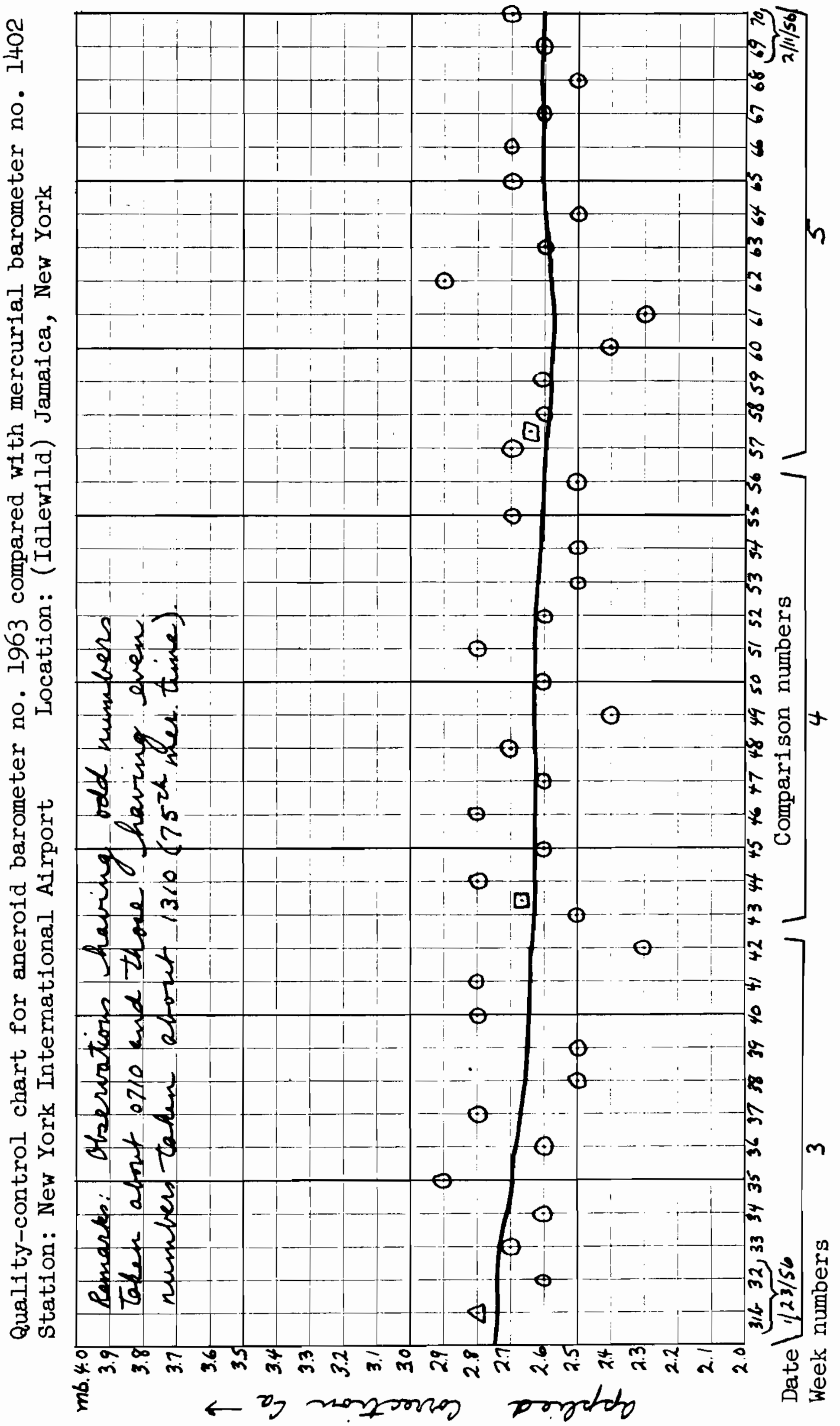


FIGURE 6.7.2(b). Illustration of quality-control chart (continued on 6.7.2(c)).

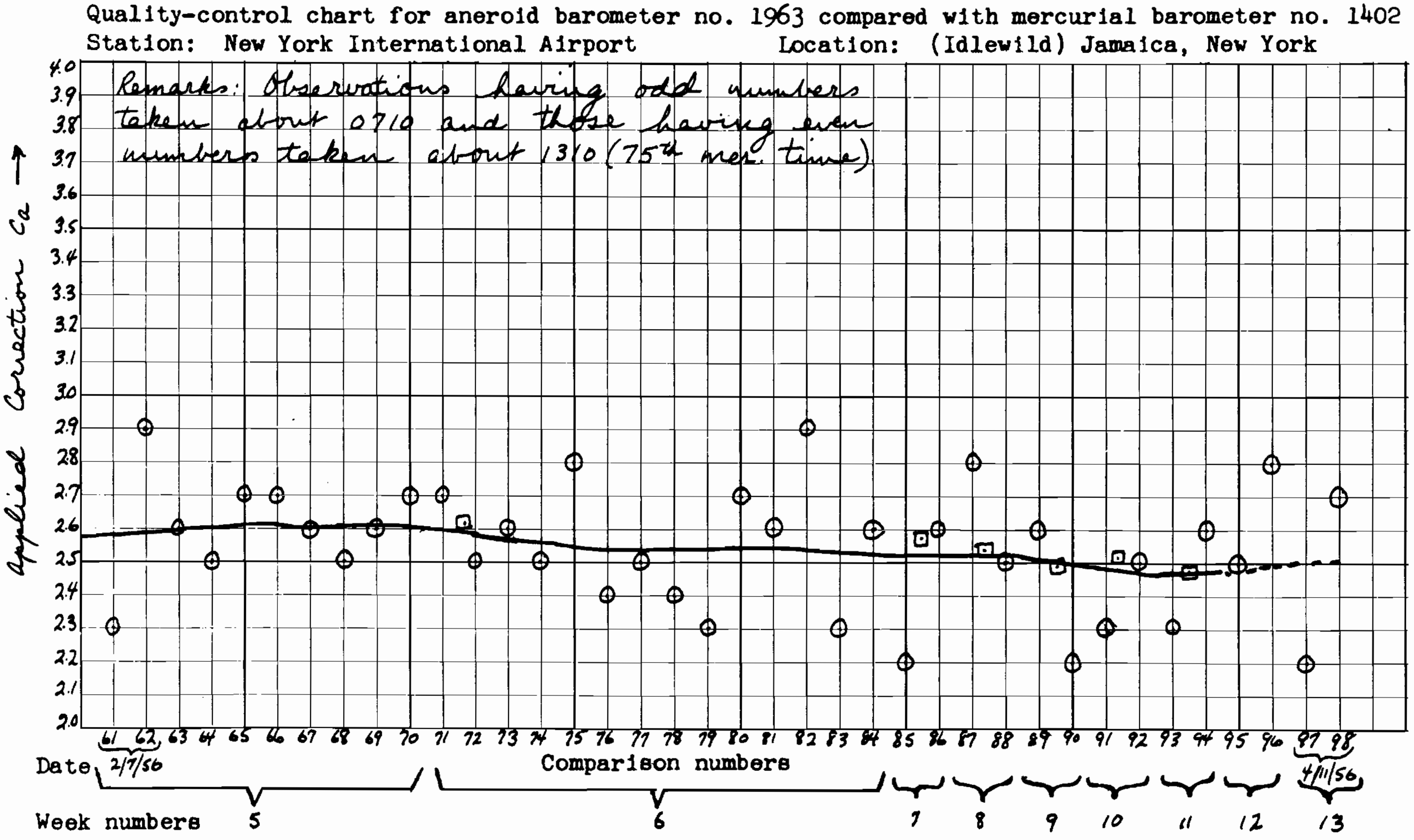


FIGURE 6.7.2(c). Illustration of quality-control chart.

<table>
<tr><td colspan="4">Comparisons 1-14 (taken days 1-7) Compared with Comparison 57-70 taken days 29-35) 28 days later.</td><td colspan="4">Comparison 15-28 (taken days 8-14) Compared with Comparison 71-84 (taken days 36-42) 28 days later.</td></tr>
<tr><td>Comparison No.</td><td>Correction (C_a)</td><td>Comparison No.</td><td>Correction (C_a)</td><td>Comparison No.</td><td>Correction (C_a)</td><td>Comparison No.</td><td>Correction (C_a)</td></tr>
<tr><td></td><td>mb.</td><td></td><td>mb.</td><td></td><td>mb.</td><td></td><td>mb.</td></tr>
<tr><td>1</td><td>3.2</td><td>57</td><td>2.7</td><td>15</td><td>2.8</td><td>71</td><td>2.1</td></tr>
<tr><td>2</td><td>3.0</td><td>58</td><td>2.6</td><td>16</td><td>2.6</td><td>72</td><td>2.5</td></tr>
<tr><td>3</td><td>2.7</td><td>59</td><td>2.6</td><td>17</td><td>2.5</td><td>73</td><td>2.6</td></tr>
<tr><td>4</td><td>2.9</td><td>60</td><td>2.4</td><td>18</td><td>2.8</td><td>74</td><td>2.5</td></tr>
<tr><td>5</td><td>2.9</td><td>61</td><td>2.3</td><td>19</td><td>2.6</td><td>75</td><td>2.8</td></tr>
<tr><td>6</td><td>3.0</td><td>62</td><td>2.9</td><td>20</td><td>2.7</td><td>76</td><td>2.4</td></tr>
<tr><td>7</td><td>2.8</td><td>63</td><td>2.6</td><td>21</td><td>2.6</td><td>77</td><td>2.5</td></tr>
<tr><td>8</td><td>2.8</td><td>64</td><td>2.5</td><td>22</td><td>2.9</td><td>78</td><td>2.4</td></tr>
<tr><td>9</td><td>2.8</td><td>65</td><td>2.7</td><td>23</td><td>2.7</td><td>79</td><td>2.3</td></tr>
<tr><td>10</td><td>2.7</td><td>66</td><td>2.7</td><td>24</td><td>2.7</td><td>80</td><td>2.7</td></tr>
<tr><td>11</td><td>3.0</td><td>67</td><td>2.6</td><td>25</td><td>2.8</td><td>81</td><td>2.6</td></tr>
<tr><td>12</td><td>2.8</td><td>68</td><td>2.5</td><td>26</td><td>2.8</td><td>82</td><td>2.9</td></tr>
<tr><td>13</td><td>3.1</td><td>69</td><td>2.6</td><td>27</td><td>2.8</td><td>83</td><td>2.3</td></tr>
<tr><td>14</td><td>2.7</td><td>70</td><td>2.7</td><td>28</td><td>2.7</td><td>84</td><td>2.6</td></tr>
<tr><td>Sum</td><td>40.4</td><td></td><td>36.4</td><td>Sum</td><td>38.0</td><td></td><td>35.8</td></tr>
<tr><td colspan="4">Difference of sums 40.4 - 36.4 = 4.0
This difference exceeds tolerance of 3.0 mb., therefore, this test should be repeated.</td><td colspan="4">Difference of sums 38.0 - 35.8 = 2.2
This difference is within tolerance of 3.0 mb., therefore, this test may be discontinued.</td></tr>
</table>

FIGURE 6.7.3. Illustration of method of compiling sums and differences of sums to test drift by comparison with the "calculated drift tolerance."

the chart. In particular, the drift will be found each successive week for a period embracing a 29-day interval, as illustrated by figs. 6.7.4 and 6.7.5 that is, for any given drift determination based on the chart, the ordinates should be read from the curve of best fit at two points 29-days apart, and the difference between the ordinates should be evaluated.

Considering as an example, the case in which the pair of comparative observations are taken every Sunday, fig. 6.7.5 illustrates the periods for which the drift data are determined on successive weeks, and pre-

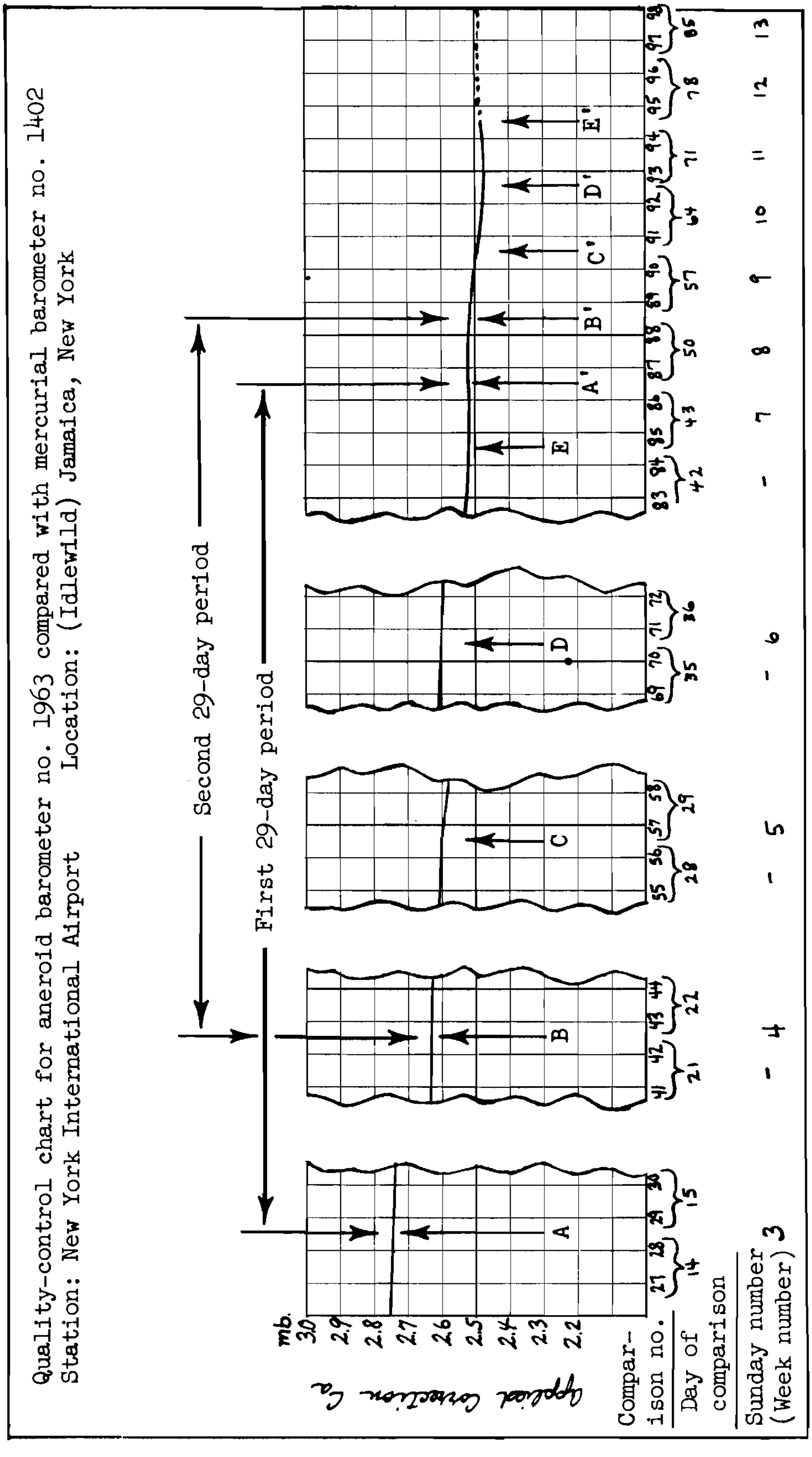


FIGURE 6.7.4. Examples of computing 29-day drift from curve of best fit. Drift is determined by reading the ordinates from the curve at two points spaced 29 days apart on the portion of the curve which is drawn solid (see secs. 6.7.2.4 and 6.7.2.9.5). The first drift value is the difference between ordinate values read at points A and A'; the next value is based on points B and B', and the following one on points C and C', etc. See fig 6.7.8. for a tabulation of results.

Col. (1)	Col. (2)*	Col. (3)*	Col. (4)	Col. (5)	Col. (6)
Time at which drift is determined from curve of best fit, namely, at end of:	Curve of best fit is to be read at points lying immediately		Examples of readings of ordinates of curve of best fit at points referred to in:		29-day drift = Difference = [Col. (5) minus Col. (4)]
	ahead of:	following:	Col. (2)*	Col. (3)*	
Sunday No.	Sunday No.	Sunday No.	mb.	mb.	mb.
9	3	7	2.74	2.52	-0.22
10	4	8	2.63	2.51	-0.12
11	5	9	2.60	2.49	-0.11
12	6	10	2.60	2.48	-0.13
13	7	11	2.52	2.48	-0.04
etc.	etc.	etc.	etc.	etc.	etc.

*The points referred to in Cols. (2) and (3) are indicated in fig. 6.7.4 by suitable letters, namely, (A) - (E), respectively, for Col. (2) and (A') - (E'), respectively, for the corresponding points in Col. (3).

FIGURE 6.7.5. Illustration of times of reading curve of best fit and of readings to determine 29-day drift.

sents examples of ordinate readings and corresponding 29-day drift determinations.

The 29-day drift determined each week from the curve of best fit in the manner illustrated in figs. 6.7.4 and 6.7.5 is used as an index to show whether the drift is excessive or not. For this purpose, a tolerable limit of 29-day drift is established; this limit being designated by the term "29-day drift criterion." The assigned absolute value of the "29-day drift criterion" is 0.25 mb.

If the absolute value of the observed 29-day drift (disregarding algebraic sign) is less than or equal to the "29-day drift criterion" of 0.25 mb., the drift is considered satisfactory.

However, if the absolute value of the 29-day drift exceeds the "29-day drift criterion" of 0.25 mb., the data should be analyzed to determine the causes of the excessive drift, whether real or apparent. Under some conditions a steady upward trend of C_a will be indicative of a slow leak, in which case certain additional readings and precautionary actions must be taken (see instructions dealing with "tail-end drift", secs. 6.7.2.5 and 6.7.2.9.6). Under some conditions the "29-day drift criterion" fails to be satisfied owing to random variability in the values of C_a. In this event, the drift determined from the curve will appear to undergo positive and negative oscillations governed by the variability of the points. Since these oscillations may reflect a combination of causes, such as slight errors in reading of the barometers or deviations in the effects of hysteresis associated with rising and falling pressure, the apparent variations in slope of the curve may not be indicative of changes in the true, long-range drift, but rather of other factors as outlined above. When a scrutiny of the data reveals that this is likely to be the actual explanation of the fluctuations in slope, it is necessary to consider certain measures to reduce the portion of the variability that stems from errors in reading or setting of barometers (see instructions regarding "variability", secs. 6.7.2.6 and 6.7.2.9.7). By taking such measures as are suggested in the latter, it may be possible generally to bring and maintain the slope within the limits specified by

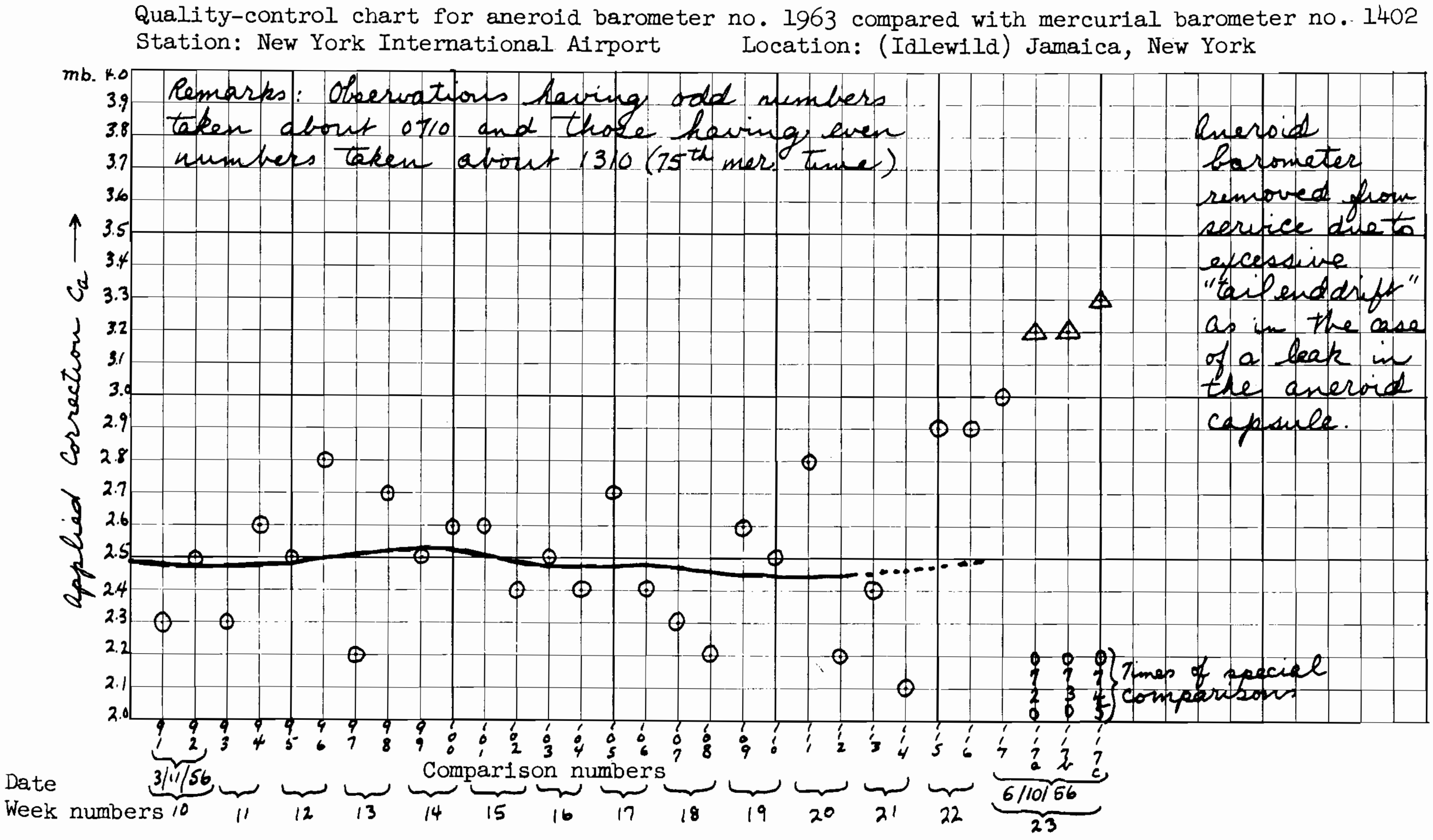
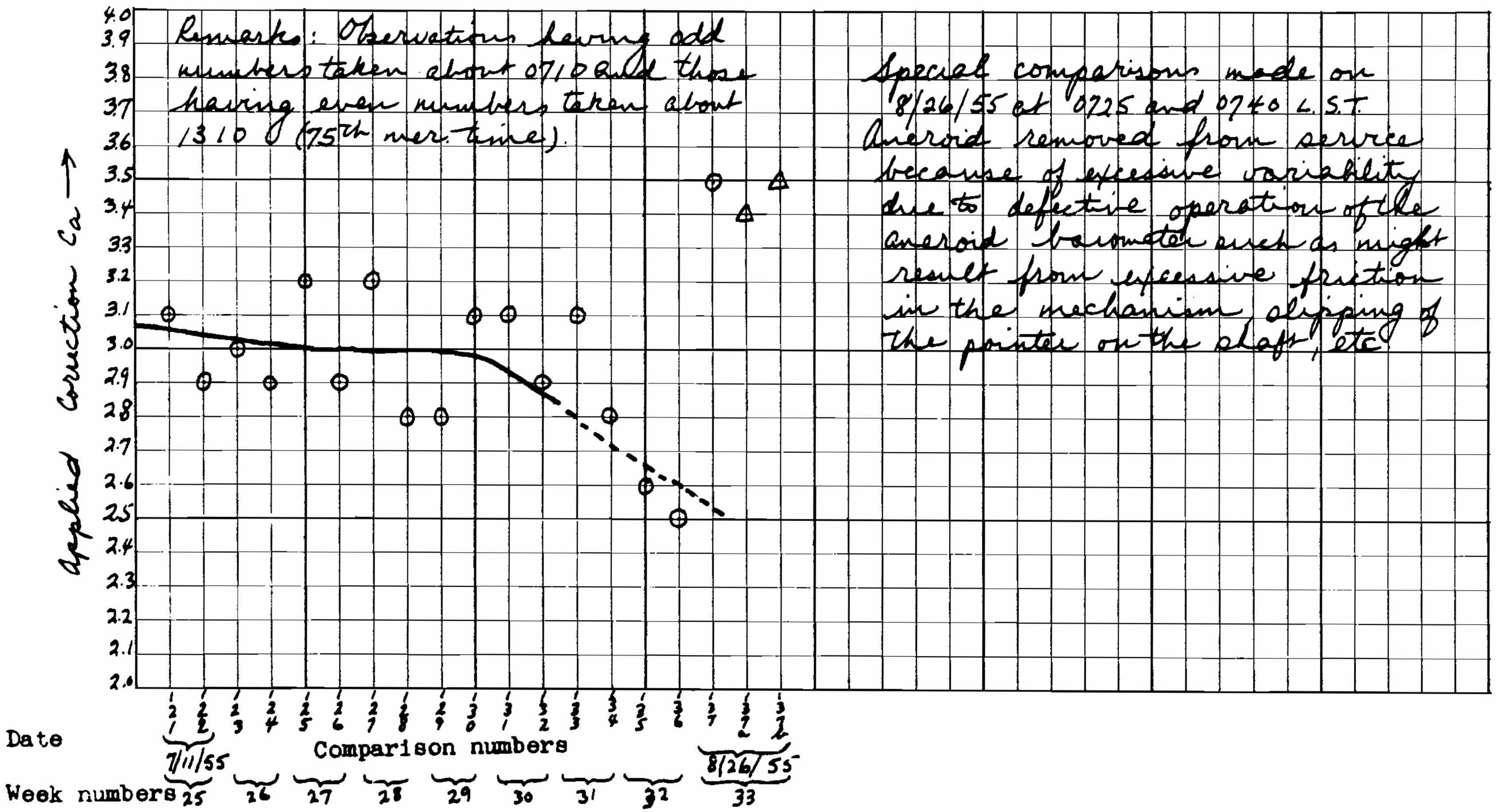


FIGURE 6.7.6. Illustration of "tail-end drift."

Quality-Control Chart for aneroid barometer no._____ compared with mercurial barometer no.______

Station: ____________________ Location: ____________________



Remarks: Observations having odd numbers taken about 0710 and those having even numbers taken about 1310 (75th mer. time).

Special comparisons made on 8/26/55 at 0725 and 0740 L.S.T. Aneroid removed from service because of excessive variability due to defective operation of the aneroid barometer such as might result from excessive friction in the mechanism, slipping of the pointer on the shaft, etc.

FIGURE 6.7.7. Illustration of excessive variability due to defects in the aneroid barometer.

the "29-day drift criterion." Should this not prove to be found in any case, the facts should be reported.

It should be noted that the program of drift investigation will be on a continuing weekly basis so long as the instrument is maintained in service.

6.7.2.5 "Tail-End Drift".—The last several points plotted on the quality-control chart should always be examined to see whether there is any evidence that the drift has suddenly accelerated very markedly, as indicated by a rapid, relatively large deviation of the plotted points from the preceding smooth curve. (See fig. 6.7.6 and 6.7.7.) Such an accelerated drift may occur if the evacuated aneroid capsule springs a leak, or if some member of the mechanism of the instrument is becoming disengaged from the attached apparatus. Evidence of springing of a leak is afforded when the corrections C_a become progressively more positive (larger and larger) at an accelerated rate. As a rule, the corrections (C_a) should not deviate by more than about 0.5 mb. from the value to be expected from the preceding smooth curve of best fit. When the "tail-end drift" appears excessive, at least two special comparative readings should be taken at 10 or 15 minute intervals. If the values of C_a found from these special readings corroborate the previously indicated evidence that the "tail-end drift" is excessive, the aneroid barometer should be taken out of service. However, in some cases, what appears to be excessive drift arises from an error in observation or in evaluation of data. In that event the error in previously obtained data should be corrected, or the erroneous value must be replaced by one of the special readings which has been checked by an additional reading. (See sec. 6.7.2.9.)

6.7.2.6 Variability.—Random variations of the plotted points on the quality-control chart, judged by comparisons with respect to the smooth curve of best fit, will be examined. (See figs. 6.7.2 and 6.7.8.) Two aspects should be kept in mind: *first,* the maximum range of the deviations of the plotted points from the smooth curve of best fit on the quality-control chart should not exceed 0.5 mb.; and *second,* at least 90% of the plotted points should be within ±0.34 mb. of the smooth curve of best fit, and not more than 10% of the points should deviate by 0.4 or 0.5 mb. from the curve. If the performance as regards variability does not meet these specifications, the procedures should be examined at every stage to determine whether the cause of the apparent poor performance can be discovered. Sometimes it may be found to stem from improper settings or readings of the mercurial barometer. Difficulties from this source may be overcome by improving the practices of the observers. However, in some cases the cause of the large random variations lies in the pumping of the mercurial barometer during periods of strong, gusty winds, or in the occurrence of pressure jumps or barometric irregularities at the times of the comparative readings. If the causes are known to be of this character, the points on the quality-control chart thus affected, if not too frequent, may be discounted. The reader is referred to sec. 6.7.2.9.7 for additional listing of causes of variability and for a brief discussion of procedures to be followed when variability is excessive.

6.7.2.7 Calculation of Mean Corrections (C_{am}).—If, and only if, all of the specifications outlined in the preceding paragraphs have been met, allowing for the exceptions stated in sec. 6.7.2.0, the aneroid barometer will be considered satisfactory for use in measurement of pressure at the station. When all of the specifications have been satisfied, the mean correction will be determined as follows: take the sum of ten values of C_a, consisting of twice-daily values for five different days spaced at weekly intervals, working backward from the last values pertaining to the day of the week on which the comparative readings will be made in the future. (See fig. 6.7.9.) For example, suppose it is planned to make the comparative observations twice on every Sunday in the future, this day of the week usually having a minimum workload. Suppose also that the last Sunday for which the pair of observations is available represents day No. 36 in the series, giving observations numbered 71 and 72. Then the last five Sundays are days numbered 8, 15, 22, 29, and 36, yielding

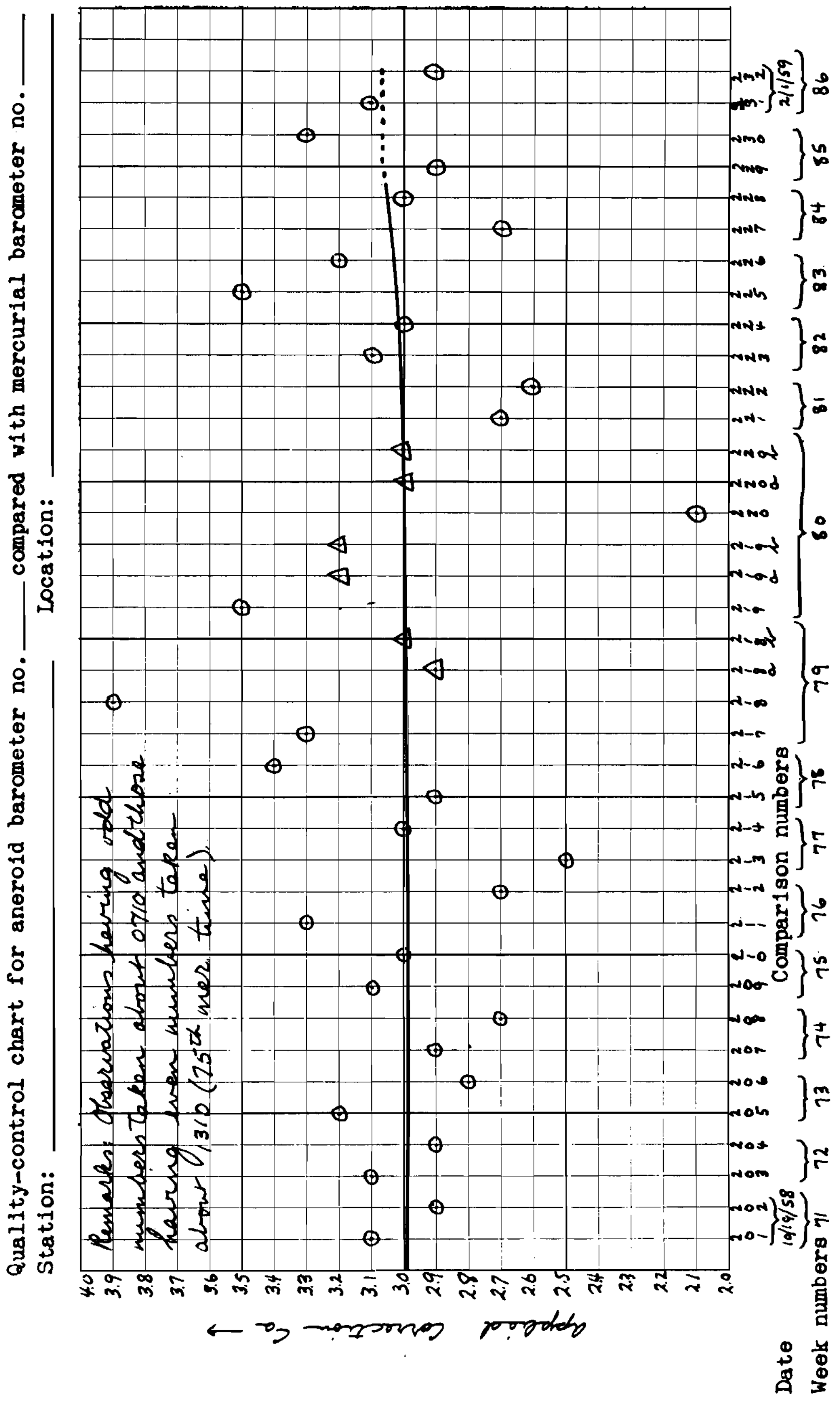


FIGURE 6.7.8. Illustration of excessive variability where *less* than 90% of the plotted points are within ±0.34 mb. of curve; also where some points vary by more than 0.5 mb. from the curve due to poor observing practice as shown by points for special comparison which were within 0.3 mb. of the curve.

Week No.	Day No.	Comparison No.	Range of Week numbers								
			1-5	2-6	3-7	4-8	5-9	6-10	7-11	8-12	9-13
1	1	1	3.2								
		2	3.0								
2	8	15	2.8	2.8							
		16	2.6	2.6							
3	15	29	2.7	2.7	2.7						
		30	2.8	2.8	2.8						
4	22	43	2.5	2.5	2.5	2.5					
		44	2.8	2.8	2.8	2.8					
5	29	57	2.7	2.7	2.7	2.7	2.7				
		58	2.6	2.6	2.6	2.6	2.6				
6	36	71		2.7	2.7	2.7	2.7	2.7			
		72		2.5	2.5	2.5	2.5	2.5			
7	43	85			2.4	2.4	2.4	2.4	2.4		
		86			2.7	2.7	2.7	2.7	2.7		
8	50	87				2.8	2.8	2.8	2.8	2.8	
		88				2.5	2.5	2.5	2.5	2.5	
9	57	89					2.6	2.6	2.6	2.6	2.6
		90					2.2	2.2	2.2	2.2	2.2
10	64	91						2.3	2.3	2.3	2.3
		92						2.5	2.5	2.5	2.5
11	71	93							2.6	2.6	2.6
		94							2.3	2.3	2.3
12	78	95								2.5	2.5
		96								2.8	2.8
13	85	97									2.2
		98									2.7
	Sums		27.7	27.7	26.4	26.2	25.7	25.2	24.9	25.1	24.7
	Means (C_{am})		*2.77	2.67	2.64	2.62	2.57	2.52	2.49	2.51	2.47

*Means will be used in actual practice only after "calculated drift tolerance" is satisfied.

FIGURE 6.7.9. Illustration of method of computing mean corrections (C_{am}) based on 10 comparisons made twice daily on the same day of the week during succeeding weeks. Each column shows the 10 values of C_a that go to form the sum on which the mean is based.

observations numbered 15, 16, 29, 30, 43, 44, 57, 58, 71, and 72. Take the sum of the C_a values found for these ten observations, and determine the corresponding mean value of C_a simply by moving the decimal point one place to the left. (Symbol C_{am} is used to denote the mean value of the correction.) The mean value of C_a thus determined will serve as the applicable correction to the readings of the aneroid barometer, for the entire week following the last day represented in the data covered by the sum of C_a values described above (in this example, the last day is No. 36 and the mean value of C_a thus found remains valid until day No. 43, when a new sum and mean is determined). Entry of the latest mean (C_{am}) will be made on the "Posted Correction Card" (see sec. 6.7.2.8).

Continuing the example, the last five Sundays counting from day No. 43, will include days numbered 15, 22, 29, 36, and 43; and from each of these days there will be obtained two observations, giving ten in all. From the sum of the ten values of C_a thus compiled, one can readily determine the mean (C_{am}). The latter mean will be valid for another week until the termination date and time; and so the process continues.

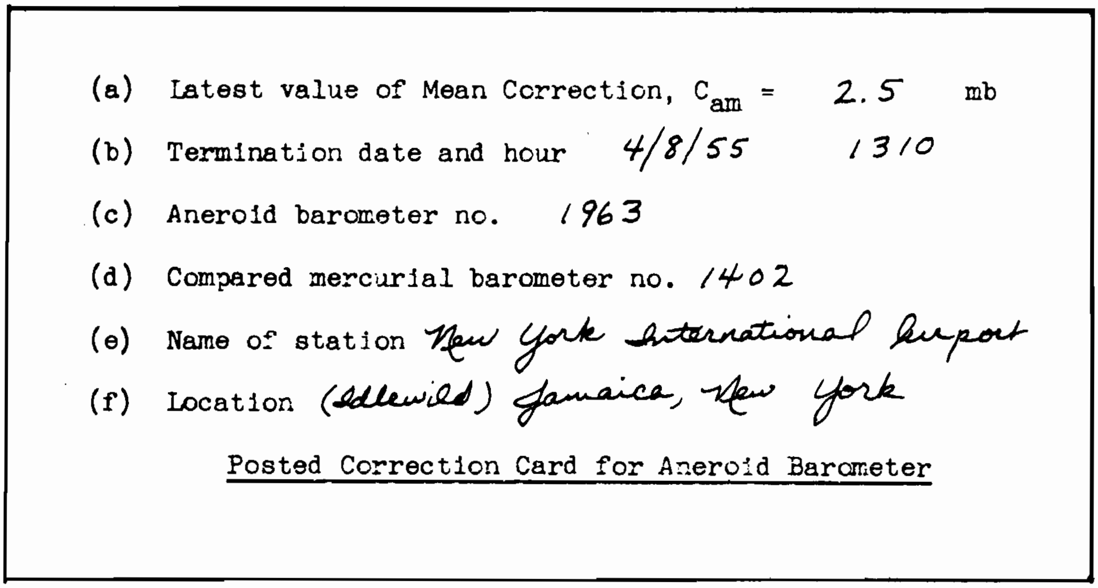
However, if any evidence subsequently secured points to the conclusion that the performance of the instrument consistently falls below the required specifications, the use of the aneroid barometer will be terminated and reliance placed on the mercurial barometer for regular pressure measurements. Special comparative readings at 10 and 15 minute intervals should be instituted any time there is a strong suspicion or evidence to the effect that the performance is unsatisfactory.

6.7.2.8 Posted Correction Card, and Application of the "Posted Correction".—A correction card will be prepared and always kept fastened in place adjacent to the aneroid barometer. (See fig. 6.7.10.) The following information will be filled in on the card:

(a) Latest value of Mean Correction, C_{am} mb.
(b) Termination date and hour
(c) Aneroid barometer No.
(d) Compared mercurial barometer No.
(e) Name of station
(f) Location

Posted Correction Card for Aneroid Barometer

The "Termination date and hour" usually represents the date and hour which is one week (168 hours) later than the time at which the last comparative observation involved in the mean was taken. When circumstances justify it, the termination date and time may be less than one week later. A regular schedule should be followed in determining the appropriate latest value of the mean correction, C_{am}, each week, at the termination date and time pertinent to the mean correction determined the previous week. In what follows, the term "Posted Correction" will be understood to refer to the latest value of the mean correction, C_{am}, for the given aneroid barometer, as entered on the card. The entries of the "posted correction" and other data on the card should always be kept current in accord with the provisions of sec. 6.7.2.7. Entries on lines (a) and (b) of the card should be made in pencil to facilitate revision each week.


(a) Latest value of Mean Correction, C_{am} = 2.5 mb
(b) Termination date and hour 4/8/55 1310
(c) Aneroid barometer no. 1963
(d) Compared mercurial barometer no. 1402
(e) Name of station New York International Airport
(f) Location (Idlewild) Jamaica, New York

Posted Correction Card for Aneroid Barometer

FIGURE 6.7.10. Illustration of posted correction card showing sample entries.

As soon as the criteria specified in secs. 6.7.2.3–6.7.2.6 (see also secs. 6.7.2.9.5–6.7.2.9.8) have been fulfilled and the mean correction (C_{am}) determined as outlined above (see fig. 6.7.9 and sec. 6.7.2.7), the aneroid barometer may be put into service for official measurements of pressure. Readings of the aneroid barometer must be corrected by application of the effective "Posted Correction", in accordance with the definitions given in sec. 6.7.1.

EXAMPLES:

Case I *Removal Correction Constant*

Reading of aneroid barometer, R_a = 1018.2 mb.
"Posted Correction," C_{am} = +2.7 mb.

Station Pressure, $P = (R_a + C_{am})$ = 1020.9 mb.

Case II *Removal Correction Variable*

Outdoor Temperature, t = 42° F.
Corresponding Removal Correction at given station (see section 4.3) = −1.8 mb.

Reading of aneroid barometer, R_a = 986.4 mb.
"Posted Correction," C_{am} = 2.5 mb.

Sum, $R_a + C_{am}$ = 988.9 mb.
Removal Correction (C_{vr}) = −1.8 mb.

Station Pressure,
$P = (R_a + C_{am} + C_{vr})$ = 987.1 mb.

6.7.2.9 Additional Details

6.7.2.9.1 *Records of Data.*—Comparative barometer readings, the calculated corrections (C_a) and sums and means of C_a will be recorded on Form WBAN 54–6.6 as illustrated in figs. 6.7.0(a–f). Instructions regarding the preparation of this form are given on its reverse side (see fig. 6.7.11 and sec. 6.7.3).

6.7.2.9.2 *Numbering of Observations.*—Regular synoptic, pressure observations used for comparative purposes will be numbered in sequence, according to the order of the observation in the series of C_a values which are tabulated on Form WBAN 54–6.6. Special or extra observations made for the purposes of determining C_a will be characterized by letters (a, b, c, d, etc.) appended to the number of the preceding regular observation. For example, suppose that **regular** observation No. 31 in the series yielded a value of C_a which deviated by more than 0.5 mb. from the smooth curve of best fit, and suppose that two special observations were then taken at 10 or 15 minute intervals after regular observation No. 31, which had been made during the course of a thunderstorm. Then, these two special observations would be numbered 31a and 31b. Suppose that Nos. 31a and 31b yield deviations of 0.2 and 0.1 mb. from the smooth curve of best fit on the quality-control chart. In that case No. 31 would be discounted or corrected and the regular schedule resumed with No. 32.

6.7.2.9.3 *Plotting of Quality-Control Chart.*—Graph paper or paper with perpendicular rulings at about 1/5 inch, 1/4 inch, or 1/2 centimeter spacings is suitable for the chart. (See figs. 6.7.1 and 6.7.2.) The ordinate scale, which refers to the correction C_a, should be chosen so that the spacing represents an interval corresponding to the nearest estimated decimal fraction of pressure unit read on the aneroid barometer, such as 0.1 mb. The abscissa scale, which refers to the observation number, should be chosen so that the same spacing represents a difference of one observation number. Values of C_a versus observation number will be plotted as points in ink. The points will be surrounded by a small circle when based on regular observations and by a small triangle when based on special observations. Horizontal spacings on the abscissa scale will be the same for both of these kinds of observations; for example, observations numbered 29, 30, 31, 31a, 31b, 32, 33, etc., will appear in sequence on the quality-control chart spaced at intervals of 1/5 inch, 1/4 inch or 1/2 centimeter. The dates of the first and last comparative observations on the chart will be indicated below the corresponding comparison numbers, which will serve as the abscissas. A note should be written below the date line stating the times at which the odd- and even-numbered comparisons, respectively, are normally taken. The times of special observations should be listed. The name of the station, and its location will be indicated in the upper portion of the chart. Also, the identification numbers of the mercurial barometer and of the aneroid barometer compared with the former should be listed. The numbers pertinent to weeks should be written on a line parallel to the abscissa scale of comparison numbers, beneath the date line. Examples of this are shown in figs. 6.7.1, 6.7.2, 6.7.4, 6.7.6, 6.7.7, and 6.7.8. Numbers used for indicating observations (comparisons) in sequential order are written in vertical arrangement on the quality-control chart to conserve horizontal space (for example, observation No. 19 is written as a 1 above a 9).

6.7.2.9.4 *Constructing Curve of Best Fit.*—A smooth curve of best fit is to be drawn free-hand, by eye estimate, in pencil on the quality-control chart (see fig. 6.7.2). It is intended that the curve represent the general trend of the plotted points, giving weight to the average taken over ten points at a time. This signifies, roughly speaking, that the curve inscribes a line showing the mean ordinates of the points when moving averages are based on groups of ten points in sequence on the chart. The curve is drawn as a solid line for the entire set of points, except for the region of the very first four and the last four points, over which portion of the chart the curve is drawn *dashed.* (Dashes are used to indicate some uncertainty in the ordinates of the moving averages of C_a when there is a lack of sufficient points on one side or the other; i.e., four points on both sides of the two for a given day are considered necessary to establish the ordinate of the solid curve for that day.) The foregoing procedure requires that the observer estimate the ordinates progressively along the curve, considering the mean generally embracing five points on either side. However, if a few points at random deviate by more than the average amount, say 0.4 or 0.5 mb., from the prevailing mean over a group of about ten points, these points may be discounted somewhat, especially if it is known that some cause, such as pumping of the mercurial barometer during squally conditions or pressure irregularities attending thunderstorms, is likely to have introduced a slight error in the comparative readings. On this account the curve should generally be fairly smooth, without insertions of frequent waviness designed to depict deviations of successive individual points. However, if a definite change in trend of the curve persists, by showing up as a marked kink with at least several points on the tail-end of the bend, then special comparative observations should be taken at 10 or 15 minute intervals to check the preceding data (see sec. 6.7.2.5). The performance of the aneroid barometer should also be carefully observed in other ways when and if such kinks appear, to determine whether there is evidence that may reveal malfunctioning of the instrument.

As a rule, an aneroid barometer of good quality which has been subjected to a long seasoning process at a station, and has been handled carefully, should be characterized by a fairly smooth curve, of very slight slope.

6.7.2.9.5 *Drift Shown by Curve of Best Fit.*—As described in subsection 6.7.2.9.4, the curve of best fit is drawn dashed over the region of the very first four and the very last four points to indicate uncertainty in the ordinates. Since drift is to be ascertained on the basis of the portion of the curve regarded as "certain", the drift determination must be limited to the last 29-day portion which is drawn solid, hence it must exclude the very first four points and the very last four points over which the curve is drawn dashed.

To consider a first example, suppose that the weekly schedule calls for a pair of comparative observations to be made each Sunday at a 6-hour interval, and suppose that the resultant C_a values are available for Sundays numbered 1, 2, 3, 4, 5, 6, 7, 8, and 9, in the sequence. According to instructions in subsection 6.7.2.9.4, the curve of best fit is constructed as a solid line covering the range of points from day No. 3 (comparisons No. 5 and 6) and extending to Sunday No. 7, inclusive, whereas the curve is drawn as a dashed line for days No. 1 and 2 (comparisions No. 1–4) and Sundays No. 8 and 9, which yield the first four and the last four points, respectively. After the second comparison on Sunday No. 9, the last 29-day interval on the solid portion of the curve embraces the points obtained on the five Sundays numbered 3–7, inclusive. It is the drift for this portion of the curve which must be examined at the time of the termination of the second comparative reading made on Sunday No. 9.

Similarly, for the second example, at the corresponding time on Sunday No. 10, the solid portion of the curve is extended to cover Sunday No. 8, the dashed portion is extended to cover Sunday No. 10, and the drift must be examined for the period embracing the five Sundays numbered 4–8, inclusive.

The drift is represented by the change in the ordinates over the 29-day interval; for instance, from Sunday No. 3 to Sunday No. 7, in the case of the first example; and from Sunday No. 4 to Sunday No. 8, in the case of the second example. (See figs. 6.7.4 and 6.7.5.) After the amount of the drift for a 29-day period has been determined, it should be recorded in the "Remarks" column of Form WBAN 54–6.6 on the next line pertinent to the date and time. In addition, the first and last comparison numbers spanned in the 29-day interval should be noted; for example, "Drift —0.22 mb.; nos. 29–86", on line No. 87, and "Drift —0.04 mb., nos. 85–94", on line No. 95.

6.7.2.9.6 *Precautions Regarding "Tail-End Drift".*—When the value of C_a is plotted as a point on the quality-control chart, the new point should be immediately compared with the preceding old points. Small fluctuations in value of C_a about the mean are to be expected, and these fluctuations should ordinarily be of the order of 0.0, 0.1, or 0.2 mb. Deviations of 0.3 mb. should occur much less frequently, while variations of 0.4 or 0.5 mb. from the mean should be rare. Accordingly a deviation of 0.4 or 0.5 mb. from the latest mean (C_{am}) should serve as a warning signal, and if time is available one or two special comparisons should be made for checking purposes. Both barometers involved in the comparisons should be tapped each time just before readings are made, in order to secure uniform accommodation of the instruments to the new conditions, and to overcome friction. Sometimes the discrepancy arises from faulty adjustment of the level of the mercury in the cistern of the Fortin barometer, and at times it arises from an inexact setting or reading of the vernier. If it is found that some observers systematically tend to yield lower or higher values of C_a than the other observers, their procedures should be compared to determine the causes of the differences, and good observing practices should be carefully followed by all concerned.

Comparative readings of the mercurial barometer and of the aneroid instrument should be made as close together as practicable, and the readings should be made independently in each case as much as possible. The corrections should be applied to the mercurial barometer data only after the readings of both instruments have been completed.

When the new value of the correction C_a deviates by more than 0.5 mb. from the preceding smooth curve, this should be regarded as a danger signal, and all necessary inspections and checks made to determine the cause, whether it be an error in reading, a mechanical failure, or something else. (See sec. 6.7.2.5.) It is obviously necessary to be careful never to drop any type of barometer.

Some possible causes of marked deviations are mentioned in the next paragraph which presents some information that should be taken into account.

6.7.2.9.7 *Study of Variability.*—The plotted points on the quality-control chart normally will display some characteristic degree of variability about the mean, as explained in sec. 6.7.2.9.6. Limits to acceptable variability have been already set forth in sec. 6.7.2.6.

Among the causes of the variability may be listed the following:

(a) unsteady barometric conditions which may result in discrepancies due to lack of simultaneity of the comparative readings or due to the effects on the instruments in different degrees (as in the case of changes or fluctuations in the local pressure associated with gusty winds, or development and movement of some type of meteorological disturbance which produces such variations, e.g., thunderstorms, "pressure jumps," gravity and mountain waves, eddies in connection with katabatic currents or deep clouds of cumuliform character, etc.);

(b) faulty observational practices;

(c) errors in readings;
(d) lack of temperature equilibrium in barometers;
(e) effect of temperature on the aneroid barometer;
(f) effects of hysteresis and changes of elastic properties;
(g) effects of irregularities and non-linearities in scales.

The matters referred to in the foregoing list have already been discussed to a greater or lesser extent; for example, a draft of cold air striking the attached thermometer may make the readings of the latter unrepresentative of the temperature of the mercurial barometer as a whole (see sec. 2.7.4).

Items (e), (f) and (g) in the list require a little more discussion. Some aneroid barometers are not perfectly compensated for temperature, hence in such cases relatively large changes in the temperature of the instrument may cause the observed correction C_a to vary accordingly. In order to determine whether this is the cause of the large deviations in C_a over a considerable period of time, it is desirable for the observer in charge to prepare a "Chart for checking temperature compensation." In this chart the observer should plot C_a against the temperature as read on the attached thermometer. When this is done for a number of points covering a wide range of temperature, one may investigate how closely C_a is correlated with the temperature reading. If the line of best fit indicates a significant slope, for example, such that a change of 30° F. in temperature appears to correspond to a change of 0.3 mb. in the correction C_a, this fact should be brought to the attention of officials for notification to next higher headquarters.

A copy of the "Chart for checking temperature compensation" should be supplied as part of the report submitting the information. The chart should have notations indicating the essential facts: name of station; its location; number of aneroid barometer; number of mercurial barometer compared with aneroid barometer; "sum of corrections" used in connection with the mercurial barometer; period of time during which the comparative observations were made. It is possible that the exposures of the two instruments differ materially to such an extent that the temperature of the mercurial barometer deviates significantly from the temperature of the aneroid barometer. If reasons exist for believing the temperature differences to be large, this view may be checked by fastening an extra thermometer in contact with the aneroid barometer and making some simultaneous readings of this thermometer and of the thermometer attached to the mercurial barometer. Conditions under which these readings are taken should be similar in general to those under which the comparative pressure observations are obtained, particularly in respect to sunshine, and operation of heating, cooling, and ventilating facilities. When comparative temperature readings are made on this basis, the results should be reported when the "Chart for checking temperature compensation" is submitted. *Caution:* One should not make comparative barometer readings when the instruments are subjected to a rapid rate of change of temperature. The rate may be judged partially by the change of attached thermometer readings with time. If the mercury and scale are not in equilibrium with the thermometer, and a difference of 1° F. or more occurs between them, a significant error will result (see sec. 2.7.4 and Tables 5.2.1, 5.2.2, and 5.2.3).

When the "Chart for checking temperature compensation" shows that the points representing C_a plotted against t (indoor temperature) scatter without any clear correlation between C_a and t (that is, no significant slope of C_a versus t being revealed, or the line of best fit being horizontal), it may be presumed that the temperature compensation is satisfactory. However, at least a 30° F. range of temperature is necessary before one can expect much effect to show up on the chart.

The quality of the performance of the pressure-measuring instruments depends upon the elastic properties of their component parts such as the diaphragm of the aneroid capsule, the linkages, etc. As long as these properties remain constant or vary slowly in a continuous manner with pressure and time, their effect on the corrections C_a may be expected to be fairly regular, in accord with the hysteresis and drift characteristics previously mentioned. However, occasionally some elastic properties may undergo abrupt changes of slight but finite amount; or slippage, and mutual adjustment between parts may occur with sudden, rapid transitions. In these cases, the values of C_a may reveal abrupt shifts, usually of slight amount. To minimize this effect, light tapping of both the mercurial and aneroid barometers before making final settings and readings is required, since the vibration may bring about adjustments to equilibrium progressively. However, one should cease tapping the Fortin barometer after the meniscus is raised to about 1/16 inch from the ivory point, and then one must complete the adjustment by means of the screw to obtain exact contact of the meniscus with the point. (See sec. 2.4.2, item (2), Cistern Setting.)

In tropical regions where the diurnal variation of pressure is marked, some idea of the effects of hysteresis (item f) in producing variability may be gained by a scrutiny of the alternate points on the quality-control chart, since odd-numbered points will tend to occur at one phase of the cycle, and the even-numbered points will tend to occur at a different phase. That is, one set may normally be associated with rising pressure, and the other with falling pressure. In this situation, hysteresis will have a tendency to cause one set to have greater values of C_a than the other. Accordingly, if the station is located in a region characterized by marked diurnal pressure variations, the observer in charge should compare the average values of C_a for odd- and even-numbered comparisons and ascertain whether there is any significant difference. If the mean difference amounts to 0.4 mb. or more, in absolute value, the effect should be considered serious, and reported to next higher headquarters.

Outside of regions where diurnal pressure variations are marked, the effects of hysteresis may be studied by comparing the values of C_a determined during periods of rising and falling pressure, respectively. It is suggested that this be done by contrasting values which stand out as relatively high and relatively low on the quality-control chart. Then the microbarograph traces should be examined to ascertain whether there is a marked tendency for the high values of C_a to be associated with rising pressure and low values to be associated with falling pressure (or vice versa). If the average difference between the values of C_a for these two conditions exceeds 0.5 mb. in absolute amount, the effect may be regarded as significant, and the findings should be reported to the next higher headquarters.

Some cases occur where the scales on the instruments have slight irregularities or where they are non-uniform (item g), thus yielding variability of the corrections. As an example consider the case of an instrument such as an aneroid barometer or altimeter-setting indicator which has a nonlinear scale. If the setting of the hand of the instrument is shifted to overcome drift or for some other reason, a departure from the original calibration of the scale occurs. The change in setting may make the reading correct at one or two points on the scale, but may cause the readings to be incorrect, at other points especially near the limits of the scales. Under such conditions, slight errors may generally appear at the extremes of low and high pressure pertaining to the scale and also at other anomalous points.

In order to test for the existence of such an effect *when excessive variability exists in the C_a values,* the observer should prepare a special graph in which C_a is plotted against the indicated reading (R) of the instrument. The values of R should cover a wide range, at least 50 millibars. With a view to extending the range as much as practicable, extra comparative readings to obtain values of C_a and R should be made during periods of unusually low or high pressure.

After a considerable number of points has been plotted on the special graph of C_a versus R over an adequate range, the observer should endeavor to construct a line of best fit based on the points. If the line is horizontal, this suggests that the correction (C_a) is apparently independent *of the read-*

ing R, which is a satisfactory characteristic. However, if the line of best fit has an appreciable slope, it appears that C_a is correlated with R. When the slope of the line is such that the change in C_a for 50 mb. change in R is 0.5 mb. or less, the effect will be considered tolerable. But when the change exceeds this amount, a report of the facts should be transmitted to next higher, appropriate headquarters. A copy of the special chart should be attached to the report. This should indicate the changes in C_a from the mean value of the readings to the two extremes (lowest and highest), all of which data are to be specified in the report. Should the variation of C_a with R be excessive (say exceeding 0.5 mb. change in C_a per 50 mb. change in R), headquarters may deem it desirable to replace the instrument.

To Summarize:

When abnormal or extreme variability is displayed by the plotted points on the quality-control chart, one or more investigations should be undertaken as found necessary to determine the causes, and to rectify the matter, if possible. Under some circumstances it may be practicable to reduce the variability; for example, by securing agreement between the observers as to the proper manner of adjusting the level of the mercury in the cistern or of setting the vernier to the top of the meniscus in the tube. In addition the proper degree and amount of tapping of barometers with a view to overcoming friction is another important aspect of observing practices which should be taken into account.

6.7.2.9.8 *Mean Correction C_{am} over a Period of Time.*—Since an aneroid barometer will be subject to drift, which becomes slower and slower over a long period of time, it is to be expected that the mean correction (C_{am}) calculated in the manner described in paragraph (7) above will gradually change but eventually will be almost constant in the course of years. While individual values of C_a will undergo slight variations owing to the reasons previously explained (see subsections 6.7.2.9.6 and 6.7.2.9.7), the mean value, C_{am}, being based on ten readings should be quite stable after the first few months of use of the aneroid barometer at the station, under the provisions of the foregoing instructions. In order to keep track of the performance of the instrument, the value of the mean correction (C_{am}) should be shown on Form WBAN 54–6.6 and on the quality-control chart, for each determination. On the chart, a point, enclosed in a small inked square, should be plotted for each calculated value of C_{am}. This point is to be located at an abscissa in the middle of the group of comparisons to which it pertains; for example, at an abscissa between the fifth and sixth values of C_a in the sequence of ten points comprising the group of data from which C_{am} is calculated.

Owing to the fact that the values of C_a depend upon both the aneroid and the mercurial barometers which are compared, any change in the performance of either instrument will be reflected in a corresponding change in the mean value C_{am}. Thus, when the use of the "Residual Correction" is introduced (see sec. 4.4), there will generally be an abrupt change of C_{am}; and likewise, when the "Residual Correction" is revised, there will be a similar revision in C_{am}. In addition, the replacement of the station mercurial barometer by another, lacking a "Residual Correction," may lead to a shift in the value of C_{am}. For these reasons, when any sudden change in C_{am} occurs, a suitable notation regarding the causes of the change should be entered both on Form WBAN 54–6.6, and on the quality-control chart.

An abrupt change in the C_a and C_{am} values will also take place in the event the zero-setting screw or device on the aneroid barometer is changed for any reason, such as, to reduce the amount of the correction, to change from a negative to a positive correction, etc. (See sec. 6.7.1.0.)

When C_a undergoes any significant change or adjustment for the reason explained above the posted correction should be revised. Also, the value of C_{am} should be re-established and verified by not less than four special comparisons over a period of not less than two hours.

6.7.3 Instructions Regarding Preparation of Form WBAN 54–6.6: Comparison of Aneroid Barometer

When an aneroid barometer is compared with a mercurial barometer for purposes of standardizing the aneroid instrument, the pertinent data should be entered on Form WBAN 54–6.6, in accordance with the following instructions, as illustrated in figs. 6.7.0 (a–f):

Heading Data

The observer should see that the name of the organization appears at the head of the form; and in the upper left-hand corner he should check the pertinent space in parentheses to show that the form refers to the comparison of an aneroid barometer. Also, he should fill in with appropriate notations all of the spaces requiring entries, as will be apparent from an inspection of the "Barometer Correction Card," Form WBAN 54–3.3.1. (Abbreviations used: "corr." denotes "correction" or "corrections"; "elev." denotes "elevation"; "merc." denotes "mercurial"; "bar." denotes "barometer"; "alt. setting ind." and "A.S. Ind." denote "altimeter-setting indicator"; "Comp. Nos." denotes "Comparison numbers." Proper units should be inserted where necessary.

Instructions for Filling in Columns

Column No. 1: Comparison No.

Comparison numbers are to be filled in by consecutive order for regular comparisons: 1, 2, 3, etc. Special comparisons will be indicated by addition of small letters to the previous regular comparison number; for example, if two special comparisons are inserted following regular comparison No. 31, the special comparisons will be designated as 31a and 31b.

Column No. 2: Month and Day

A number system is used to indicate the month number, as follows: January, 1; February, 2; March, 3; April, 4; May, 5; June, 6; July, 7; August, 8; September, 9; October, 10; November, 11 and December, 12. The entry in the column will consist of month number, a slant, and day number; for examples, January 2 is represented as 1/2; September 8 as 9/8; etc. The year (or years) involved on the form will be indicated in the heading; for example, if all of the comparative data given on the form were obtained during February and March, 1956, the year 1956 in the heading will be sufficient to identify the year; but if some of the data were obtained during December, 1956, and some during January, 1957, both of the years (1956–1957) written in the year space of the heading will show the appropriate years relating to the data in col. 2.

Column No. 3: Time (LST)

Local standard time (LST) to the nearest minute, on a twenty-four hour clock, is entered; for example, 1:12 a.m., is written 0112; 12:10 p.m. is written 1210, and 11:14 p.m. is written 2314. The proper meridian for the standard of time should be written in at the head of the column (e.g., 90th Mer.)

Column No. 4: Temp. Attach. Therm.

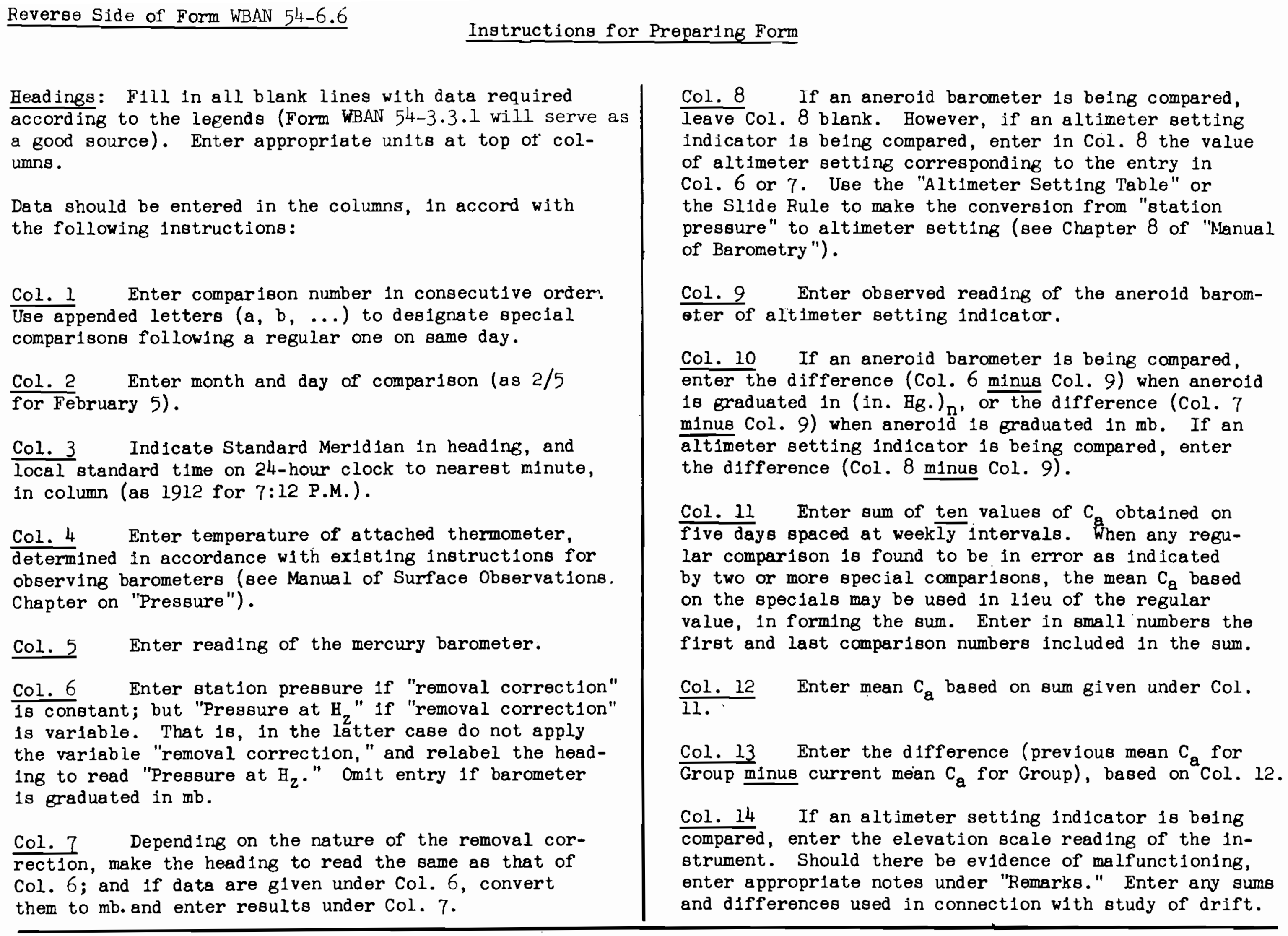
Observe the temperature of the attached thermometer on commencing the comparative reading of the mercurial barometer, and enter in the column the value of temperature thus determined. Indicate the units (°F. or °C. as the case may be) immediately above the heavy line at the head of the column.

Column No. 5: Observed Barometer Reading

Adjust the mercurial barometer and tap it in accordance with existing instructions. Observe the reading and enter the value in column No. 5. Immediately thereafter tap the aneroid barometer, observe its reading, and enter the latter reading in column No. 9. Enter the appropriate units at the heads of the respective columns.

Column No. 6: Station Pressure

Apply the "Sum of Corrections" (see Barometer Correction Card) and the temperature correction for the mercurial barometer (see Chapter 5) to the observed mercurial barometer reading. Enter the resultant value (to the nearest thousandth of an inch) in column No. 6, and check that the units in the heading are pertinent. When and if the "removal correction" is zero or constant, the resultant value last referred to represents the "station pressure"; hence under those circumstances the heading of the column is appropriate.



Reverse Side of Form WBAN 54-6.6

Instructions for Preparing Form

Headings: Fill in all blank lines with data required according to the legends (Form WBAN 54-3.3.1 will serve as a good source). Enter appropriate units at top of columns.

Data should be entered in the columns, in accord with the following instructions:

Col. 1 Enter comparison number in consecutive order. Use appended letters (a, b, ...) to designate special comparisons following a regular one on same day.

Col. 2 Enter month and day of comparison (as 2/5 for February 5).

Col. 3 Indicate Standard Meridian in heading, and local standard time on 24-hour clock to nearest minute, in column (as 1912 for 7:12 P.M.).

Col. 4 Enter temperature of attached thermometer, determined in accordance with existing instructions for observing barometers (see Manual of Surface Observations. Chapter on "Pressure").

Col. 5 Enter reading of the mercury barometer.

Col. 6 Enter station pressure if "removal correction" is constant; but "Pressure at H_z" if "removal correction" is variable. That is, in the latter case do not apply the variable "removal correction," and relabel the heading to read "Pressure at H_z." Omit entry if barometer is graduated in mb.

Col. 7 Depending on the nature of the removal correction, make the heading to read the same as that of Col. 6; and if data are given under Col. 6, convert them to mb. and enter results under Col. 7.

Col. 8 If an aneroid barometer is being compared, leave Col. 8 blank. However, if an altimeter setting indicator is being compared, enter in Col. 8 the value of altimeter setting corresponding to the entry in Col. 6 or 7. Use the "Altimeter Setting Table" or the Slide Rule to make the conversion from "station pressure" to altimeter setting (see Chapter 8 of "Manual of Barometry").

Col. 9 Enter observed reading of the aneroid barometer of altimeter setting indicator.

Col. 10 If an aneroid barometer is being compared, enter the difference (Col. 6 minus Col. 9) when aneroid is graduated in $(\text{in. Hg.})_n$, or the difference (Col. 7 minus Col. 9) when aneroid is graduated in mb. If an altimeter setting indicator is being compared, enter the difference (Col. 8 minus Col. 9).

Col. 11 Enter sum of ten values of C_a obtained on five days spaced at weekly intervals. When any regular comparison is found to be in error as indicated by two or more special comparisons, the mean C_a based on the specials may be used in lieu of the regular value, in forming the sum. Enter in small numbers the first and last comparison numbers included in the sum.

Col. 12 Enter mean C_a based on sum given under Col. 11.

Col. 13 Enter the difference (previous mean C_a for Group minus current mean C_a for Group), based on Col. 12.

Col. 14 If an altimeter setting indicator is being compared, enter the elevation scale reading of the instrument. Should there be evidence of malfunctioning, enter appropriate notes under "Remarks." Enter any sums and differences used in connection with study of drift.

FIGURE 6.7.11. Illustration of the reverse side of Barometer Comparisons Form WBAN 54-6.6.

However, when the "removal correction" is variable and has not been applied to the observed reading of the mercurial barometer, the value to be entered in column No. 6 represents the "pressure at H_z"; that is, the pressure at the actual elevation of the cistern of the mercurial barometer, denoted by H_z. Hence, under the latter circumstances, the heading of column No. 6 will be revised by ink notations to read "pressure at H_z," and the word "Station" will be deleted. (*Note:* Col. No. 6 is specifically designed for a mercurial barometer graduated in inches. If, however, the barometer is graduated in millibars, enter the appropriate data directly in Col. No. 7, and leave Col. No. 6 blank.)

Column No. 7: Station Pressure

The heading of column No. 7 will be made to agree with that of column No. 6 when the latter has been changed. In case column No. 9 is in millibars, enter under column No. 7 the value in millibars (to the nearest 0.1 mb.) corresponding to the value under column No. 6. (The observer must be certain that the appropriate conversion table is used for conversion from inches of mercury (standard) to millibars. See sec. 1.4.) However in case column No. 9 is in inches of mercury omit entries under column No. 7.

Column No. 8: Altimeter Setting

No entry is to be made in this column when the readings involve comparison of aneroid and mercurial barometers.

Column No. 9: Observed Reading (Aneroid)

Delete the portion of the caption which is inappropriate (that is, delete "or A.S. Ind."), and fill in the proper unit at the head of the column. The aneroid barometer must be tapped just before reading it, and the value of the reading should be entered to the nearest decimal fraction of a unit which may be estimated, (for example, to the nearest tenth of a mb.). (*Note:* In order to minimize the time interval between readings of the two barometers, the mercury barometer should be set first as required under the given conditions, then the aneroid barometer should be read as soon as practicable after the setting of the mercury instrument, and finally the reading of the mercury barometer should be taken.)

Column No. 10: Correction (C_a)

The correction, as defined in sec. 6.7.1, should be entered in column No. 10. Accordingly, when the aneroid barometer is graduated to read in millibars, and the heading of column No. 7 is filled in properly to agree with that of column No. 6 (see instructions relating to those columns), the value of C_a is given by the following relationship: (value in column No. 7 *minus* value in column No. 9). However, when the aneroid barometer is read in inches of mercury, the value of C_a is given by the relationship: (value in column No. 6 *minus* value in column No. 9).

Column No. 11: Sum of C_a for Group; and Comp. Nos.

This column is used for summary purposes; hence, as a general rule, every line does not have an entry. The group always consists of ten (10) values of C_a, ending with the last one for the day; and the sum is based on pairs taken 6 hours apart for five days *spaced at weekly intervals.* These five days are always taken as the same day of the week; for example, if it is planned to have the pair of comparative readings observed every Sunday, then the sum for the group is obtained by the algebraic addition of the ten values of C_a observed on the five successive Sundays. The comparison numbers comprising the group will be indicated by small numbers showing the first and the last comparison numbers; for example, 85–94. If additional space is needed, the numbers involved will be entered under "Remarks." The entries of "Sum of C_a for the Group and the Comparison Numbers" are to be made on the line pertaining to the last comparison number included in the group (thus on line for comparison No. 94 in the example).

Column No. 12: Mean C_a for Group

The "Mean C_a for the Group" (C_{am}) is found from the corresponding sum for the group given on the same line in column No. 11; and it is obtained from the sum simply by moving the decimal point one place to the left. For example, if the sum is 25.6 mb., the mean is 2.56 mb., which should be entered in the column. (Note: The quantity to be given on the "Posted Correction Card" should be the mean value rounded to the nearest readable decimal place on the scale of the aneroid barometer; in this example, therefore, the card would show $C_{am} = 2.6$ mb.)

Column 13: Difference between Successive Means

Enter in column 13 the difference given in accord with the relationship: (last "Mean C_a for Group" *minus* immediately preceding "Mean C_a for Group"). The result, with the proper algebraic sign and carried to the nearest hundredth of a millibar, should be entered on the same line as the last "Mean C_a for Group." For example, consider the following illustrative data:

Comp. Nos.	Col. 12 Mean C_a for Group	Col. 13 Difference Between Successive Means
	mb.	*mb.*
85–94	2.49	
87–96	2.51	+0.02
89–98	2.47	−0.04

Column 14: Remarks

When evidence of barometer malfunction is found, or if errors in any data are detected, appropriate notes should be entered in this column. Information regarding a resetting of the aneroid barometer or a change in the mercurial barometer should also be indicated. The sums for 14 values of C_a as required in accordance with sec. 6.7.2.3, with the first and last of the comparison numbers comprised in the sum, should also be recorded under "Remarks"; for example:

"Nos. 1–14, C_a sum 40.4 mb.", entered on line No. 14

"Nos. 15–28, C_a sum 38.0 mb.", entered on line No. 28

"Nos. 57–70, C_a sum 36.4 mb.", entered on line No. 70

"Nos. 71–84, C_a sum 35.8 mb.", entered on line No. 84.

Likewise, readings taken from the curve of best fit on the quality-control chart in accordance with sec. 6.7.2.4 and the corresponding drift should be entered under "Remarks," for example:

"Curve Nos. 28–29, $C_a = 2.74$ mb.", entered on line No. 28

"Curve Nos. 86–87, $C_a = 2.52$ mb.", entered on line No. 86

"Curve Nos. 84–85, $C_a = 2.52$ mb.", entered on line No. 84

"Curve Nos. 94–95, $C_a = 2.47$ mb.", entered on line No. 94

"Drift −0.22 mb.: Nos. 29–86", entered on line No. 87

"Drift −0.04 mb.; Nos. 85–94", entered on line No. 95.

If additional space is necessary for entering remarks, the reverse side of the form or extra attached sheets of paper may be used. In such cases make a note on the face of the form calling attention to the location of these additional remarks; for example "See over," or "See attached sheet" (see fig. 6.7.0(f)).

6.8 STANDARDIZATION OF ALTIMETER-SETTING INDICATORS

6.8.0 General Information Concerning Altimeter-Setting Indicators

The altimeter-setting indicator (see sec. 2.9.2 and figs. 6.8.1 and 6.8.2) is a specialized form of aneroid barometer designed to indicate the "altimeter setting" directly, provided the instrument is properly calibrated and adjusted. It is capable of indicating changes in altimeter setting with precision. "Altimeter setting" is defined in Chapter 8.

Since accurate altimeter settings are required on an absolute basis to satisfy the needs of aviation, the data provided by the instrument must always be properly corrected. For this reason it is necessary to compare the readings of the altimeter-setting indicator with the altimeter setting obtained by converting station pressure to the corresponding altimeter setting by means of an appropriate table. (It should be understood that the station pressure in this case is determined by use of a standardized mercurial barometer.) Such comparisons permit the obtainment of corrections (C_a) to the readings of the altimeter-setting indicator, and these corrections after suitable averaging must be applied to the readings of the indicator in order to yield accurate altimeter settings. To a certain extent the procedures for obtaining such corrections are similar to those used for securing corrections to be applied to aneroid barometers (see sec. 6.7).

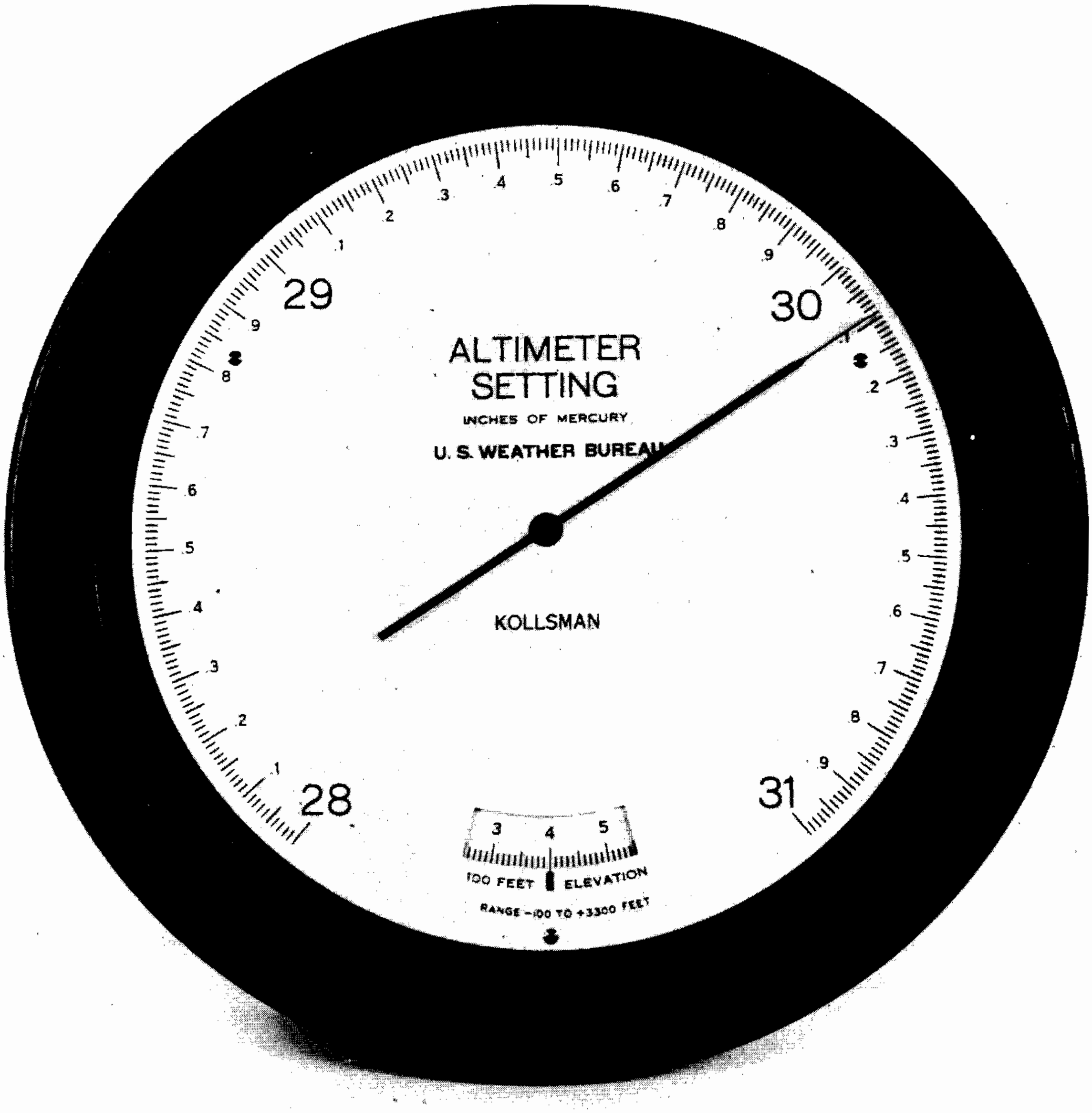


FIGURE 6.8.1. Illustration of one type of altimeter-setting indicator showing the dial and pointer for indicating the altimeter setting and the adjustable elevation scale at the bottom of the dial.

The table for converting from station pressure to corresponding altimeter setting must be prepared by methods which are described in Chapter 8. This table is calculated for the case of a perfectly accurate altimeter-setting indicator, and therefore does not itself involve instrumental errors.

Fig. 6.8.3 illustrates an example of the table which is prepared to give the altimeter setting corresponding to any station pressure (P), appropriate to the station elevation at the station. A table based on any other elevation would not yield correct results.

Inasmuch as the altimeter-setting indicator is a form of precision aneroid barometer it has similar characteristics, which have already been described in sec. 2.10. This signifies that the altimeter-setting indicator will be subject to "creep" or "drift", hysteresis, and other mechanical effects. The differences between the instruments lie in the

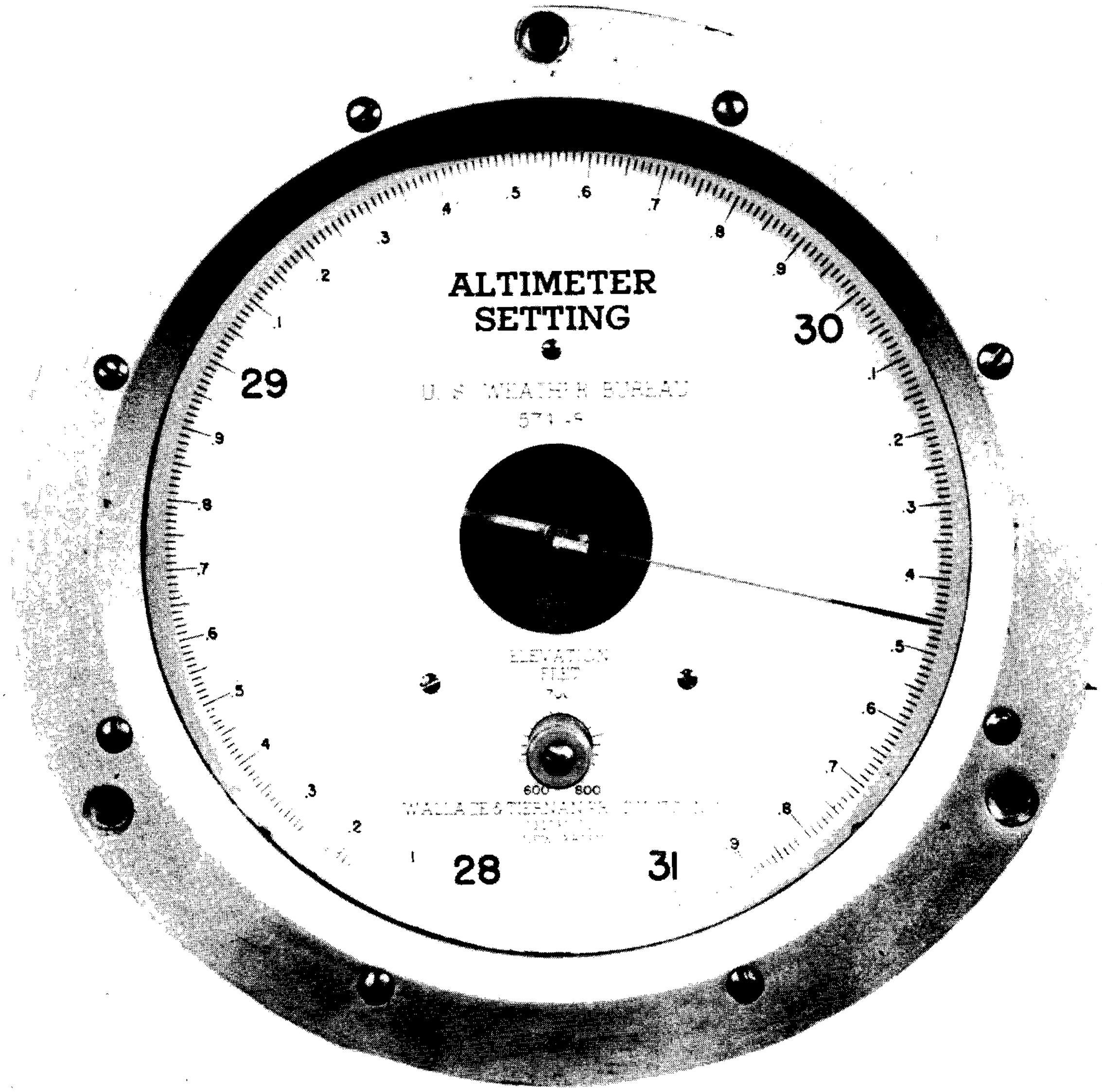


FIGURE 6.8.2. Illustration of one type of altimeter-setting indicator showing the dial and pointer for indicating the altimeter setting, also the elevation scale and adjustment screw in the lower portion of the dial.

mechanisms: in the case of the aneroid barometer the linkages and scale are designed to yield direct pressure readings; whereas in the case of the altimeter-setting indicator the mechanism and scale are constructed to provide altimeter settings. However, one important distinction must be considered, and this stems from the fact that altimeter setting is dependent on elevation as well as on pressure in a non-linear manner. On this account the altimeter-setting indicator is provided with an adjustment for elevation. In particular, the case of the instrument has a screw which may be turned to reset the device accordingly, where the proper setting position is shown by the index of the special elevation scale on the face of the instrument. (For example, the setting is for an elevation of about 400 feet in fig. 6.8.1.) Any significant change of elevation of the instrument will necessitate an appropriate change in the setting position according to

Marquette, Michigan **Station Elevation H_p = 734 feet**

Sta. Pres. (inches)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
26.30	27.01	27.02	27.03	27.04	27.05	27.06	27.07	27.09	27.10	27.11
26.40	27.12	27.13	27.14	27.15	27.16	27.17	27.18	27.19	27.20	27.21
26.50	27.22	27.23	27.24	27.25	27.26	27.27	27.28	27.29	27.30	27.31
26.60	27.32	27.33	27.34	27.35	27.36	27.37	27.38	27.39	27.40	27.41
26.70	27.42	27.43	27.44	27.45	27.46	27.47	27.48	27.49	27.50	27.51
26.80	27.52	27.53	27.55	27.56	27.57	27.58	27.59	27.60	27.61	27.62
26.90	27.63	27.64	27.65	27.66	27.67	27.68	27.69	27.70	27.71	27.72
27.00	27.73	27.74	27.75	27.76	27.77	27.78	27.79	27.80	27.81	27.82
27.10	27.83	27.84	27.85	27.86	27.87	27.88	27.89	27.90	27.91	27.92
27.20	27.93	27.94	27.95	27.96	27.97	27.98	27.99	28.00	28.01	28.03
27.30	28.04	28.05	28.06	28.07	28.08	28.09	28.10	28.11	28.12	28.13
27.40	28.14	28.15	28.16	28.17	28.18	28.19	28.20	28.21	28.22	28.23
27.50	28.24	28.25	28.26	28.27	28.28	28.29	28.30	28.31	28.32	28.33
27.60	28.34	28.35	28.36	28.37	28.38	28.39	28.40	28.41	28.42	28.43
27.70	28.44	28.45	28.46	28.47	28.48	28.50	28.51	28.52	28.53	28.54
27.80	28.55	28.56	28.57	28.58	28.59	28.60	28.61	28.62	28.63	28.64
27.90	28.65	28.66	28.67	28.68	28.69	28.70	28.71	28.72	28.73	28.74
28.00	28.75	28.76	28.77	28.78	28.79	28.80	28.81	28.82	28.83	28.84
28.10	28.85	28.86	28.87	28.88	28.89	28.90	28.91	28.92	28.93	28.94
28.20	28.95	28.96	28.98	28.99	29.00	29.01	29.02	29.03	29.04	29.05
28.30	29.06	29.07	29.08	29.09	29.10	29.11	29.12	29.13	29.14	29.15
Sta. Pr.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09

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FIGURE 6.8.3(a). Sample of table for determining altimeter setting that corresponds to station pressure (p. 1 of 2).

this scale. When this setting is altered, the correction of the instrument may change also. Therefore, it is necessary to re-establish the appropriate correction in accordance with procedures outlined in the succeeding subsections, whenever the elevation of the instrument is changed or a readjustment is made in the setting of the elevation scale.

A slight readjustment of the setting of the elevation scale is permitted in order to secure the desired algebraic sign and magnitude of the correction which is to be established, as explained in sec. 6.8.2.0.

If the altimeter-setting indicator ever drifts to such an extent that the setting on the elevation scale goes outside the limits of

Sc 4/6/56 **ALTIMETER SETTINGS** p. 2 of 2

Sta. Pres. (inches)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
28.40	29.16	29.17	29.18	29.19	29.20	29.21	29.22	29.23	29.24	29.25
28.50	29.26	29.27	29.28	29.29	29.30	29.31	29.32	29.33	29.34	29.35
28.60	29.36	29.37	29.38	29.39	29.40	29.41	29.43	29.44	29.45	29.46
28.70	29.47	29.48	29.49	29.50	29.51	29.52	29.53	29.54	29.55	29.56
28.80	29.57	29.58	29.59	29.60	29.61	29.62	29.63	29.64	29.65	29.66
28.90	29.67	29.68	29.69	29.70	29.71	29.72	29.73	29.74	29.75	29.76
29.00	29.77	29.78	29.79	29.80	29.81	29.82	29.83	29.84	29.85	29.86
29.10	29.87	29.88	29.90	29.91	29.92	29.93	29.94	29.95	29.96	29.97
29.20	29.98	29.99	30.00	30.01	30.02	30.03	30.04	30.05	30.06	30.07
29.30	30.08	30.09	30.10	30.11	30.12	30.13	30.14	30.15	30.16	30.17
29.40	30.18	30.19	30.20	30.21	30.22	30.23	30.24	30.25	30.26	30.27
29.50	30.28	30.29	30.30	30.31	30.32	30.33	30.34	30.36	30.37	30.38
29.60	30.39	30.40	30.41	30.42	30.43	30.44	30.45	30.46	30.47	30.48
29.70	30.49	30.50	30.51	30.52	30.53	30.54	30.55	30.56	30.57	30.58
29.80	30.59	30.60	30.61	30.62	30.63	30.64	30.65	30.66	30.67	30.68
29.90	30.69	30.70	30.71	30.72	30.73	30.74	30.75	30.76	30.77	30.78
30.00	30.79	30.80	30.81	30.82	30.83	30.85	30.86	30.87	30.88	30.89
30.10	30.90	30.91	30.92	30.93	30.94	30.95	30.96	30.97	30.98	30.99
30.20	31.00	31.01	31.02	31.03	31.04	31.05	31.06	31.07	31.08	31.09
Sta. Pr.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09

Marquette, Michigan **Station Elevation H_p = 734 feet**

FIGURE 6.8.3(b). Sample of table for determining altimeter setting that corresponds to station pressure (p. 2 of 2).

the designed range of the elevation scale on the instrument at hand, it is necessary to secure a replacement. (For example, the designed range of the elevation scale is —100 feet to + 3300 feet for the instrument shown in fig. 6.8.1; and 600 to 800 feet in the case of the instrument shown in fig. 6.8.2.)

Whenever it is necessary to change the setting of the elevation scale for the purpose of securing a small, convenient correction (preferably positive), the observer should take note of the difference between the reading on that scale and the actual elevation of the instrument above mean sea level. Should the difference exceed 100 feet, action should be taken to notify appropriate headquarters, so that remedial measures may be taken, if necessary.

It has been pointed out that the altimeter setting varies with pressure in accord with a non-linear relationship, depending upon the elevation. For this reason any significant discrepancy between the setting of the elevation scale and the actual elevation of the instrument may cause the device to depart from its original calibration at points on the scale other than the one or two for which the readings are correct.

The effect may become manifest by means of the variability among the points on the quality-control chart, especially by the deviation between the values of C_a for readings at low and high pressure. Some data may be studied to determine whether this effect is present in any particular instrument after it has been in use for some time at a station. The procedure for doing this has already been described in sec. 6.7.2.9.7. In particular for this case, a special graph is prepared with points plotted, based on value of C_a versus reading (R) of the altimeter-setting indicator. When necessary, extra comparative readings should be taken at times of low and high pressure in order to cover as great a range as practicable. If the line of best fit constructed on the basis of the plotted points has a slope such that the change in C_a exceeds 0.01 inch of mercury per 1.50 inches of mercury change in R, a report of the facts will be rendered to the next higher headquarters. A copy of the chart should be attached. Headquarters may recommend a replacement of the instrument when the slope is considered excessive.

Errors of the altimeter-setting indicator arising from normal sources such as slow drift may be overcome by the application of a suitable correction determined in accordance with the instructions given hereunder. However, an error which appears owing to the development of a leak in the aneroid capsule cannot be corrected for consistently. In this eventuality, the instrument should be taken out of service immediately and a replacement procured. As in the case of an aneroid barometer which develops a leak, this serious defect will become manifest by a marked *apparent* decrease of altimeter setting not substantiated by other evidence based on readings of the mercurial barometer and microbarograph. Observers must always be on the alert for the telltale signs of a leak in the aneroid capsule.

When an altimeter setting indicator but not an aneroid barometer is available at a station, it is permissible to deduce station pressure with the aid of a reading of the former instrument. In this case the reading is first corrected by applying the average C_a correction based on the last ten comparisons, and due allowance is also made for the "removal correction," if any (see secs. 6.8.1.0–6.8.1.2). Finally, the thus-corrected altimeter setting is converted to the corresponding station pressure by means of an appropriate type of table or computer (see sec. 8.1.2), based on the proper elevation. With regard to the table, one may use the type shown in fig. 6.8.3 employing inverse interpolation, or one may make use of a specially prepared table which gives the station pressure directly as function of corrected altimeter setting (see sample in fig. 6.8.4).

Examples:

Given: Station elevation, H_p = 734 feet.[4]

Given: Corrected altimeter setting = 30.14 in. Hg.

(A) Using fig. 6.8.3, the altimeter setting is found in the body of the table, and the corresponding station pressure is found from the sum of the arguments given in the left-hand side and at the head of the column; in this case station pressure =(29.30 + 0.06) in. Hg = 29.36 in. Hg. This procedure illustrates inverse interpolation or application of a table.

(B) Using fig. 6.8.4, the corrected altimeter setting is the argument, and the station pressure is given in the body of the table. In this case, we find directly station pressure = 29.36 in. Hg.

6.8.1 Definitions of Corrections, C_a, of Altimeter-Setting Indicator

6.8.1.0 General Information.—The following notation is used:

P = station pressure (that is, pressure at the level of the station elevation, H_p);

P_z = pressure at the level of the actual elevation of the barometer (H_z);

---

[4] The "removal correction" is assumed constant.

Marquette, Michigan Station Elevation H_p = 734 Feet

(Tabular values are station pressures)

Altimeter Setting	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
28.00	27.27	27.28	27.29	27.30	27.31	27.32	27.33	27.33	27.34	27.35
28.10	27.36	27.37	27.38	27.39	27.40	27.41	27.42	27.43	27.44	27.45
28.20	27.46	27.47	27.48	27.49	27.50	27.51	27.52	27.53	27.54	27.55
28.30	27.56	27.57	27.58	27.59	27.60	27.61	27.62	27.63	27.64	27.65
28.40	27.66	27.67	27.68	27.69	27.70	27.71	27.72	27.73	27.74	27.75
28.50	27.76	27.77	27.78	27.78	27.79	27.80	27.81	27.82	27.83	27.84
28.60	27.85	27.86	27.87	27.88	27.89	27.90	27.91	27.92	27.93	27.94
28.70	27.95	27.96	27.97	27.98	27.99	28.00	28.01	28.02	28.03	28.04
28.80	28.05	28.06	28.07	28.08	28.09	28.10	28.11	28.12	28.13	28.14
28.90	28.15	28.16	28.17	28.18	28.19	28.20	28.21	28.22	28.23	28.24
29.00	28.24	28.25	28.26	28.27	28.28	28.29	28.30	28.31	28.32	28.33
29.10	28.34	28.35	28.36	28.37	28.38	28.39	28.40	28.41	28.42	28.43
29.20	28.44	28.45	28.46	28.47	28.48	28.49	28.50	28.51	28.52	28.53
29.30	28.54	28.55	28.56	28.57	28.58	28.59	28.60	28.61	28.62	28.63
29.40	28.64	28.65	28.66	28.67	28.68	28.68	28.69	28.70	28.71	28.72
29.50	28.73	28.74	28.75	28.76	28.77	28.78	28.79	28.80	28.81	28.82
29.60	28.83	28.84	28.85	28.86	28.87	28.88	28.89	28.90	28.91	28.92
29.70	28.93	28.94	28.95	28.96	28.97	28.98	28.99	29.00	29.01	29.02
29.80	29.03	29.04	29.05	29.06	29.07	29.08	29.09	29.10	29.11	29.12
29.90	29.13	29.14	29.15	29.15	29.16	29.17	29.18	29.19	29.20	29.21
Alt.Stg.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09

LCR:Sc 10/10/55 Station Pressure as a Function of Altimeter Setting p. 1 of 2

FIGURE 6.8.4(a). Sample of a special table for determining station pressure that corresponds to altimeter setting (p. 1 of 2).

A_p = altimeter setting determined by tables (or slide rule computer) on the basis of the station pressure (P) as an argument, where tables (or computer evaluations) depend upon parameter H_p;

A_z = altimeter setting determined by tables on the basis of the pressure P_z as argument, where tables (or computer evaluations) depend on the parameter H_z;

A_i = altimeter setting indicated by the Altimeter-Setting Indicator;

C_a = correction applicable to A_i.

As in the case described in subsection 6.7.1, the definition of C_a depends upon the character of the removal correction, whether constant or variable (see Form WBAN 54–3.3.1, and Chapter 4).

6.8.1.1 Definition of C_a in Case Where Removal Correction is Constant.—When the

LCR:Sc 10/10/55 Station Pressure as a Function of Altimeter Setting p. 2 of 2

Altimeter Setting	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
30.00	29.22	29.23	29.24	29.25	29.26	29.27	29.28	29.29	29.30	29.31
30.10	29.32	29.33	29.34	29.35	29.36	29.37	29.38	29.39	29.40	29.41
30.20	29.42	29.43	29.44	29.45	29.46	29.47	29.48	29.49	29.50	29.51
30.30	29.52	29.53	29.54	29.55	29.56	29.57	29.58	29.59	29.60	29.61
30.40	29.61	29.62	29.63	29.64	29.65	29.66	29.67	29.68	29.69	29.70
30.50	29.71	29.72	29.73	29.74	29.75	29.76	29.77	29.78	29.79	29.80
30.60	29.81	29.82	29.83	29.84	29.85	29.86	29.87	29.88	29.89	29.90
30.70	29.91	29.92	29.93	29.94	29.95	29.96	29.97	29.98	29.99	30.00
30.80	30.01	30.02	30.03	30.04	30.05	30.05	30.06	30.07	30.08	30.09
30.90	30.10	30.11	30.12	30.13	30.14	30.15	30.16	30.17	30.18	30.19
31.00	30.20	30.21	30.22	30.23	30.24	30.25	30.26	30.27	30.28	30.29
31.10	30.30	30.31	30.32	30.33	30.34	30.35	30.36	30.37	30.38	30.39
31.20	30.40	30.41	30.42	30.43	30.44	30.45	30.46	30.47	30.48	30.49
31.30	30.50	30.51	30.52	30.53	30.54	30.55	30.55	30.56	30.57	30.58
31.40	30.59	30.60	30.61	30.62	30.63	30.64	30.65	30.66	30.67	30.68
Alt.Stg.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09

Marquette, Michigan Station Elevation H_p = 734 Feet

(Tabular values are station pressures)

FIGURE 6.8.4(b). Sample of a special table for determining station pressure that corresponds to altimeter setting (p. 2 of 2).

removal correction is constant, the definition of C_a is given by

$$C_a = (A_p - A_i). \qquad (1)$$

In this case the application of C_a is in accord with the relationship

$$A_p = (A_i + C_a). \qquad (2)$$

This may be interpreted to signify that the algebraic sum of A_i and C_a under the given condition yields the altimeter setting calculated on the basis of the station pressure (P) existing at the station elevation (H_p).

6.8.1.2 Definition of C_a in Case Where Removal Correction is Variable.—When the removal correction is variable, the definition of C_a is given by

$$C_a = (A_z - A_i). \qquad (3)$$

Under this condition, the application of C_a is in accord with the equation

$$A_z = (A_i + C_a). \qquad (4)$$

This signifies that the algebraic sum of A_i and C_a yields the altimeter setting calculated on the basis of the barometric pressure (P_z) existing at the level of the cistern of the mercurial barometer (H_z).

6.8.1.3 Significance of C_a.—By virtue of the foregoing two definitions of C_a, it may be seen that C_a includes a correction to cause the reading given by the altimeter setting when corrected to agree with the altimeter setting that would be calculated from the barometric pressure as determined from the mercurial barometer appropriate to some elevation (H_p or H_z in the two respective cases). In addition, the value of C_a involves a correction to allow for the difference in elevation between the altimeter-setting indicator and H_p or H_z, depending upon whether the removal correction is constant or variable, respectively.

In the first case (see sec. 6.8.1.1), this signifies that a perfect altimeter would indicate the elevation H_p when subjected to the barometric pressure at the level ten (10) feet above the station elevation H_p; in the second case (see sec. 6.8.1.2), the statement signifies that a perfect altimeter would indicate the elevation H_z when subjected to the barometric pressure existing at the level ten (10) feet above the elevation of the cistern of the mercurial barometer (H_z). By "perfect altimeter" is meant one which remains calibrated exactly in accordance with the Standard Atmosphere, and functions precisely in the manner required by theoretical design. It is assumed in the foregoing that each instrument must have its altimeter setting adjusted to the current value pertinent to the specified elevation, (H_p or H_z, respectively).

A question often arises as to whether an altimeter setting obtained for one elevation is valid for an altimeter at a different elevation in the same locality. It is useful to take note of the fact that if a perfect altimeter is set on the basis of the altimeter setting valid for a given elevation (such as H_p or H_z as explained in the previous paragraph), the readings of the altimeter would still be accurate even when the instrument is raised or lowered say 50 feet from the 10–foot level above H_p (or H_z as the case may be). Perfect accuracy would be achieved when the atmospheric temperature is in harmony with the vertical temperature distribution assumed in the definition of the Standard Atmosphere. When an altimeter is raised or lowered with respect to the datum level for altimeter settings, described above, errors in altitude reading of altimeters occur when a deviation exists between mean temperature of the pertinent actual air column and the mean temperature of the appropriate portion of Standard Atmosphere column. For every 10° F. deviation of such temperature values the error amounts to 2% of the difference in altitude from the datum level. To consider an example: Temperature deviation of 30° F., and difference in altitude 50 feet; then the error in reading of the altimeter is $2\% \times (30° \text{ F.}/10° \text{ F.}) \times 50 \text{ feet} = 3 \text{ feet}$. Even if the temperature deviation were 90° F., which occurs only rarely, the error would only be 9 feet, a value appreciably smaller than the typical instrumental error of altimeters. (See sec. 8.0.7 for more details.)

6.8.2 Basic Procedures for Standardizing Altimeter-Setting Indicators

6.8.2.0 General Information.—Altimeter-setting indicators are standardized very nearly in the same way as aneroid barometers, so that the basic procedures for standardization already described in secs. 6.7.2.1–6.7.2.9 are also valid for altimeter-setting indicators except for several details, explained in the following sec., No. 6.8.2.1. In order to avoid repetition of the material in secs. 6.7.2.1–6.7.2.9 which is applicable to both kinds of instruments, observers at stations equipped with either the aneroid barometer or the altimeter-setting indicator should be familiar with the information contained in those sections. Criteria and tolerances pertinent to the altimeter-setting indicator but different from those for the aneroid barometer are stipulated where necessary.

The altimeter-setting indicator is equipped with an "Elevation Scale." This is used as an index of the adjustment of the instrument, depending upon its elevation. By means of the set screw provided on the instrument, the apparatus must be set approximately at the proper elevation, but yet at an "Elevation Scale Reading" (see fig. 6.8.1) such that the correction C_a will always have only one algebraic sign (plus or minus, not both) and be relatively small in absolute magnitude. The plus sign is considered preferable. Preference is given to a correction, C_a, which always is maintained with a constant positive algebraic sign because in this case application of the correction is less likely to lead to errors in algebraic addition than if the correction fluctuated in algebraic sign about zero (i.e., was sometimes plus and sometimes minus).

6.8.2.1 Résumé of General Plan for Standardizing Altimeter-Setting Indicators

(1) *Comparative Observations*

Comparative observations to determine C_a will be made in accordance with the instructions given in subsections 6.7.2.1 (see also secs. 6.7.2.9.1, 6.7.2.9.2, and Form WBAN 54–6.6). This involves twice-daily readings of the mercurial barometer and of the altimeter-setting indicator, at a 6–hour interval. At first the daily schedule of comparative readings lasts at least 36 days, and if certain criteria are satisfied the schedule is shifted to a weekly basis. Data are tabulated on Form WBAN 54–6.6.

(2) *Quality-Control Chart*

A quality-control chart is prepared, to show the plot of C_a versus comparison number and week number. The following ordinate scale is recommended: a vertical spacing of 1/2 inch to represent an altimeter setting interval of 0.01 inch of mercury. On this chart a curve of best fit is constructed (see secs. 6.7.2.2, 6.7.2.9.2, 6.7.2.9.3 and 6.7.2.9.4).

(3) *Drift Calculations*

Drift is checked by calculations as outlined in sec. 6.7.2.3.

(4) *Drift Determined from Curve*

From the curve of best fit drawn on the quality-control chart, values of C_a spaced at 29-day intervals are read off the curve, and the drift is determined from the change in C_a over 29-day intervals, following in principle the procedure described in subsections 6.7.2.4 and 6.7.2.9.5. *The "29-day drift criterion" adopted for the altimeter-setting indicator is 0.010 inch of mercury per 29 days.*

(5) *"Tail-End Drift" Checked*

By inspection of the last several points plotted on the quality-control chart, it will be necessary to observe whether the "tail-end drift" is excessive or remains within tolerable limits. In general, the corrections (C_a) should not deviate by more than 0.020 inch of mercury from the value to be expected from the preceding smooth curve of best fit. When the "tail-end drift" appears excessive, at least two special comparative readings should be taken at 10 to 15 minute intervals. For further information see secs. 6.7.2.5 and 6.7.2.9.6.

(6) *Variability Checked*

Random variations of points plotted on the quality-control chart will be reviewed by comparison with the smooth curve of best fit. The maximum range of deviations from the curve should rarely exceed 0.020 inch of mercury; at least 90% of the plotted points should be within ± 0.015 inch of mercury; and not more than 10% of the points should deviate by more than 0.016–0.020 inch of mercury from the curve. (See secs. 6.7.2.6, 6.7.2.9.7, and 6.8.0 for additional procedural details.)

(7) *Mean correction (C_{am}) Calculated*

If the criteria referred to in paragraphs (3), (4), (5), and (6) above are satisfied, the mean correction (C_{am}) will be calculated in accord with the provisions of sec. 6.7.2.7. See sec. 6.7.2.9.8 for additional pertinent information.

(8) *"Posted Correction Card" Prepared*

A "Posted Correction Card for the Altimeter-Setting Indicator" will be prepared similar in principle to the card described in sec. 6.7.2.8, and in accord with instructions somewhat similar to those given in that place.

Examples of application of the appropriate, current posted correction for altimeter-setting indicators are as follows:

EXAMPLES

Case I. *Removal Correction Constant*

Reading of altimeter-setting
indicator, ……… A_i = 30.230 in. Hg
"Posted Correction," ……… C_{am} = +0.035 in. Hg

Correct altimeter setting
($A_i + C_{am}$) ……… = 30.265 in. Hg

This is valid for conversion to station pressure pertaining to the station elevation, H_p; but when the data have to be issued for aviation services the altimeter setting is rounded: 30.27 in. Hg.

Case II. *Removal Correction Variable*

Reading of altimeter-setting
indicator, ……… A_i = 30.235 in. Hg
"Posted Correction," ……… C_{am} = +0.050 in. Hg

Corrected altimeter setting
($A_i + C_{am}$) ……… = 30.285 in. Hg
(pertinent to H_z, actual barometer elevation).

This result applies to the actual elevation of the ivory point of the mercury barometer (H_z), and is used for conversion to pressure relating to that level; hence if the station pressure is desired the "removal correction" must be applied to the pressure found for the level H_z.

With regard to the validity of the altimeter setting for other elevations, see sec. 6.8.1.3.

6.8.2.2 Instructions Regarding Preparation of Form WBAN 54–6.6: Comparison of Altimeter-Setting Indicator.—When an altimeter-setting indicator is compared with a mercurial barometer for purposes of standardizing the indicator, the pertinent data should be entered on Form WBAN 54–6.6, in accordance with appropriate instructions. The instructions given in sec. 6.7.3 regarding the various columns on the form are valid for the altimeter-setting indicator as well as for the aneroid barometer, with certain exceptions which are presented below. Where the same instructions apply to both instruments, this is indicated simply by a reference to sec. 6.7.3; but where the instructions differ in the two cases, the necessary instructions pertinent to the altimeter-setting indicator are stated hereunder, according to the various columns on the form.

Heading Data

In the upper left-hand corner the observer should check the pertinent space in parentheses to show that the form refers to the comparison of an altimeter-setting indicator. See also sec. 6.7.3.

Column No. 1: Comparison No.

See sec. 6.7.3.

Column No. 2: Month and Day

See sec. 6.7.3.

Column No. 3: Time (LST)

See sec. 6.7.3.

Column No. 4: Temp. Attach. Therm.

See sec. 6.7.3.

Column No. 5: Observed Barometer Reading

Instructions same as those in sec. 6.7.3, provided words "altimeter-setting indicator" replace words "aneroid barometer."

Column No. 6: Station Pressure

See sec. 6.7.3.

Column No. 7: Station Pressure

Entries in Col. 7 are to be omitted except when the original station pressures are determined directly in millibars.

Column No. 8: Altimeter Setting

Using the station pressure data in Col. 6 (or Col. 7 whichever is appropriate) as arguments, find the corresponding altimeter settings by means of the appropriate "Altimeter-Setting Table" or "Pressure Reduction Computer" and enter the results on the proper lines in Col. 8. The "Altimeter-Setting Table" and the "Pressure Reduction Computer" are described in Chapter 8. It is important to note that in case I where the removal correction is constant, the proper elevation datum which should serve as the basis for the calculations of the table or the slide rule is H_p (station elevation); whereas in case II where the removal correction is variable, the proper elevation datum which should serve as the basis for the calculations of the table or the slide rule is H_z (elevation of the cistern of the mercury barometer). At the commencement of the program and at the time of any change in elevation (either instrumental or station), the observer should check whether the appropriate elevation is used in connection with the table or slide rule.

Column No. 9: Observed Reading (Altimeter-Setting Indicator)

Delete the portion of the caption which is inappropriate (that is, delete "Aneroid or") and fill in the proper unit at the head of the column; that is, $(\text{in. Hg})_n$. The altimeter-setting indicator must be tapped just before reading it, and the value of the reading should be entered to the nearest graduated unit, for example, to the nearest 0.01 inch of mercury. (*Note:* In order to minimize the time interval between readings of the two barometers, the altimeter setting indicator should be read as soon as practicable after completion of the setting of the mercurial barometer. See note in sec. 6.7.3 under "Column No. 9.")

Column No. 10: Correction (C_a)

The correction as defined in secs. 6.8.1.1 and 6.8.1.2, should be entered in Col. 10; accordingly, C_a is given by the following relationship: (value in Col. 8 *minus* value in Col. 9). Indicate the appropriate units at the head of Col. 10.

Column No. 11: Sum of C_a for Group; and Comp. Nos.

See sec. 6.7.3.

Column No. 12: Mean C_a for Group

See sec. 6.7.3.

Examples: If the "Sum of C_a for Group" based on ten observations is entered under Col. 11 as 0.42 inch of mercury, the "Mean C_a for Group" is entered in Col. 12 as 0.042 inch of mercury; but the rounded value to be used on the "Posted Correction Card for the Altimeter-Setting Indicator" is 0.04 inch of mercury.

Column No. 13: Difference between Successive Means

Enter in Col. 13 the difference given in accord with the relationship: (last "Mean C_a for Group") *minus* (immediately preceding "Mean C_a for Group"). The result, with the proper algebraic sign and carried out to the nearest thousandth of an inch, should be entered on the same line as the last "Mean C_a for Group." The arrangement is similar to that illustrated in sec. 6.7.3, with different units.

Column No. 14: Remarks

See sec. 6.7.3.

The elevation scale reading should be entered once on the first line of each form. Otherwise it need not be given on any other line except when the instrument is reset.

6.9 COMPARISON OF MARINE ANEROID BAROMETERS

6.9.0 Introduction

Aneroid barometers and barographs used on ships should be checked at frequent intervals for the purpose of determining the instrumental corrections pertinent to them. Such corrections must be applied to their readings in order to obtain accurate pressure data.

Instructions are given in this section regarding procedures for determining these instrumental corrections. Two classes of ships are dealt with here: (1) U.S. Navy and U.S. Coast Guard vessels; and (2) ships operated by commercial interests which provide meteorological observations on a cooperative basis. Most of the ships considered in class (1) which are under the control of the U.S. Coast Guard fall into the category of "Ocean Station Vessels." This group of vessels has been designated to cruise in certain limited areas at certain scheduled times partly for the specific purpose of making both surface and upper-air meteorological observations; hence, it is of vital importance that the data which they yield be of the highest possible degree of accuracy. Likewise, it is essential that the reports received from other ships engaged in the cooperative marine meteorological program be highly accurate, since the construction of weather charts for the oceans and the provision of storm warnings for these areas, as well as for adjoining coastal regions, depend vitally upon them.

Sec. 6.9.1 gives instructions relating to barometer comparison procedures pertinent to ships of the U.S. Navy and U.S. Coast Guard; while sec. 6.9.2 presents instructions applicable to ships in the marine cooperative program.

In sec. 6.9.0.1 information is provided regarding the conditions under which comparisons of barometers may be undertaken, based on the experience that certain meteorological situations exist, such as those involving strong winds, which are unfavorable for the obtainment of reliable results; while other conditions occur, of a milder or more suitable character, which are favorable. Sec. 6.9.0.2 describes briefly the instruments which are employed as local "comparison standards" for the checking or calibration of marine aneroid barometers, and refers to the procedures for the determination of any corrections that may be necessary for these "comparison standards" themselves. Sec. 6.9.0.3 deals with the "inspection aneroid barometer" and outlines how these barometers are to be standardized. It indicates the times at which the inspection aneroid barometer is to be checked; while it also provides criteria relative to the conditions under which the corrected readings of this instrument may be used for purposes of comparison with the readings of barometers installed on ships in port.

With regard to procedures for comparisons of barometers on U.S. Coast Guard vessels employed as "Ocean Station Vessels," the work of coordinating the comparisons is done by the "*Port Station Supervisor,*" who is an official of the U.S. Weather Bureau designated to act in this capacity. As a rule the "Port Station Supervisor" serves as the "*inspector*" who is responsible for checking the meteorological instrumentation and general meteorological operations on these vessels when they return to port. The "Port Station Supervisor" is authorized to obtain the cooperation of designated employees to assist him in regard to the making of actual comparative barometer readings, under the general supervision and with the concurrence of the Meteorologist in Charge of the Port Station. Thus, under certain circumstances, some employee other than the "Port Station Supervisor" may be authorized to act as "inspector" for the purpose of taking comparative barometer readings on board ships in port.

In the case of barometer comparisons involving commercial vessels or other ships not in the category of "Ocean Station Vessels," the official of the U.S. Weather Bureau responsible at a given harbor for checking the meteorological equipment and observational work pertaining to such ships operating under a cooperative program is termed the "*Port Meteorological Officer.*" As a general rule, he serves as the "inspector" in connection with the program, and takes charge of the work of making the barometer comparisons.

Some vessels have a complement of meteorological or aerological personnel who conduct the observational work at sea. In the case of such vessels, it is considered that the personnel will take all necessary steps to safeguard their equipment and to maintain the highest possible level of accuracy in connection with this work. In harmony with this guiding principle, it will be noted that the instructions pertaining to barometer comparisons for such vessels as indicated in sec. 6.9.1 are very stringent, and require the undertaking of simultaneous comparative observations at the port station and on the ship under certain conditions when the vessels are in port.

With respect to vessels not having any meteorological or aerological personnel, for example ships which provide observations under the marine cooperative program, the pertinent instructions given in sec. 6.9.2 do not call for such simultaneous comparative barometer readings, since reliance must then be placed upon the several comparisons made by the inspector when he visits the ships.

Instructions relating to the handling of barographs (or microbarographs) on ships are presented in sec. 6.10.

6.9.0.1 Conditions Affecting Comparison of Barometers.—It is recommended that comparisons be undertaken preferably when the average wind speed is *10 knots or less.* When the wind speed is 20 knots, the effects of the wind on the pressure within different structures may produce a deviation of as much as 0.5 mb. in some cases, which is too large to tolerate. Since the wind pressure varies as the square of the speed, it will be obvious that comparisons made under conditions of strong, gusty wind would be subject to serious errors (see sec. 2.11.1).

Preference should be given to situations when the barometer is fairly steady or changing slowly. Conditions which exist when the barometer is fluctuating or changing rapidly are generally unfavorable.

If comparisons are to be made between barometers at two different locations, best results are generally obtained when temperatures, winds, and pressures are more or less uniform and fairly steady over the area. Thus, if possible, comparisons between barometers should be generally avoided during stormy conditions. When one of the barometers is installed at a location where there is in operation a high-velocity air conditioning and ventilating system, or when either instrument is installed in a tall air-conditioned building, discrepancies may arise owing to the effects of the system or artificial environment, as the case may be (see sec. 2.11.2). In the latter situation, it may be desirable during the calibration period to have an opening or vent connecting the outside with the space in which the barometer is located.

Aneroid barometers should, insofar as practicable, be compared at nearly the same temperature at which they are to be used or at which they have been standardized. Observance of this principle will aid in minimizing errors due to imperfect temperature compensation.

6.9.0.2 Comparison Standard Barometers.—A "comparison standard barometer" is simply a mercury barometer used as the standard or reference instrument when comparing it with or calibrating another barometer. In this section the other barometer is of the aneroid type.

Comparison standard barometers may have different degrees of reliability or absolute accuracy, depending upon their bore, calibration, construction, quality of vacuum, and other factors. Therefore, the following priority list is established, the first being regarded as of the best quality, etc.:

(1) a substandard mercury barometer ("secondary standard barometer" with bore 0.5 to 0.6 in. or more);
(2) a home-station standard barometer used by field aides and inspectors for comparing barometers at various stations in their region (usually this category is of about 0.25 inch bore if a substandard barometer of 0.5 or 0.6 inch bore is not available);
(3) a station barometer (usually with a bore of about 0.25 inch).

When checking or calibrating an aneroid barometer, the comparison standard barometer should be chosen primarily from the type which is the highest available on the priority list, other conditions being equal. However, if one of the instruments lower on the list is much closer to the aneroid barometer being checked than the highest available on the list, the lower one may be used as the comparison standard barometer. The term "much closer" in the previous sentence should generally be interpreted in the sense of "least in regard to normal pressure difference"; that is, the words should be taken to imply that the normal pressure difference between the site of the finally chosen comparison barometer and the site of the aneroid barometer ought to be considerably less in most instances than between the location of the highest available instrument on the list and the site of the aneroid barometer.

Consistent use of the same comparison standard barometer at a port is quite essential when recurrent series of comparisons are made involving the aneroid barometer on a given ship. In this manner the results obtained on different trips to a particular port are likely to show better agreement.

When the aneroid barometer and the comparison standard barometer are in separate locations, the schedule of the times of readings should be arranged carefully in advance of the comparisons so that the data will be obtained simultaneously from both instruments.

The calibration or standardization of comparison standard barometers should be carried out at fairly regular intervals, usually at least once every year. Instructions regarding the comparison of mercury barometers with a substandard or standard barometer should be followed for this purpose, in accordance with secs. 6.4–6.6.

6.9.0.3 Inspection Aneroid Barometer.—The "*inspection aneroid barometer*" is a portable aneroid instrument which is employed to serve as a link in determining the relationship between the pressures yielded by a comparison standard barometer and the readings of an aneroid barometer installed on board ship. This link is established by making comparative readings between the inspection aneroid barometer and each of the other two instruments mentioned in the previous sentence.

It is important to handle all of these delicate instruments with great care, keeping in mind the information presented in secs. 2.8.2, 2.10.1, 2.10.4, A–2.16, and A–2.21. Special precautions should be taken to avoid subjecting the aneroid barometers to shocks, jolts, etc., since mechanical concussion can throw them out of calibration or do serious damage.

The inspection aneroid barometer should be standardized in accordance with the provisions of sec. 6.7. Under the procedures described in sec. 6.7, the inspection aneroid barometer will be compared twice daily with a comparison standard barometer (usually of the Fortin mercury type) over a certain period of time, until there is established the appropriate "mean correction of *aneroid* barometer," or for short "mean correction," denoted by C_{am}. A quality-control chart will be prepared and maintained for the given instrument.

The quality-control chart is intended to aid in the determination of the mean correction, C_{am}. During the life history of the barometer at the station, the chart reveals how well the instrument maintains a specific value of the mean correction, and whether the individually determined "corrections of the aneroid barometer," C_a, manifest marked variability with respect to the mean correction (C_{am}). After the mean correction has been established for the first time, regular weekly comparisons should be continued in accordance with the instructions of sec. 6.7, and the individual results (C_a) should be shown on the quality-control chart, using a distinctive type of dot for the plotted points. With regard to comparisons made at times other than those allotted to the regular weekly schedule of comparative readings described in sec. 6.7, the results of such special observations should also be plotted on the chart, but different types of marks should be made for the points depending upon the purpose, to distinguish them from the regular ones which are obtained weekly.

When an inspection aneroid barometer is to be used for the purpose of comparison with a barometer installed on a U.S. Coast Guard ship which serves as an "Ocean Station Vessel," it is necessary to check the inspection barometer on three separate occasions as indicated below:

(1) Before departure of the inspector from his home station at the port;
(2) on shipboard when the vessel's aneroid barometer is being compared; and,
(3) at the time of the return of the inspector to his home station.

A similar program may be pursued in the case of U.S. Navy vessels which have a complete aerological unit.

However, in other cases such as those involving commercial ships which provide meteorological observations on a cooperative basis, it is only necessary to check the inspection barometer on the two occasions listed above under items (1) and (3); while the step indicated under item (2) will be omitted in these cases.

The process of checking referred to under items (1) and (3) requires that the inspector make three sets of comparative readings between his inspection aneroid barometer and his home-station comparison standard barometer for the purpose of determining the average of the three individual values of C_a thus ascertained (see sec. 6.7). A larger set of comparative readings may be taken if desired. The set of readings should be obtained at intervals over a period of time which may generally range from 10 to 60 minutes, depending somewhat upon the steadiness of the pressure and wind conditions, the extent of the temperature difference between indoors and outdoors, and upon the convenience of the observer. By taking the average of the set of several individual values of C_a thus determined and comparing this average with the mean correction, C_{am}, previously established, the inspector will be enabled to judge whether the inspection aneroid barometer is holding its calibration. A tolerance of 0.02 inch of mercury will be allowed between the average of the specified set of values of C_a and the mean correction, C_{am}.

In regard to item (2) the following instructions will govern the inspector on shipboard: Arrange a set of *at least* four simultaneous readings in accordance with a definite schedule fixed in advance. The readings required for comparative purposes are those made with the following: (a) The best available comparison standard mercury barometer at the port station selected in harmony with the provisions of sec. 6.9.0.2; (b) the inspection aneroid barometer; and (c) the ship's aneroid barometer. The help of a cooperator at the port station should be enlisted to secure the readings required under (a) above. On the other hand, the inspector will make the readings pertaining to (b) and (c). When preparing the schedule of simultaneous readings, the inspector and the cooperator at the port station should agree on the precise times at which each will make the readings. These times should be at intervals of *at least* 15 minutes; although intervals of 30 minutes, 1 hour, or 2 hours would be preferable. There should be a rigid adherence to the adopted schedule both on the ship and at the local shore station. If advisable, several additional simultaneous readings may be planned at successive uniform intervals, when there is doubt concerning the practicability of either party in the arrangement completing the task in accordance with the originally specified plan which involves merely four sets of readings.

The planning of the schedule may be carried out by prearrangement at the home station before the inspector leaves or by special agreement reached over the telephone between the inspector and the cooperator at an earlier or later time. In order that the data obtained from their two instruments be on a comparable basis, the readings of each instrument must be properly corrected and then reduced to sea level. This implies that the "mean correction" (C_{am}) should be applied to the readings of the inspection aneroid barometer before reducing the data to sea level for the elevation at which the barometer is located. Likewise, the simultaneous readings of the comparison standard barometer should be corrected to obtain the station pressures and the latter should be reduced to sea level, using as the temperature argument the current outdoor temperature to the nearest degree F. Lastly, a comparison should be made between the pressures reduced to sea level as determined from the inspection aneroid barometer on shipboard and those determined simultaneously from the comparison standard barometer at the port station.

If the difference between the mean of the set of four or more pressures reduced to sea level obtained from the two sources is 0.02 inch of mercury or less, and if also the mean value of C_a for the inspection aneroid barometer determined just before leaving the home station (see item (1) above) does not differ by more than 0.02 inch of mercury from the currently accepted value of the mean correction (C_{am}), the readings of the inspection aneroid barometer corrected in accordance with this value of C_{am} will be considered valid for purposes of comparison against the ship's barometer.

However, if the differences exceed the tolerances in either of these two cases, the pressure reduced to sea level from the station pressures given by the comparison standard mercury barometer at the home station will be compared directly with the pressure reduced to sea level at the vessel on the basis of the simultaneous readings of the ship's aneroid barometer. The data thus compared will yield the corrections necessary for the latter instrument as indicated in sec. 6.9.1.2, whenever the differences referred to above exceed the tolerances.

After the inspector returns to his home station in the port, he should undertake the operation listed in item (3) above. This requires the making of three sets of comparative readings between the inspection aneroid barometer and the appropriate comparison standard barometer, as soon as practicable following his return (see sec. 6.9.0.1). On the basis of the three sets of data thus obtained the inspector should compute the mean value of C_a for the inspection aneroid barometer, in accordance with the pertinent formulas given in sec. 6.7. He should then take the difference between the currently accepted "mean correction" (C_{am}) for the instrument and the mean of the three values of C_a determined as indicated in the previous sentence. If the difference thus ascertained is within a tolerance of 0.02 inch of mercury, it will generally be assumed that the inspection aneroid barometer has maintained a satisfactory level of performance during the given day, considering also the results of the comparisons made while on shipboard.

However, in the event that the mean of the three values of C_a thus determined under the provisions of item (3) departs by more than 0.02 inch of mercury from the value of the mean correction (C_{am}) which was previously in effect, the inspector should study the matter further, make additional tests, and endeavor to ascertain whether the inspection aneroid barometer actually gives positive evidence that it has departed significantly from its previous calibration. When such positive evidence is found, and especially if the instrument appears to function improperly, the inspection aneroid barometer should be taken out of service. A tolerance of 0.02 inch of mercury will be permitted.

If the instrument does not give any evidence of malfunction but shows a significant departure, additional comparative readings should be taken in relation to the home-station comparison standard barometer in order to establish a revised, better-fitting value of the mean correction (C_{am}), pertinent to the inspection aneroid barometer. The instructions given in sec. 6.7 will govern with regard to the determination of the original and revised values of C_{am}.

A tag, card, or other record should be kept with the inspection aneroid barometer to indicate the latest determined value of C_{am} for the instrument, and the date of its evaluation. More complete records should be maintained at the home station, particularly in connection with the quality-control chart for the barometer.

Bearing in mind the fact that the comparative results yielded by individual mercury barometers in any group may possibly differ among themselves, the inspector should maintain consistency with regard to the mercury comparison standard barometer which he employs for standardizing or checking his inspection aneroid barometer and other barometers, both at the home station and on shipboard. The same principle applies in regard to the standard used as a reference basis for any barometer installed on a given ship.

The possibility of imperfect temperature compensation of the aneroid barometer introduces a problem which must be taken into account. Thus, let T_s represent the temperature at which the inspection aneroid barometer is normally standardized. Suppose that at any time comparative readings are made, its temperature is markedly different from T_s. Then, if the aneroid instrument is not perfectly compensated for temperature, an error could develop, since the mean correction, C_{am}, determined at average temperature, T_s may not be strictly valid under these other conditions of temperature. In order to minimize the possible errors from this source, the inspector should allow some reasonable time for the barometer to come to equilibrium in its new environment when it is brought from outdoors to indoors through a marked differential of temperature. By playing a fan on the barometer, the speed with which it approaches equilibrium of temperature with the surroundings can be considerably increased. Also, by placing the aneroid barometer in contact with a metal surface at room temperature, the approach to equilibrium can be accelerated. However, no one should, for this purpose, expose the instrument to or place it into contact with sources having a much higher or lower temperature, since the delicate apparatus may suffer damage from the effects.

6.9.1 Comparison of Barometers on Board U. S. Coast Guard and Naval Ships

6.9.1.0 General Information Regarding Comparisons Involving U.S. Ships.—The instructions given in secs. 6.9.0.1, 6.9.0.2, and 6.9.0.3 will apply in respect to the program of comparison of barometers on ships under the control of the U.S. Coast Guard, U.S. Navy, and any other U.S. Government agencies desiring to adhere to the provisions of this Manual. Specific additional instructions are given in secs. 6.9.1.1–6.9.1.4 pertinent to cases falling into these categories. Sec. 6.9.1.1 is concerned with procedures involved when the portable inspection aneroid barometer is compared on board ship with the aneroid barometer installed on the vessel. On the other hand, sec. 6.9.1.2 deals with the procedures applicable when the comparison standard mercury barometer at the port station is compared with the aneroid barometer installed on the ship (see also sec. 6.9.0.3). Form WBAN 54–6.9.1 (WB Form 455–8) is to be employed for the entry of the comparative data involving ships of the above-mentioned categories. Examples are given of the use of this form. Sec. 6.9.1.3 describes the method recommended for posting the corrections on the vessel, in order to show the values which must be applied to the readings of the ship's aneroid barometer for the purpose of determining the station pressure and the sea-level pressure, respectively. Sec. 6.9.1.4 pertains to the adjustment of the ship's aneroid barometer, giving instructions which are applicable whenever the correction to actual pressure at the instrument is excessive (more than 1 millibar).

6.9.1.1 Ship's Aneroid Compared with Inspection Aneroid Barometer.—At least four comparisons should be made between the ship's aneroid barometer and the inspection aneroid barometer while the latter is aboard the vessel. The time intervals between comparative readings should be at least 15 minutes; although it is considered preferable that longer intervals be employed, for example, multiples of 15 minutes, such as 30 minutes, 1 hour, 2 hours, etc. When making the comparisons, the inspection aneroid barometer is to be mounted beside and at the same level as the ship's aneroid barometer. Both instruments should be placed in the normal operating positions at which they were calibrated. When selecting the occasions for making the comparisons, it is desirable to pick situations which provide favorable conditions as recommended in sec. 6.9.0.1.

The comparative readings are to be entered on Form WBAN 54–6.9.1, of which at least three copies are to be prepared. One of the copies is to be transmitted to the appropriate depot or office (in the case of the Weather Bureau, the destination is to be the Central Office); the second copy is to be filed at the supervising port station where the inspector maintains his headquarters; and the third copy is to be retained in the ship's file. Figs. 6.9.0 and 6.9.1 illustrate the appearance of the form when it is prepared in typical cases, involving ship's aneroid barometers which are graduated in millibars and inches of mercury, respectively. Essential points of the instructions relating to the preparation of the form are printed on its face.

In the case of comparisons pertaining to aneroid barometers installed on U.S. Coast Guard Cutters which serve as Ocean Station Vessels, it is necessary to indicate by a check mark at the top of the form in the appropriate space whether the readings are made immediately before a patrol begins (Pre-patrol); or whether they are made immediately after a patrol ends (Post-patrol).

The following instructions will govern the preparation of Form WBAN 54–6.9.1, apart from the obvious entry of data required for the heading (see examples in figs. 6.9.0 and 6.9.1):

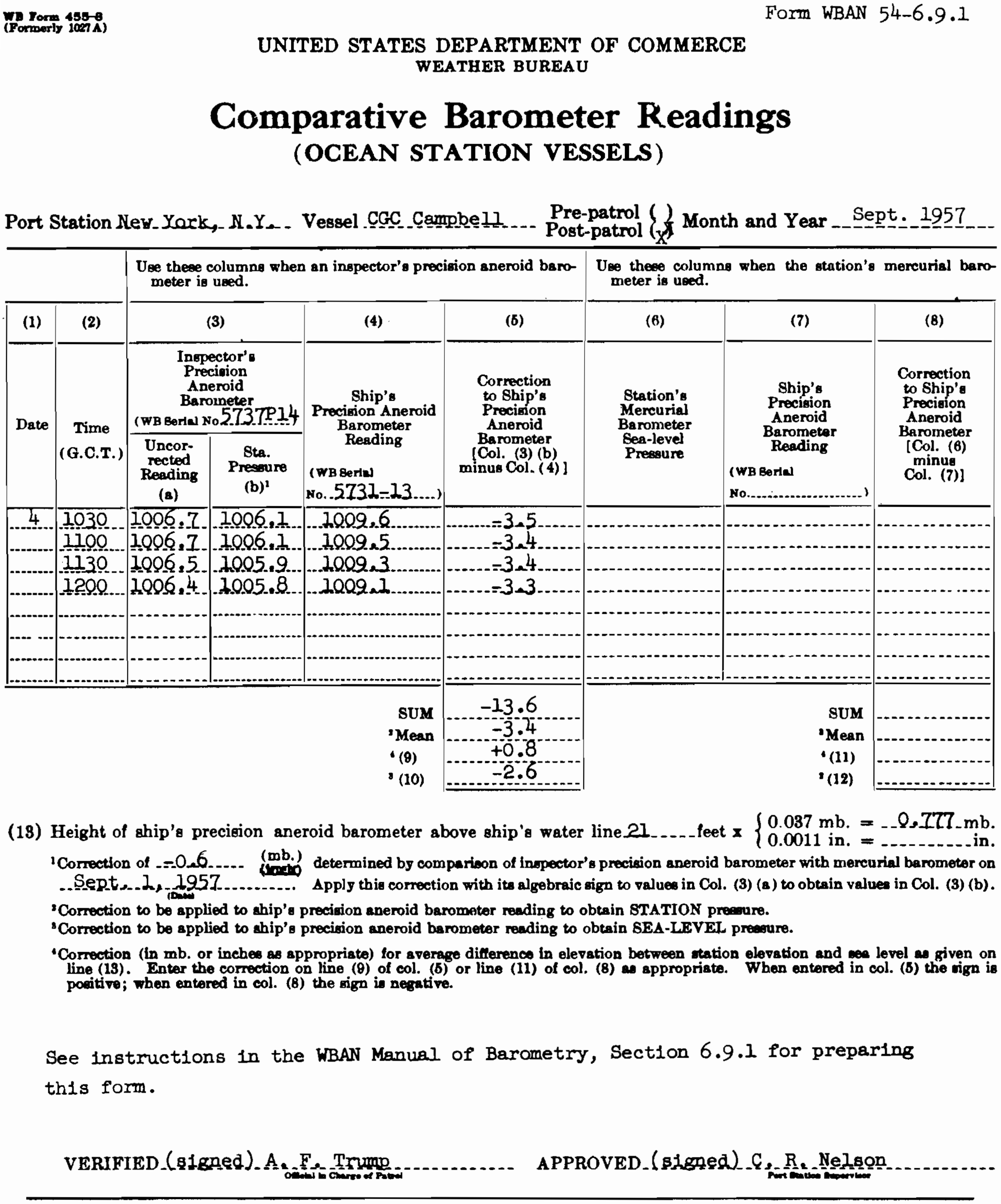
Col. (1): Enter day of month. (Month and year are to be given in the heading.)

Col. (2): Enter Greenwich Civil Time to the nearest minute.

Col. (3): At the head of the column indicate the serial number of the inspector's aneroid barometer. Under column 3(a) enter the actual observed (uncorrected) reading of the inspector's aneroid barometer; and under column 3(b) enter the corrected reading of this instrument, which is referred to as "station pressure." Before the inspector can obtain the latter, he must first enter in the space beside Footnote 1 the "mean correction" (C_{am}) which has been established for his barometer in accordance with the instructions contained in sec. 6.7. The date on which the value of C_{am} was determined should be indicated. Then, the inspector must apply this correction with the appropriate algebraic sign to the observed reading given under column 3 (a) in order to obtain the "station pressure," which is to be entered under column 3 (b).

Col. (4): Enter the actual reading of the ship's aneroid barometer which is observed simultaneously with the reading of the inspector's aneroid barometer indicated under column 3(a). The serial number of the ship's aneroid barometer should be indicated at the head of column (4).

Col. (5): Enter with the proper algebraic sign the difference between the value entered under column 3(b) and that entered under column (4); that is, Col. 3(b) *minus* Col. (4). The difference thus defined represents the individual correction for the given observation to be applied to the *reading*



WB Form 455-8
(Formerly 1027 A)

Form WBAN 54-6.9.1

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

Comparative Barometer Readings
(OCEAN STATION VESSELS)

Port Station New York, N.Y. Vessel CGC Campbell Pre-patrol ( ) Post-patrol (X) Month and Year Sept. 1957

		Use these columns when an inspector's precision aneroid barometer is used.				Use these columns when the station's mercurial barometer is used.		
(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)
Date	Time (G.C.T.)	Inspector's Precision Aneroid Barometer (WB Serial No. 5737P14) Uncorrected Reading (a)	Sta. Pressure (b)[1]	Ship's Precision Aneroid Barometer Reading (WB Serial No. 5731-13)	Correction to Ship's Precision Aneroid Barometer [Col. (3) (b) minus Col. (4)]	Station's Mercurial Barometer Sea-level Pressure	Ship's Precision Aneroid Barometer Reading (WB Serial No.)	Correction to Ship's Precision Aneroid Barometer [Col. (6) minus Col. (7)]
4	1030	1006.7	1006.1	1009.6	-3.5			
	1100	1006.7	1006.1	1009.5	-3.4			
	1130	1006.5	1005.9	1009.3	-3.4			
	1200	1006.4	1005.8	1009.1	-3.3			

SUM	-13.6	SUM	
[2]Mean	-3.4	[2]Mean	
[4](9)	+0.8	[4](11)	
[3](10)	-2.6	[3](12)	

(13) Height of ship's precision aneroid barometer above ship's water line 21 feet x { 0.037 mb. = 0.777 mb. / 0.0011 in. = ______ in. }

[1] Correction of -0.6 (mb.) ~~(inch)~~ determined by comparison of inspector's precision aneroid barometer with mercurial barometer on Sept. 1, 1957 (Date) Apply this correction with its algebraic sign to values in Col. (3) (a) to obtain values in Col. (3) (b).

[2] Correction to be applied to ship's precision aneroid barometer reading to obtain STATION pressure.

[3] Correction to be applied to ship's precision aneroid barometer reading to obtain SEA-LEVEL pressure.

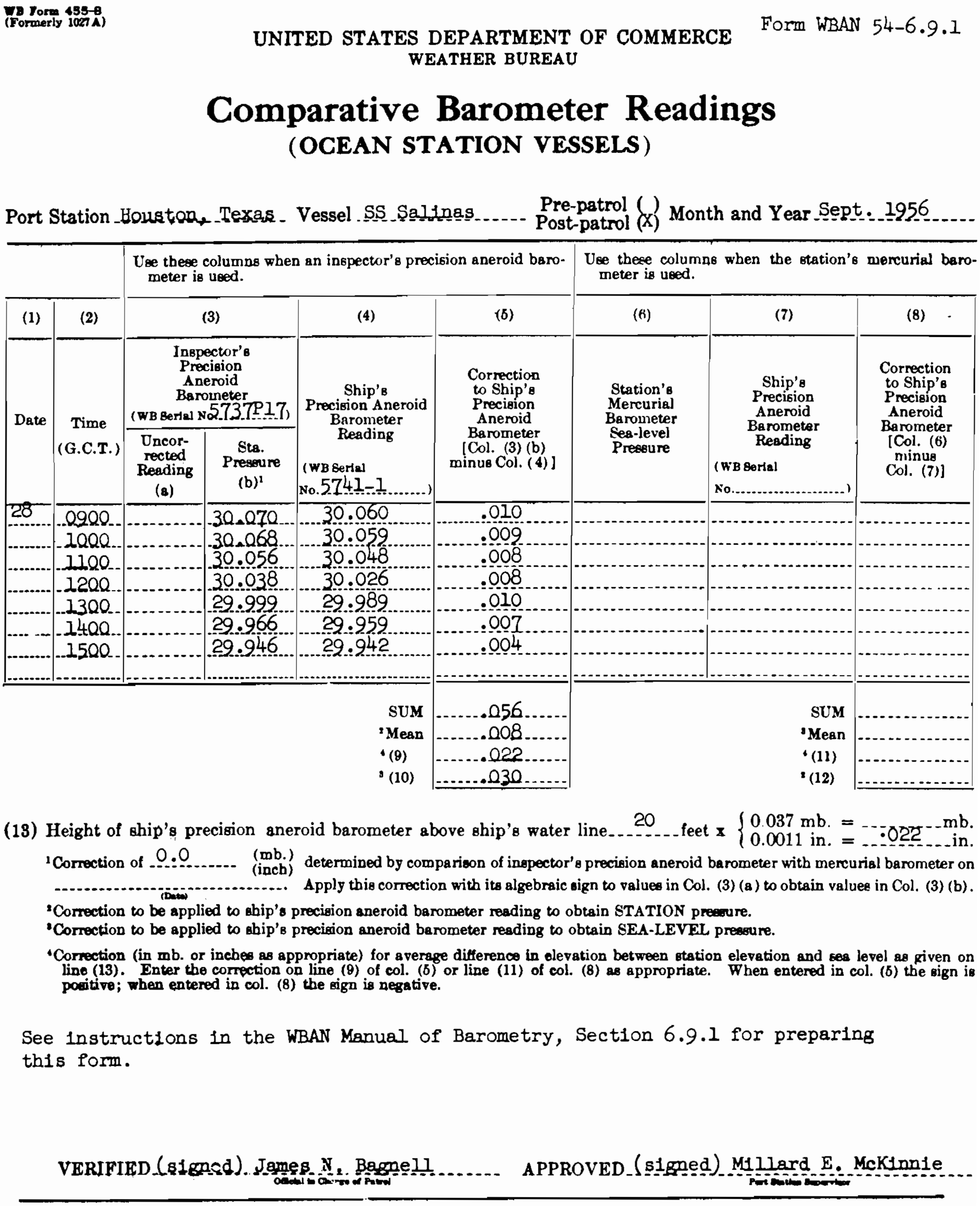
[4] Correction (in mb. or inches as appropriate) for average difference in elevation between station elevation and sea level as given on line (13). Enter the correction on line (9) of col. (5) or line (11) of col. (8) as appropriate. When entered in col. (5) the sign is positive; when entered in col. (8) the sign is negative.

See instructions in the WBAN Manual of Barometry, Section 6.9.1 for preparing this form.

VERIFIED (signed) A. F. Trump
Official in Charge of Patrol

APPROVED (signed) C. R. Nelson
Port Station Supervisor

FIGURE 6.9.0. Example of comparative barometer readings taken on board a U.S. Coast Guard cutter employed as an "Ocean Station Vessel." Comparisons were made between the inspector's precision aneroid barometer and the ship's aneroid barometer which yielded readings in millibars.



WB Form 455-B
(Formerly 1027 A)

Form WBAN 54-6.9.1

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

Comparative Barometer Readings
(OCEAN STATION VESSELS)

Port Station Houston, Texas Vessel SS Salinas Pre-patrol ( ) Post-patrol (X) Month and Year Sept. 1956

		Use these columns when an inspector's precision aneroid barometer is used.				Use these columns when the station's mercurial barometer is used.		
(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)
Date	Time (G.C.T.)	Inspector's Precision Aneroid Barometer (WB Serial No. 5737P17) Uncorrected Reading (a)	Inspector's Precision Aneroid Barometer Sta. Pressure (b)[1]	Ship's Precision Aneroid Barometer Reading (WB Serial No. 5741-1)	Correction to Ship's Precision Aneroid Barometer [Col. (3) (b) minus Col. (4)]	Station's Mercurial Barometer Sea-level Pressure	Ship's Precision Aneroid Barometer Reading (WB Serial No.)	Correction to Ship's Precision Aneroid Barometer [Col. (6) minus Col. (7)]
28	0900		30.070	30.060	.010			
	1000		30.068	30.059	.009			
	1100		30.056	30.048	.008			
	1200		30.038	30.026	.008			
	1300		29.999	29.989	.010			
	1400		29.966	29.959	.007			
	1500		29.946	29.942	.004			
				SUM	.056		SUM	
				[2]Mean	.008		[3]Mean	
				[4](9)	.022		[4](11)	
				[3](10)	.030		[2](12)	

(13) Height of ship's precision aneroid barometer above ship's water line 20 feet x { 0.037 mb. = ______ mb. / 0.0011 in. = .022 in. }

[1] Correction of 0.0 (mb.) (inch) determined by comparison of inspector's precision aneroid barometer with mercurial barometer on ______ (Date) Apply this correction with its algebraic sign to values in Col. (3) (a) to obtain values in Col. (3) (b).

[2] Correction to be applied to ship's precision aneroid barometer reading to obtain STATION pressure.

[3] Correction to be applied to ship's precision aneroid barometer reading to obtain SEA-LEVEL pressure.

[4] Correction (in mb. or inches as appropriate) for average difference in elevation between station elevation and sea level as given on line (13). Enter the correction on line (9) of col. (5) or line (11) of col. (8) as appropriate. When entered in col. (5) the sign is positive; when entered in col. (8) the sign is negative.

See instructions in the WBAN Manual of Barometry, Section 6.9.1 for preparing this form.

VERIFIED (signed) James N. Bagnell
Official in Charge of Patrol

APPROVED (signed) Millard E. McKinnie
Port Station Supervisor

FIGURE 6.9.1. Example of comparative barometer readings taken on board a ship used as an "Ocean Station Vessel." Comparisons were made between the inspector's precision aneroid barometer and the ship's aneroid barometer which yielded readings in inches of mercury.

of the ship's aneroid barometer in order to determine the station pressure at the given time. At the foot of column (5), next to the word "Sum" enter the algebraic sum of the values given in the body of the column and the proper sign must be indicated. Next to the word "Mean" enter the quotient obtained when the "Sum" is divided by the number of observations, showing the same algebraic sign as pertains to the "Sum." (For further details see below.) (*Note:* The "Mean" represents the correction which should be applied to the actual readings of the ship's precision aneroid barometer in order to obtain the *station pressure*, where the latter in this case denotes the true pressure at the level of the barometer.)

Line (13): Write the value of the height of the ship's precision aneroid barometer above the ship's water line, in feet, as it would be on the average under normal operating conditions at sea. If the barometer is graduated in millibars, multiply the specified height by the factor 0.037 mb., and enter the product in the space immediately to the right of the factor. However, if the barometer is graduated in inches of mercury, multiply the height by the factor 0.0011 inch of mercury, and enter the product to the right of the factor.

(*Note:* The product of the height and the specified factor in each case represents the amount of the correction to be added to the true pressure at the given height in order to obtain the sea-level pressure, in millibars and inches of mercury, respectively; under the assumption that the air temperature is 50° F. and the pressure about 30 inches of mercury.)

Line (9): Enter on line (9), which is near the lower part of column (5), the value of the product determined in accordance with the instructions pertaining to Line (13); use the value rounded to the nearest tenth of a millibar when the ship's aneroid is graduated in millibars; but use the value of the product rounded to the nearest thousandth of an inch of mercury when the ship's aneroid is graduated in inches of mercury. Prefix a plus (+) sign before the value entered on line (9).

Line (10): Under Col. (5), obtain the algebraic sum of the quantity labeled "Mean" and the value on Line (9); and enter the result on Line (10) with the appropriate algebraic sign.

(*Note:* Owing to the method employed to determine Line (10) this result represents the value that must be applied as a correction to the actual observed reading of the ship's precision aneroid barometer in order to ascertain the sea-level pressure.)

Verification and Approval of Form

The Official in Charge of the meteorological work on the vessel, or his duly authorized assistant, should verify the computations on the form; and sign it in the lower, left-hand corner. If an inspector has made the actual readings, he should also write his signature in the space above. The completed form is to be brought to the attention of the port station supervisor in charge of marine meteorological work, for review, approval and signature, prior to departure of the vessel from the port, if practicable. If this is not feasible, the person named in the first sentence is authorized to approve the completed form. In cases where the correction of the inspector's precision aneroid barometer does not satisfy the tolerance laid down in sec. 6.9.0.3, (that is, when the checks made at the inspector's home station before his departure and on shipboard reveal that the correction of the instrument differs by more than 0.02 inch of mercury from the previously established value of the "mean correction," C_{am}, the results of the procedure illustrated in figs. 6.9.0 and 6.9.1 will not be approved, and in its stead the procedure described in sec. 6.9.1.2 will be employed. The corrections to the ship's aneroid barometer ascertained with the aid of the comparisons described above should be posted on a card near the barometer, in accordance with instructions given in sec. 6.9.1.3.

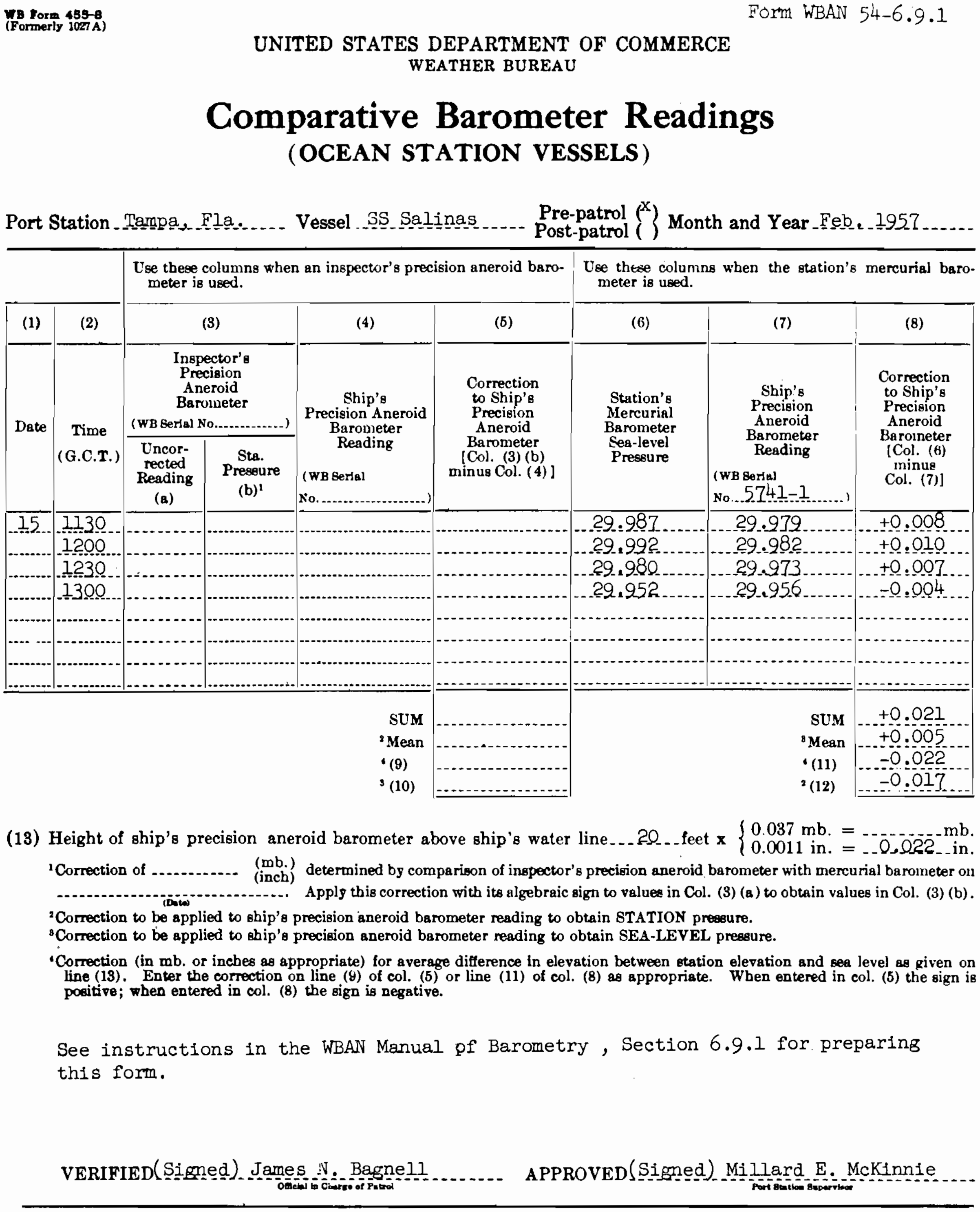
6.9.1.2 Ship's Aneroid Compared with Comparison Standard Barometer.—The procedure described under this heading will be applicable whenever the performance of the inspector's precision aneroid barometer does not fulfill the requirements specified in sec. 6.9.0.3. Under the terms of sec. 6.9.0.3, it is necessary to check the inspector's aneroid barometer before this instrument is taken from the port station and also after it is brought on board the vessel. The instructions call for the taking of sets of three or four comparative readings between that instrument and the comparison standard barometer. From this point, the instructions require the determination of the average value of the correction (C_a) pertaining to the inspector's aneroid barometer on the basis of these two sets of readings, respectively. It will be remembered that the average value of the correction found in each of these cases is to be compared with the "mean correction" (C_{am}) previously established for the inspector's aneroid barometer under the provisions of sec. 6.7. A tolerance of 0.02 inch of mercury is permitted. Therefore, if the difference between the "mean correction" (C_{am}) and the average correction in either case exceeds 0.02 inch of mercury, the performance of the inspector's aneroid barometer will be considered questionable. In that event, it will be necessary to make use of comparative readings which involve the ship's aneroid barometer and the comparison standard mercury barometer at the port station, both sets of readings being reduced to sea level in order to render them directly comparable.

Under the conditions specified in the last few sentences of the previous paragraph, readings of the ship's precision aneroid barometer will be made on the vessel simultaneously with readings of the comparison standard mercury barometer at the port station. The intervals of time should be at least 15 minutes, and it is considered desirable to employ somewhat longer intervals, if convenient, such as 2 hours, 1 hour, or 30 minutes.

Arrangements must be made in advance between the inspector or the ship's meteorological personnel and someone at the port station who can act as a cooperator to help schedule and make the simultaneous readings involving the comparison standard mercury barometer at the station. No less than four comparative readings of good or acceptable quality are required for this set. If desired, additional readings may be made, as a safeguard that the number of good or acceptable comparative data meet the minimum requirements. Readings should be made carefully at the times agreed upon in the prearranged schedule. If practicable, the period of time over which the schedule will be in effect should be selected somewhat in advance on the basis of the best available forecast with a view to conducting the operations under favorable conditions as outlined in sec. 6.9.0.1.

Entries of comparative readings and other relevant data should be on Form WBAN 54–6.9.1 (WB Form 455–8), making use especially of columns 1, 2, 6, 7, and 8. Fig. 6.9.2 provides an example, involving a case where the ship's precision aneroid barometer is graduated in inches of mercury. When the barometer is graduated in these units, the readings should be taken to the nearest thousandth of an inch of mercury; whereas, when it is graduated in millibars, the readings and pertinent computations should be carried out to the nearest tenth of a millibar.

At the head of Form WBAN 54–6.9.1, entries will be made of the obvious items (viz., name of port station, name of vessel, month and year). In the case of U.S. Coast Guard Cutters employed as Ocean Station Vessels an X mark should be made in the space labelled "Pre-patrol" when the comparative readings are carried out just before the ship departs on its mission; whereas, a similar mark should be made in the space labelled "Post-patrol" when *they are carried*



WB Form 455-8
(Formerly 1027A)

Form WBAN 54-6.9.1

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

Comparative Barometer Readings
(OCEAN STATION VESSELS)

Port Station Tampa, Fla. Vessel SS Salinas Pre-patrol (X) Post-patrol ( ) Month and Year Feb. 1957

		Use these columns when an inspector's precision aneroid barometer is used.				Use these columns when the station's mercurial barometer is used.		
(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)
Date	Time (G.C.T.)	Inspector's Precision Aneroid Barometer (WB Serial No.)		Ship's Precision Aneroid Barometer Reading (WB Serial No.)	Correction to Ship's Precision Aneroid Barometer [Col. (3) (b) minus Col. (4)]	Station's Mercurial Barometer Sea-level Pressure	Ship's Precision Aneroid Barometer Reading (WB Serial No. 5741-1)	Correction to Ship's Precision Aneroid Barometer [Col. (6) minus Col. (7)]
		Uncorrected Reading (a)	Sta. Pressure (b)[1]					
15	1130					29.987	29.979	+0.008
	1200					29.992	29.982	+0.010
	1230					29.980	29.973	+0.007
	1300					29.952	29.956	-0.004
				SUM			SUM	+0.021
				[2] Mean			[3] Mean	+0.005
				[4] (9)			[4] (11)	-0.022
				[3] (10)			[2] (12)	-0.017

(13) Height of ship's precision aneroid barometer above ship's water line 20 feet x { 0.037 mb. = ______ mb. / 0.0011 in. = 0.022 in. }

[1] Correction of ______ (mb.) (inch) determined by comparison of inspector's precision aneroid barometer with mercurial barometer on ______ (Date) Apply this correction with its algebraic sign to values in Col. (3) (a) to obtain values in Col. (3) (b).

[2] Correction to be applied to ship's precision aneroid barometer reading to obtain STATION pressure.

[3] Correction to be applied to ship's precision aneroid barometer reading to obtain SEA-LEVEL pressure.

[4] Correction (in mb. or inches as appropriate) for average difference in elevation between station elevation and sea level as given on line (13). Enter the correction on line (9) of col. (5) or line (11) of col. (8) as appropriate. When entered in col. (5) the sign is positive; when entered in col. (8) the sign is negative.

See instructions in the WBAN Manual pf Barometry , Section 6.9.1 for preparing this form.

VERIFIED (Signed) James N. Bagnell
Official in Charge of Patrol

APPROVED (Signed) Millard E. McKinnie
Port Station Supervisor

FIGURE 6.9.2. Example of comparative barometer readings taken in connection with an "Ocean Station Vessel" in port, where sea-level pressures determined with the aid of data obtained from the port station mercury barometer were compared with the readings of the ship's aneroid barometer.

out just after the ship arrives in port on return from patrol duty.

The following instructions will govern the preparation of Form WBAN 54–6.9.1 (see example in fig. 6.9.2):

Col. (1): Enter day of month.

Col. (2): Enter Greenwich Civil Time, to the nearest minute.

Col. (6): Enter the pressure reduced to sea level as determined at the port station on the basis of the station pressure determined with the aid of the comparison standard mercury barometer, where the temperature argument used in reducing the pressure to sea level is the outdoor temperature at the time indicated in Col. (2).

Col. (7): Enter at the head of the column the serial number of the ship's precision aneroid barometer; and in the body of the column enter the actual, observed reading of the instrument.

Col. (8): Enter with the proper algebraic sign the difference between the value entered under column (6) and that entered under column (7); that is, Col. (6) *minus* Col. (7). The difference thus defined represents the individual correction for the given observation to be applied to the reading of the ship's aneroid barometer in order to determine the pressure reduced to sea level at the location of the ship. (This definition is only valid under the assumption that the ship and the station lie on the same isobar of sea level pressure.) At the foot of column (8), next to the word "Sum," enter the algebraic sum of the individual values given in the body of the column, and the proper sign must be indicated. Next to the word "Mean" enter the quotient obtained when the "Sum" is divided by the number of observations, showing the same algebraic sign as pertains to the "Sum." (*Note:* The "Mean" represents the average correction which should be applied to the actual observed readings of the ship's aneroid barometer in order to obtain the pressure reduced to sea level.)

Line (13): Write the value of the height of the ship's precision aneroid barometer above the ship's water line, in feet, as it would be on the average under normal operating conditions at sea. If the barometer is graduated in millibars, multiply the specified height by the factor 0.037 mb., and enter the product in the space immediately to the right of the factor. However, if the barometer is graduated in inches of mercury, multiply the height by the factor 0.0011 inch of mercury, and enter the product to the right of the factor. (*Note:* The product of the height and the specified factor in each case represents the amount of the correction to be added to the true pressure at the given height in order to obtain the sea-level pressure, in millibars and inches of mercury, respectively; under the assumption that the air temperature is 50° F. and the pressure about 30 inches of mercury.)

Line (11): Enter a minus (—) sign followed by the numerical value of the product given at the right-hand end of line (13), which should be in units consistent with those employed in the upper portion of column (8).

Line (12): Add algebraically the value given on the line marked "Mean" in column (8) and the value given on line (11); and finally enter the result obtained by this addition on line (12), with the proper algebraic sign. (*Note:* The quantity determined as the algebraic sum of the "Mean" and the value on line (11) represents the correction which should be applied to the actual observed readings of the ship's precision aneroid barometer in order to obtain the *station pressure,* where the latter in this case denotes the true pressure at the level of the barometer.)

Verification and Approval of Form

The Official in Charge of the meteorological work on the vessel, or his duly authorized representative, should verify the computations on the form; and sign it in the lower, left-hand corner. If an inspector has made the actual readings, he should write his signature in the space above. The completed form is to be brought to the attention of the port station supervisor in charge of marine meteorological work, for his review, approval, and signature, prior to departure of the vessel from the port if practicable. If this is not feasible, the person named in the first sentence is authorized to approve the completed form. The final corrections shown on the form should be posted on a card in accordance with the provisions of sec. 6.9.1.3.

6.9.1.3 Posting of Corrections for Ship's Aneroid Barometer.—After the computations involved on Form WBAN 54–6.9.1 have been checked and the form has been approved, the final results are to be posted on a card to indicate the corrections which must be applied to the observed readings of the ship's precision aneroid barometer in order to obtain the station pressure and the sea-level pressure, respectively. The card should be mounted next to the aneroid barometer on the vessel in such a position that it can always be readily seen. It is considered advisable to install the card under the protection of an envelope made of transparent plastic material. The following illustrates the nature of the information which should be shown on the card:

(1) Name of ship ____________

(2) Serial number of barometer ________

(3) Port ____________

(4) Date of determination ____________

(5) Correction to obtain station pressure __

(6) Correction to obtain sea-level pressure __

Items (5) and (6) must indicate carefully the proper sign of the correction and the units. Note will be taken of the fact that item (5) can be found on completed Form WBAN 54–6.9.1 under column (5), line labeled "Mean"; or under column (8), line (12). On the other hand, item (6) can be found under column (5), line (10); or under column (8), line labeled "Mean."

The port station supervisor should maintain a record at the port station for each ship, indicating the various pertinent data. Fig. 6.9.3 illustrates the information thus entered on the "Ship Record Card" with regard to "Barometer Comparisons." Included under this heading should be entries which indicate the following:

(1) Under "Bar. No.," the serial number of the instrument.

(2) Under "Cor.," the correction which should be applied to the observed reading of the barometer in order to obtain the station pressure at the level of the instrument.

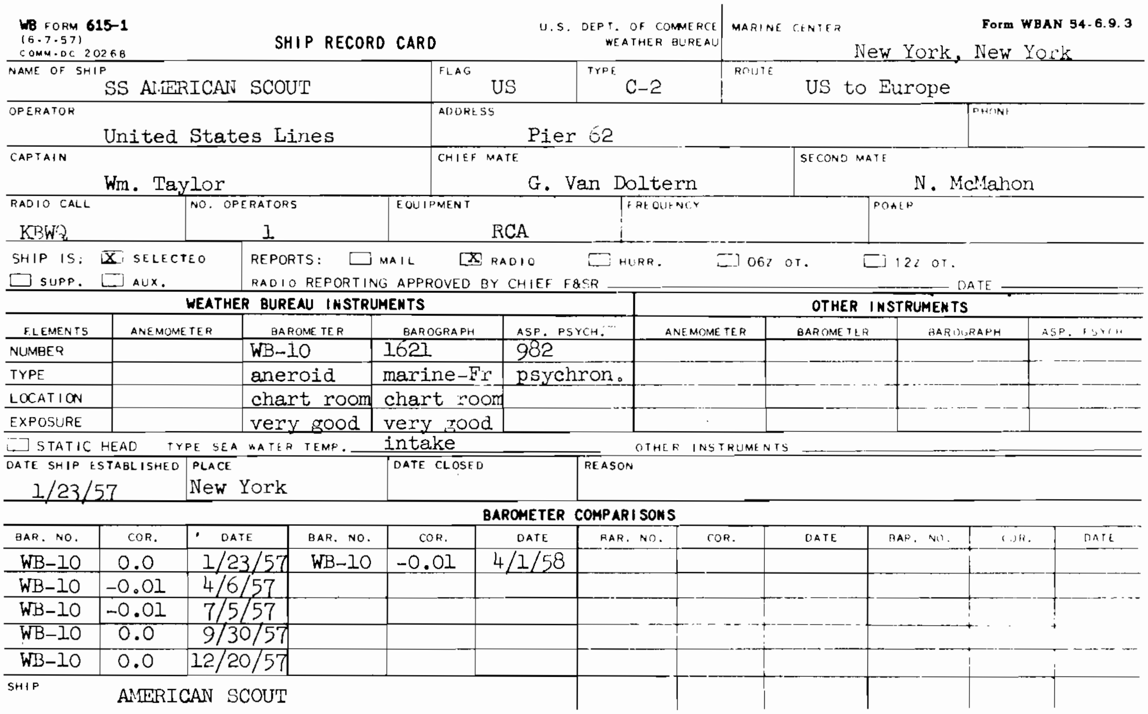
(3) Under "Date," the date on which the correction was determined.

6.9.1.4 Aneroid Barometer Adjustments.—When reference is made here to the term "correction," it will be understood as pertaining to the correction which must be applied to the observed readings of the precision aneroid barometer on board the ship in order to obtain the station pressure, that is, the pressure existing at the level of the instrument.

As a general rule, it is desirable that the correction be within a limit of 1.0 millibar. If the correction exceeds this limit, certain types of aneroid barometers may be adjusted in order to reduce the correction to a smaller value, preferably zero (0).

However, there are some types of aneroids which are so constructed that it is inadvisable for anyone in the field to endeavor to adjust them; these types being of the kind where the zero-adjusting screw cannot be reached without disassembling part of the instrument, thus leaving the way open for possible damage to its mechanism. No attempt should be made by personnel in the field to adjust aneroid barometers of this character.

To summarize: If the zero-adjustment screw can be reached without taking the instrument apart to any extent, and if the correction exceeds 1.0 millibar (or 0.030



WB FORM **615-1**
(6-7-57)
COMM-DC 20268

SHIP RECORD CARD

U.S. DEPT. OF COMMERCE
WEATHER BUREAU

MARINE CENTER New York, New York

Form WBAN 54-6.9.3

NAME OF SHIP SS AMERICAN SCOUT	FLAG US	TYPE C-2	ROUTE US to Europe

OPERATOR United States Lines	ADDRESS Pier 62	PHONE
CAPTAIN Wm. Taylor	CHIEF MATE G. Van Doltern	SECOND MATE N. McMahon

RADIO CALL KBWQ	NO. OPERATORS 1	EQUIPMENT RCA	FREQUENCY	POALP

SHIP IS: ☒ SELECTED ☐ SUPP. ☐ AUX.

REPORTS: ☐ MAIL ☒ RADIO ☐ HURR. ☐ 06Z OT. ☐ 12Z OT.

RADIO REPORTING APPROVED BY CHIEF F&SR ________ DATE ________

	WEATHER BUREAU INSTRUMENTS				OTHER INSTRUMENTS			
ELEMENTS	ANEMOMETER	BAROMETER	BAROGRAPH	ASP. PSYCH.	ANEMOMETER	BAROMETER	BAROGRAPH	ASP. PSYCH.
NUMBER		WB-10	1621	982				
TYPE		aneroid	marine-Fr	psychron.				
LOCATION		chart room	chart room					
EXPOSURE		very good	very good					

☐ STATIC HEAD TYPE SEA WATER TEMP. intake OTHER INSTRUMENTS ________

DATE SHIP ESTABLISHED 1/23/57	PLACE New York	DATE CLOSED	REASON

BAROMETER COMPARISONS

BAR. NO.	COR.	DATE	BAR. NO.	COR.	DATE	BAR. NO.	COR.	DATE	BAR. NO.	COR.	DATE
WB-10	0.0	1/23/57	WB-10	-0.01	4/1/58						
WB-10	-0.01	4/6/57									
WB-10	-0.01	7/5/57									
WB-10	0.0	9/30/57									
WB-10	0.0	12/20/57									

SHIP AMERICAN SCOUT

FIGURE 6.9.3. Example of Ship Record Card, Form WBAN 54–6.9.3, used for maintaining a record of the corrections pertaining to the aneroid barometer on a specified ship. The record is prepared by the Port Meteorological Officer.

inch of mercury), it will be permissible for inspectors or duly authorized personnel to adjust the aneroid barometer carefully with a view to reducing the correction to zero. Otherwise, it will not be permissible for personnel in the field to make such adjustments.

As an example, it may be mentioned that there is one type of precision aneroid barometer where the adjustment screw will be found underneath the plug screw that is located near the static connection opening in the aneroid case. After the plug screw and washer are removed, the adjustment screw will be visible. Adjustments of this latter screw may be made to minimize the correction if it exceeds 1.0 mb. Immediately after the completion of the adjustment, the plug screw and washer should be replaced. Fig. 6.9.4 illustrates one design of precision marine aneroid barometer which has the adjustment screw underneath the plug screw at the bottom; but this particular design does not have an air-tight case.

Whenever it is planned to make an adjustment in an aneroid barometer, comparative readings should be made *both before and after* the adjustment is carried out. The instructions given in secs. 6.9.1.1 and 6.9.1.2 will govern such comparisons. New corrections will be determined and posted on the basis of the final set of comparative readings. The comparative data obtained before and after the adjustment will be recorded on separate copies of Form WBAN 54–6.9.1; and these copies will be attached to one another. Suitable notations will be entered on both forms to indicate which form relates to the comparisons made *before* and which to those made *after* the adjustment. The

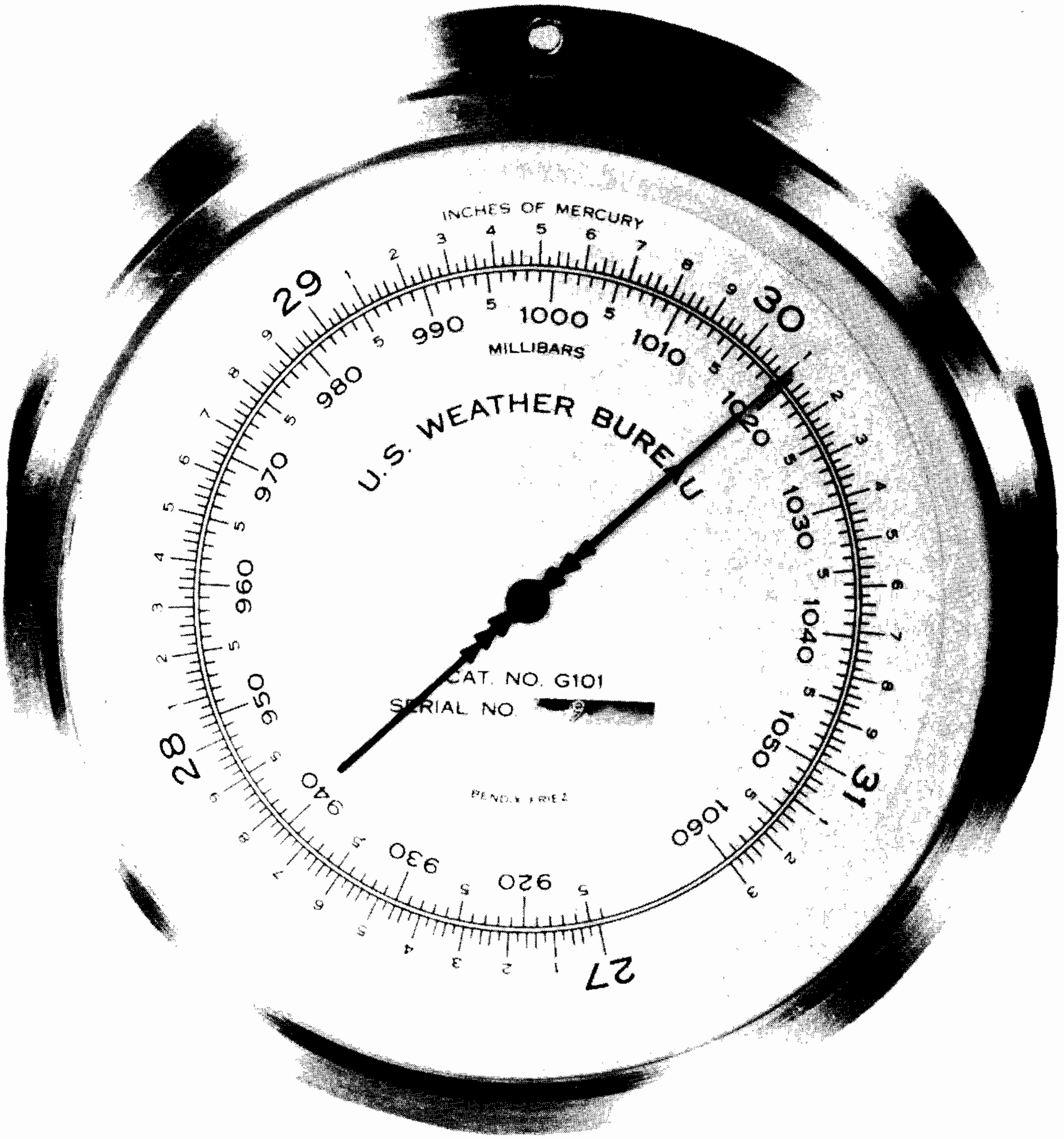


FIGURE 6.9.4. Marine aneroid barometer.

notations should indicate the direction and amount of the adjustment.

6.9.2 Comparison of Barometers on Board Commercial Ships

6.9.2.0. General Information.—Instructions are given in sec. 6.9.2.1 relative to the comparison of aneroid barometers installed on commercial or other ships, excluding those of the U.S. Coast Guard or U.S. Navy which have as one of their primary functions the taking of meteorological or aerological observations at sea (the case of the latter class of ships being covered in sec. 6.9.1). The port meteorological officer, an official of the U.S. Weather Bureau stationed at certain ports, is authorized to assist in the checking of aneroid barometers installed on board any vessels in port, when the officers of the ships agree to or seek help regarding such a program of comparisons. All ships which provide meteorological observations on a cooperative basis while at sea are automatically given assistance by the port meteorological officer with regard to the comparison of their barometers. As a general rule, such ships are visited by a port meteorological officer at least once each 90 days.

When the aneroid barometer on any of the ships under consideration is judged to be functioning properly, it is compared several times with the inspector's precision aneroid barometer during the course of the visit. The inspector thus establishes a correction to the ship's aneroid barometer, and the latest determined value of this correction is to be applied to the readings of the barometer in order to obtain the so-called "*barometer corrected,*" which will be understood as the *corrected sea-level pressure.* Revised values of the correction may have to be established from time to time when and if the vessel's aneroid barometer drifts or shifts slightly in respect to setting or calibration.

In cases, however, where the ship's aneroid barometer is judged to be erratic or to be malfunctioning, the instructions given in sec. 6.9.2.2 will be put into effect. Under the terms of the latter instructions the aneroid barometer will be subjected to a calibarometer test. By means of this test it will be possible to determine whether the instrument is not performing properly; or whether it simply needs a revised correction.

Matters pertaining to the barographs (or microbarographs) installed on board ships are dealt with in sec. 6.10.

6.9.2.1 Ship's Aneroid Barometer Compared with Inspection Aneroid.—The provisions of sec. 6.9.0.3 will govern the handling and standardization of the inspector's precision aneroid barometer. In accordance with the instructions in sec. 6.7, a so-called "mean correction," denoted by C_{am}, will be determined for the inspection aneroid barometer following a certain period of tests and comparative readings in relation to a comparison standard mercury barometer.

Immediately before the visit of an inspector to any ship and upon his return to the home station at the port, the inspection barometer should itself be checked, in accordance with the instructions contained in sec. 6.9.0.3.

When an inspector is planning or preparing to visit a ship for the purpose of obtaining comparative barometer readings, he should give consideration to the information presented in sec. 6.9.0.1 for guidance regarding the choice of conditions most favorable for the specified purpose.

At the time of a visit of an inspector to a ship, he should make certain inquiries of the ship's personnel who have had most frequent occasion to observe the vessel's aneroid barometer. The purpose of the inquiries is to ascertain, if practicable, whether the instrument has given any evidence of malfunctioning or erratic behavior without reason. For example, it might be asked whether the needle of the ship's aneroid barometer has made a rather significant or large jump when gently tapped on any one or more occasions during the period since the previous comparisons. Such behavior is sometimes indicative of excessive friction of the aneroid mechanism or looseness of the needle.

At least three comparisons should be made between the inspection aneroid barometer and the ship's aneroid barometer during the course of the inspector's visit to the ship. Simultaneous readings will be made of both instruments. To the readings of the inspection aneroid barometer there will be applied the *algebraic sum of two corrections* as follows: (A) The value of C_{am} pertinent to the instrument; that is, the "mean correction," C_{am}, determined in accordance with instructions in sec. 6.7 to correct the readings to actual station pressure at the level of the barometer; and (B) the correction to reduce pressure to sea level from the average height of the barometer above the water-line, assuming normal draft. Thus, the result obtained when the algebraic sum of these two corrections has been applied to the reading of the inspection aneroid barometer is the *pressure reduced to sea level* on board ship under normal draft conditions.

The reading of the ship's aneroid barometer will be subtracted from the "pressure reduced to sea level on board ship under normal draft conditions" obtained in the manner explained above; and the *difference* determined on the basis of this subtraction represents the individual correction for the ship's aneroid barometer. In other words, if this correction is applied with its proper algebraic sign to the observed reading of the ship's aneroid barometer, the result is the pressure reduced to sea level under normal draft.

Depending upon the time available, the inspector will make three or more sets of comparative readings of the two instruments under consideration, and determine the difference as defined in the previous paragraph for each set. Then he will compute the algebraic sum of the differences for all of the sets of comparative readings. Finally, the inspector will calculate the *mean difference,* by dividing the algebraic sum by the number of observations, and he will indicate its proper algebraic sign. The *mean difference* determined in this manner represents the "*total correction*" for the ship's aneroid barometer *under normal draft conditions.* By definition, the "total correction" in this case is the correction which, when applied to the reading of the ship's aneroid barometer, yields the pressure reduced to sea level under the assumption that the barometer is at the height above the water-line that prevails under normal loading conditions of the ship at sea.

The inspector will prepare a sticker for the instrument giving the following information:

(1) Port ....
(2) Barometer Number ....
(3) Date ....
(4) Total Correction ....

With regard to the "total correction," it is essential to indicate the appropriate algebraic sign in front of the value; and also to explain to the responsible officers on board ship the significance and application of this correction. The sticker will be pasted on the face of the barometer.

A record of the foregoing information will be made by the inspector; and the record will be transferred to Form WBAN 54–6.9.3 as illustrated in fig. 6.9.3. The port meteorological officer will maintain a file, kept up to date, of Form WBAN 54–6.9.3 pertinent to all ships for which the information is available.

If the ship's aneroid barometer manifests erratic operation or malfunctioning during the course of the comparative readings, this condition should be brought to the attention of the responsible officer on board ship, and action should be taken promptly to replace the defective instrument or to subject it to further tests by means of a calibarometer in accordance with instructions in sec. 6.9.2.2.

As a general rule, it is advantageous for the "total correction" of the ship's aneroid barometer to be a small positive number, such as about 0.03 to 0.06 inch of mercury, or about 1.0 to 2.0 millibars. If necessary to achieve this end, very slight adjustments may be made in the setting of the instrument for the purpose, provided that the adjustments can be undertaken without disassembling the barometer. See sec. 6.9.1.4 regarding limitations in connection with the adjustment of aneroid barometers. After any adjustments are made, special precautions are necessary to establish the "total correction" soundly on the basis of a goodly number of comparative barometer readings, such as 5 to 10.

In order to calculate the "correction to reduce pressure to sea level" for any given height of barometer above the water-line (see item (B) above), the method shown on line (13) of Form WBAN 54–6.9.1 will be employed (see examples in figs. 6.9.0, 6.9.1, and 6.9.2). Thus, in the case of a barometer graduated to read in millibars, the given height (in feet) should be multiplied by the factor 0.037 mb., in order to obtain the pertinent correction to reduce pressure to sea level. On the other hand, if the barometer is graduated to read in inches of mercury, the height (in feet) should be multiplied by the factor 0.0011, in order to obtain the correction to reduce pressure to sea level.

Whenever the cargo or load on the ship may vary so widely that a considerable variation occurs in the height of the barometer above the ship's water line, it is necessary for the inspector to furnish information to the ship's officers regarding the values of the "total correction" appropriate to the various heights of the barometer above the water line most commonly experienced. For example, in the case of a tanker which has a normal load of fuel oil, the value of the "total correction" pertinent to this situation is to be based on the height of the barometer above the water line under conditions of normal load. However, if the tanker will sometimes run light and therefore ride high out of the water, the "total correction" pertinent to the latter situation should be based on the height of the barometer under these conditions. Therefore, it is required in the case of vessels subject to considerable variations in height of the barometer above the water line that generally two values of the "total correction" be furnished; namely, one for *normal load*, and a second for *running light*. The different values of the "total correction" thus furnished on the sticker should be clearly labeled. The respective applications of the corrections in these two cases should be carefully explained by the inspector to the responsible ship's officers.

6.9.2.2 Calibarometer Tests.—When there is some question concerning the reliability of a ship's aneroid barometer, it is generally subjected to a calibarometer test. Fig. 6.9.5 illustrates one design of calibarometer. This apparatus is arranged so that a given aneroid barometer may be sealed within a glass enclosure, permitting an observer to make readings of the instrument while the pressure and temperature inside the enclosure are controlled. By means of comparative readings obtained under these conditions, it is possible to calibrate the aneroid barometer and to determine whether it is functioning properly.

Data secured in the course of a calibarometer test are recorded on Form WBAN 54–6.9.2, as illustrated in fig. 6.9.6.

In making the calibarometer tests, the ship's aneroid barometer is sealed in the glass enclosure of the apparatus. Then, the pressure within the enclosure is controlled to decrease in more or less uniform steps until a satisfactory minimum is reached, at a pressure slightly greater than the lowest scale reading of the aneroid. Next, on the up-swing of the cycle, the pres-

SAMPLE CALCULATION

"Total correction" for ship's aneroid barometer

Ship: S.S. Morning Star Port: New York, N.Y. Date: March 2, 1959 Barometer height: normal 24 ft.; running light 32 ft.

"Mean correction" of inspection aneroid barometer, C_{am} +0.5 mb.

Correction for reduction of pressure to sea level with normal load =
24 feet × 0.037 mb. per foot = $C_{rn} = +0.89$ mb.

Correction for reduction of pressure to sea level running light =
32 feet × 0.037 mb. per foot = $C_{rl} = +1.18$ mb.

Algebraic sum of C_{rn} and C_{am} is $+0.89 + (+0.5)$ mb. $= K = +1.4$ mb.

Time 75th mer.	Reading of inspection aneroid barometer R_i	$(R_i+K)=P_o$ Pressure reduced to sea level (normal load)	Reading of ship's aneroid barometer R_s	$(P_o - R_s)$
	mb.	*mb.*	*mb.*	*mb.*
1400	1023.6	1025.0	1023.9	+1.1
1415	1023.4	1024.8	1023.8	+1.0
1430	1023.3	1024.7	1023.6	+1.1

Sum +3.2
"Total correction," normal load=Mean +1.1 mb.

"Total correction, running light" = "Mean" + $(C_{rl} - C_{rn}) = +1.1 + (1.18 - 0.89) = +1.1 + 0.29 = 1.4$ mb.

FIGURE 6.9.5. Calibarometer apparatus used to produce controlled pressure and temperature conditions for testing and calibrating aneroid barometers.

sure is controlled to increase in similar steps until a satisfactory maximum is attained, at a pressure slightly less than the highest scale reading of the aneroid. In no case should the needle of the aneroid be forced to go outside of its normal operating scale range. At each step, while the pressure in the enclosure is maintained at a constant value, the readings of the comparison standard barometer that comes with the apparatus and of the ship's aneroid barometer should be taken simultaneously. The time of the readings for each step will be noted.

Under the block headed "Pressure" on Form WBAN 54–6.9.2, entries will be made of the following data:

Col. (1): Local standard time.

Col. (2): Observed reading of the comparison standard barometer associated with the calibarometer.

Col. (3): Corrected reading of the comparison standard barometer, representing the true atmospheric pressure at the level of the ship's aneroid barometer.

Col. (4): Observed reading of the ship's aneroid barometer.

Col. (5): Difference: Col. (3) *minus* Col. (4), showing the proper sign.

Form 455-9
(Formerly WB 1202A)

Form WBAN 54-6.9.2

COMPARATIVE BAROMETER READINGS
(MARINE COOPERATIVE)

IDENTIFICATION DATA

Vessel and Agent Am. Mu. Independence Baro. No. SF-8072 New (WB) Barometer Recently Assigned

Location Chart Room (on ship) MAKE & MFR. SERIAL NO. Taylor-Aneroid

DATE 11-22-56 STATION San Diego, Calif. BY J. F.

TEST DATA

☒ Calibarometer ☐ Check-Comparison

(Check one)

PRESSURE

TIME (LST) (1)	COMP. Unc. (2)	STD. Cor. (3)	SHIP BARO. (4)	CORR. (Col. 3-4) (5)
1300	29.87	29.89	29.92	-.03
1303	29.58	29.60	29.62	-.02
1306	29.28	29.30	29.32	-.02
1309	28.98	29.00	29.03	-.03
1312	28.65	28.66	28.68	-.02
1315	28.29	28.30	28.33	-.03
1318	27.98	28.00	28.01	-.01
1321	28.98	29.00	29.03	-.03
1324	30.08	30.10	30.13	-.03
1327	30.38	30.40	30.43	-.03
1330	30.68	30.70	30.71	-.01
1333	30.98	31.00	31.01	-.01
			SUM	-.27
			MEAN	-.02
			20 ft. *MSL RED. FACTOR	+.02
			POSTED CORR.	0.00

*Obtain reduction factor by multiplying height of ship's barometer in feet above sea level (when permanently mounted) by .0011"; add algebraically to "mean" to obtain posted correction.

TEMPERATURE
(for calibarometer tests only)

TEMP. (°F) (6)	COMP. Unc. (7)	STD. Cor. (8)	SHIP BARO. (9)	CORR. (Col. 8-9) (10)
75 (rm)	30.192	30.04	30.06	-.02
50	30.182	30.03	30.04	-.01
30	30.187	30.04	30.04	0
74 (rm)	30.195	30.05	30.07	-.02
90	30.179	30.03	30.05	-.02
105	30.174	30.03	30.05	-.02
73 (rm)	30.169	30.03	30.04	-.01

HYSTERESIS
(for calibarometer tests only)

COMP. STD (11)	SHIP BARO. (12)	CORR. (13) (Col. 11-12)
DOWN SCALE 29.00	29.03	-.03 (a)
UP SCALE 29.00	29.03	-.03 (b)
	DIFFERENCE (a - b)	0.00

Commerce-Weather Bureau, Washington, D. C.

FIGURE 6.9.6. Example of results obtained in a calibarometer test pertaining to a given aneroid barometer.

At the foot of Column (5) the algebraic sum of the entries made in the body of that column will be indicated opposite the word "Sum." Then, opposite the word "Mean" there will be indicated the result obtained by dividing the "Sum" by the number of observations.

The notation "MSL Red. Factor" below "Mean" under Column (5) represents the *correction to reduce pressure to sea level* on shipboard based on the normal height of the ship's aneroid barometer above the water line. The value of this correction is calculated in the manner shown on line (13) of Form WBAN 54–6.9.1, as illustrated in figs. 6.9.0, 6.9.1, and 6.9.2.

Finally, the correction to reduce pressure to sea level as defined in the previous paragraph is added algebraically to the value indicated for the "Mean" under Column (5), and the result obtained thereby is entered on the last line of Column (5) opposite "Posted Corr." which represents the "Posted Correction." This is the same as the "total correction" defined in sec. 6.9.2.1. It may be considered as the correction which is to be applied to the observed reading of the ship's aneroid barometer when installed on the vessel at the normal height above the water line in order to obtain the pressure reduced to sea level.

As the tests are conducted, the inspector should observe the behavior of the ship's aneroid barometer with a view to detecting evidences of malfunctioning or erratic operation. Some indications of this nature may be revealed by erratic variations in the values determined for entry in the body of Column (5), provided that the pressure is held quite steady during each step of the test and the two readings are taken close together in time. However, if the instrument is of good quality and the tests are carried out properly, the entries under Column (5) should be characterized by a relatively high degree of consistency.

Whenever a precision aneroid barometer is employed as the comparison standard barometer during the course of hysteresis tests, its readings *after being corrected* for the effects of hysteresis are compared with the observed readings of the ship's aneroid barometer. The results cannot be considered valid for hysteresis investigations without the application of such corrections. In cases where hysteresis corrections are pertinent a record of these data should be made on Form WBAN 54–6.9.2.

For purposes of obtaining data necessary for the "Hysteresis" test indicated in the block shown in the lower right-hand corner of Form WBAN 54–6.9.2, readings should be taken during the above-mentioned pressure test in such a manner that at one of the steps on the decreasing pressure phase of the cycle and at one of the steps on the increasing phase of the cycle the same value of true pressure be established, on the basis of equal corrected readings of the comparison standard barometer. The common value of true pressure which is recommended for this purpose is 29.000 inches of mercury; however, any common value for these two points fairly close to this amount, although different, will serve the purpose. The simultaneous readings of the ship's aneroid barometer for the two steps under consideration having a common value of true pressure should be recorded under Column (12) of Form WBAN 54–6.9.2. If the common value of true pressure for the two steps is different from 29.000 inches of mercury, the actual amount of the common value for the two steps based on decreasing and increasing pressure, respectively, should be entered under Column (11). In Column (13) the observer should enter the difference determined as: The value under Col. (11) *minus* the value under Col. (12). The difference for the readings on the decreasing pressure phase is designated by (a); while the difference on the increasing pressure phase is designated by (b). At the foot of Column (13), the observer will record the value of the difference between (a) and (b). It will be noted that a difference of zero (0) for (a–b) is indicative of good hysteresis characteristics; whereas, a relatively large magnitude for the difference (a–b) reveals poor characteristics in this regard.

Information regarding hysteresis and the tolerance for it is given in secs. 2.10.4 and 2.10.5; while figs. 2.10.1(a) and 2.10.1(b) illustrate the magnitude of the hysteresis effects that may be considered acceptable for precision aneroid barometers over a relatively large range of pressure variation. In the case of the hysteresis test results shown in fig. 6.9.6, one is concerned with a pressure variation of 1 inch of mercury (from 29. in. Hg to 28 in. Hg, and return up to 29 in. Hg). Since the tolerance is 0.2 percent of the range, the acceptable hysteresis effect in this example is 0.002 inch of mercury. However, if there had been observed a difference (a — b) of as much as 0.01 inch of mercury apart from rounding errors for the given pressure variation of 1 in. Hg, the tolerance would be clearly exceeded and the performance of the instrument would be regarded as unsatisfactory for precision work.

Temperature tests are conducted by means of the calibarometer in order to determine whether the ship's aneroid barometer is properly compensated for temperature. Data pertaining to such tests are to be recorded on Form WBAN 54–6.9.2, under the block headed "Temperature." Comparative barometer readings are to be taken at the temperatures listed in Column (6), *after the ship's aneroid barometer has been subjected to the indicated temperature for at least one hour in the case of each value listed.* (Observers will understand that the purpose of the minimum exposure time of 1 hour for each value of temperature is to permit the aneroid barometer to come to equilibrium.) On the lines marked (rm) which represents "room temperature," the actual thermometer readings at the location of the ship's aneroid barometer in the calibarometer should be entered under Column (6), following the minimum exposure time of 1 hour. In Columns (7) and (9) there should be entered the observed (uncorrected) readings of the comparison standard barometer and of the ship's aneroid barometer, respectively; while in Column (8) the values of true pressure pertinent to the level of the latter instrument are to be entered, as determined by correcting the data given in Col. (7). In Column (10) the differences represented by the values "Column (8) *minus* Column (9)" are to be indicated.

The following *tolerance* is permitted in connection with the effects of temperature change on *marine aneroid barometers* such as the type illustrated in fig. 6.9.4: Over the range of temperature from 100° F. to 40° F., the indicated reading should not change by more than 0.00067 inch of mercury for each degree Fahrenheit change in temperature, or 0.0406 mb. per degree Celsius, under the assumption that the ambient pressure remains constant.

Sometimes there may be actual changes in pressure which must be taken into account. In order to make proper allowances for the effects of actual changes in ambient pressure in checking whether the tolerance is satisfied, it is necessary to investigate the variation with temperature of the difference between the corrected pressure based on the comparison standard barometer and the observed reading of the ship's aneroid barometer; that is, one must determine whether the change in the difference on proceeding from room temperature to another value of temperature, either greater or less, occurs at a rate exceeding that specified by the tolerance. Therefore, we are concerned with the variation in the differences indicated in Column (10) of the form, as compared with the deviation between the differences permitted according to the product of the observed temperature departure and the given tolerance rate.

For example, if comparative barometer readings are taken at room temperature 75° F. and also at 50° F., this involves a change of 25° F.; hence for this case the permitted variation in the difference between the two barometers is 25° F. × 0.00067 inch of mercury per °F., which is equal to 0.017 inch of mercury. Since the observed variation in the difference illustrated in fig. 6.9.6 was 0.01 inch of mercury for this change in temperature, the results are tolerable; that is, at 75° F., the difference was —0.02 in. Hg while at 50° F., the difference was —0.01 in. Hg; therefore, the deviation between these two values was 0.01 in. Hg, which is within the acceptable limit of 0.017 in. Hg as calculated above.

With regard to *precision aneroid barometers* the following *tolerance* is permitted: Over the temperature range from 100° F. to 40° F., the indicated reading *should not* change by more than 0.0004 inch of mercury for each degree Fahrenheit change in temperature, or 0.024 mb. per °C., under the assumption that the pressure remains constant.

In cases where the ship's aneroid barometer yields a performance not as good as required under the specified tolerances for any of the tests made with the calibarometer, action should be taken to replace the defective barometer with one which gives satisfactory performance.

After any ship's aneroid barometer has been tested by means of a calibarometer and found to function in an acceptable manner, it may be returned to the ship for use. However, the total correction for the instrument should be determined on board the vessel after its return, in accordance with the provisions of sec. 6.9.2.1 or other applicable instructions. In every case the inspector should post the pertinent value of the total correction on the face of the barometer immediately after determination of the correction so that it will be available for observational purposes. As a matter of interest, the inspector should compare the total correction determined on board ship with the posted correction ascertained by means of the calibarometer. If the two differ significantly, the matter should be investigated.

6.10 STANDARDIZATION OF BAROGRAPHS

6.10.0 General Information

The principle of operation and the characteristics of the aneroid barograph have already been described in sec. 2.9. In the case of the types of barographs which were generally used before say 1935, the ratio of the vertical movement of the pen to the pressure change in inches of mercury is 1–1; whereas in the case of the newer models generally used since then, the ratio is 2.5–1. While the practice has developed in the United States of calling the latter instruments "microbarographs" and "open-scale barographs," we shall simply employ the term "barograph" when referring to them, provided there is no ambiguity. When it is necessary to distinguish definitely between the two types mentioned above, one can employ the terms "1–1 barograph" and "2.5–1 barograph," respectively. Figs. 2.9.0 and A–2.21.10 illustrate the "2.5–1 barograph" which is generally used at land stations; while fig. 2.9.1 shows the more modern design of the "2.5–1 barograph" equipped with an air-tight, sealed case and outside nipple. The latter feature permits the instrument to be connected to a static pressure head by means of a tube (see fig. 2.11.0). Employment of a static pressure head in the system is desirable when the observation site is subject to strong relative winds, as on ocean-going vessels or mountain stations. The instrument pictured in fig. 2.9.1 has been designed to permit its being used on ships at sea, since the apparatus is provided with means for damping out the effect of vibrations and very short-period pressure changes caused by the rising and falling of the ship.

In fig. A–2.21.10 there is shown the "station pressure adjustment screw"; while the corresponding device is indicated in figs. 2.9.0 and 2.9.1 as the "pressure adjusting knob." Barographs are provided with this knurled nut to permit adjusting the pen position on the chart when the case cover is open. This enables an observer to reset the pen so that the correction to the reading of the barograph will be zero.

Barographs of modern design are equipped with a device for adjusting the ratio of the pen movement to the pressure change which causes the pen motion. With some mechanisms the ratio is not constant over the entire range; hence, the specifications for modern barographs require the provision of a device which permits one to control the ratio at each point over the range of operation of the instrument. When the ratio is absolutely constant for all points of the entire range, the performance of the barograph is termed "linear." In cases where perfect linearity in performance is achieved, any correction to the reading which is determined at a single point on the range will apply with equal validity at all other points over the entire range of operation.

It is the practice at the factories of manufactures of modern barographs to adjust the devices mentioned in the previous paragraph with a view to securing a very nearly, if not perfect, linear performance. Calibrations are performed at the factories in order to determine the corrections applicable to the readings at various points distributed over the entire pressure range of the barograph. In cases where the results of the calibrations show that the corrections are all alike over the full range, this implies that the desired linearity of performance has been achieved. However, if the corrections differ significantly among themselves over the operating range of the instrument, further adjustments of the devices are required until a linear performance is secured, or at least a tolerable approximation to it is obtained. Therefore, when the barographs are delivered by the manufacturer to the government agency making the purchase, the instruments are supposed to yield either a linear performance or a satisfactory approximation to such performance, conforming to the existing specifications. Under normal quality control procedures, the government agency which purchases the instruments has its inspector at the factory or instrument laboratory select barographs at random from those delivered by the manufacturer and the inspector will perform individual calibrations and other tests on these barographs. When the results of the experiments reveal that the quality of the batch is below that required under the specifications, the manufacturer is held responsible, and he will make the readjustments of the devices or other modifications required in order to meet the specifications. In the case of handmade equipment, individual inspection and calibration of the product is required.

Under the system described in the previous paragraph, it can be expected that barographs shipped to stations will, as a rule, satisfy the specifications in regard to linearity of performance. From the standpoint of the observer, this simply implies that if a correction is found at any given reading, it will apply equally well at all other readings. Whenever this condition is satisfied, it is possible to reset the pressure adjusting knob until the correction is zero for the reading at the time of observation, and it should theoretically also remain zero for other readings.

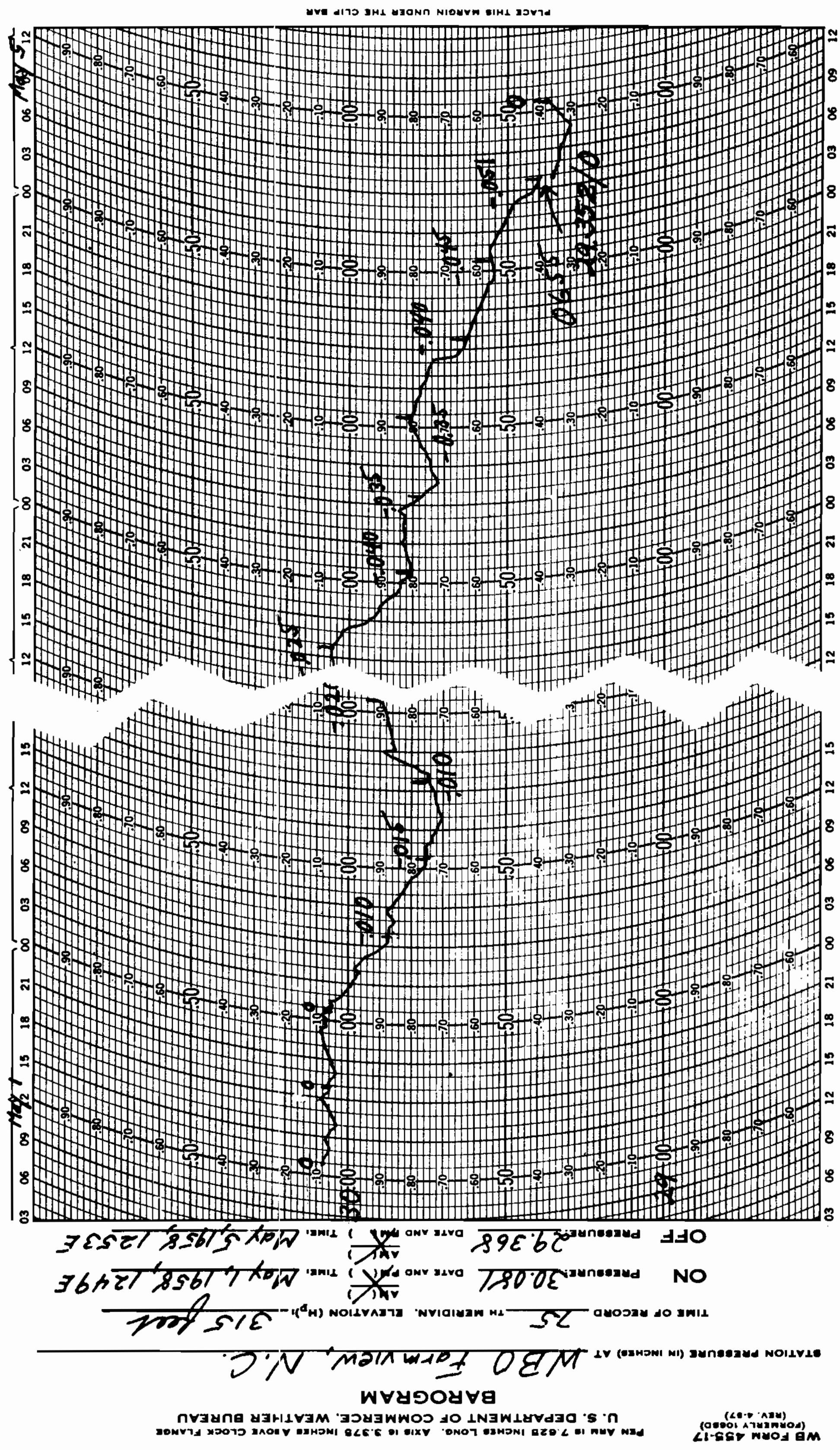
However, the barograph does not always yield such linear behavior over a long period of time; therefore, it is necessary to redetermine the correction at certain intervals. Generally, the departure from linearity will stem from effects of hysteresis, imperfect temperature compensation, friction, and other mechanical characteristics of the instrument.

At land stations, observers are required to determine the correction for the barograph at the time of each regular 6–hourly synoptic observation, and also at any time the barogram is changed or the pressure adjusting knob is reset. Entries on the barogram are illustrated in fig. 6.10.0. Details regarding these procedures are given in sec. 6.10.1; but at this point it may be remarked that the correction is determined by subtracting the actual reading of the barograph from the *station pressure* which is found simultaneously on the basis of the mercury barometer or precision aneroid barometer reading.

On vessels, observers should set the pressure adjusting knob so that the barograph will read the *sea-level pressure* directly each time that the barogram is changed. Certain information is entered on the barogram as illustrated in fig. 6.10.1. Further details concerning the procedures involving barographs on shipboard are given in sec. 6.10.2.

The procedures both for land stations and vessels, mentioned above, are based on the assumption that the barograph always functions perfectly, in accordance with the specifications under which the instrument was procured. Unfortunately, however, this assumption is not fulfilled in every case.

It is for this reason that the user of any barograph must be constantly on the alert for signs of defects which may develop. Most serious is the development of a slow leak in the aneroid element. This is generally indicated by a progressive algebraic increase in the correction found necessary when comparisons are made at more or less regular intervals of time. In other words, if it is necessary to adjust the pen toward higher readings each time in order to reduce



WB FORM 455-17 (FORMERLY 1068D) (REV. 4-57)

PEN ARM IS 7.625 INCHES LONG. AXIS IS 3.375 INCHES ABOVE CLOCK FLANGE

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

BAROGRAM

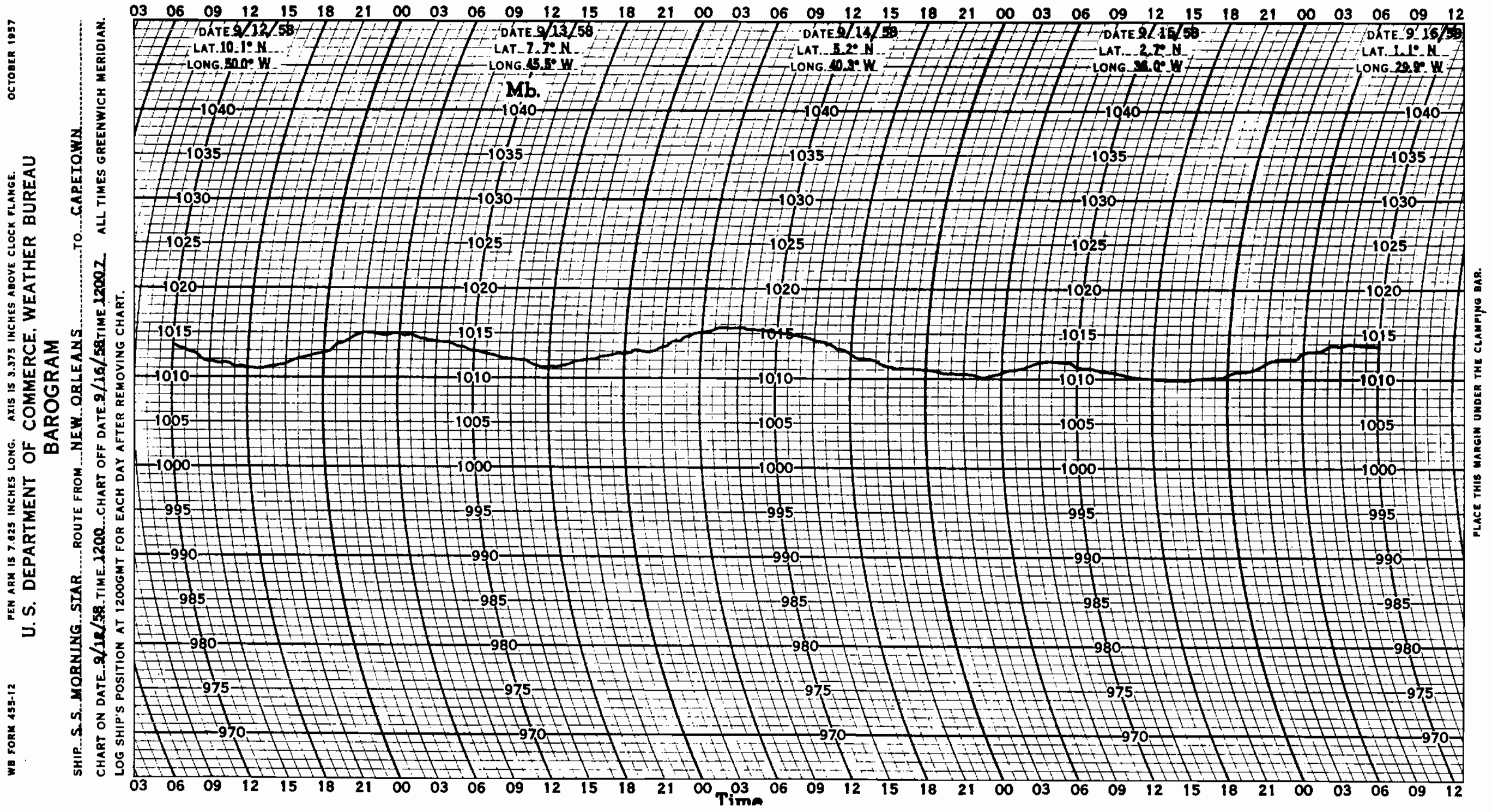
STATION PRESSURE (IN INCHES) AT WBO Farmview, N.C.

TIME OF RECORD 75 TH MERIDIAN. ELEVATION (H_p): 315 feet

ON PRESSURE: 30.081 DATE AND (AM/PM) TIME: May 1, 1958, 1249E

OFF PRESSURE: 29.368 DATE AND (AM/PM) TIME: May 5, 1958 1253E

FIGURE 6.10.0. Open-scale barograph record (Form WBAN 54–2.9.3) obtained by means of the barograph shown in fig. 2.9.0. Data to be entered by station personnel are indicated on the barogram.



WB FORM 455-12 PEN ARM IS 7.625 INCHES LONG. AXIS IS 3.375 INCHES ABOVE CLOCK FLANGE. OCTOBER 1957

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

BAROGRAM

SHIP S.S. MORNING STAR ROUTE FROM NEW ORLEANS TO CAPETOWN

CHART ON DATE 9/12/58 TIME 1200 CHART OFF DATE 9/16/58 TIME 1200Z ALL TIMES GREENWICH MERIDIAN.

LOG SHIP'S POSITION AT 1200GMT FOR EACH DAY AFTER REMOVING CHART.

DATE 9/12/58 LAT. 10.1° N LONG. 50.0° W

DATE 9/13/58 LAT. 7.7° N LONG. 45.5° W

DATE 9/14/58 LAT. 5.2° N LONG. 40.3° W

DATE 9/15/58 LAT. 2.7° N LONG. 36.0° W

DATE 9/16/58 LAT. 1.1° N LONG. 29.9° W

FIGURE 6.10.1. Open-scale barograph record (Form WBAN 54–2.9.1) obtained on a ship by means of the barograph shown in fig. 2.9.1. Data to be entered by a ship's officer are indicated near top and left-hand side.

the correction to zero, the observer should consider the possibility that a slow leak has formed in the element. Thus, in cases where the rate of increase of the correction is much larger algebraically than has ever been experienced before on a daily or 4–day basis, and where the increase persists over a period of days or weeks, action should be taken to requisition a new barograph. The instrument which is defective should be taken out of service.

Another kind of defect becomes manifest when the correction varies significantly with pressure in a systematic manner. For example, if the corrections determined at times when the pressure is high and low differ appreciably from the correction ascertained under average pressure readings, it would appear that the performance of the barograph is not linear. After this behavior is first noticed, the observer should take special pains to check whether this conclusion is verified. He may do this by determining the correction more frequently than usual over as wide a range of pressure as occurs during the period of investigation, and he should make a plot of the correction against pressure in the form of a graph. In the case of a barograph in good working order, the corrections are essentially constant over the pressure range; hence, the plotted points will yield, practically speaking, a *horizontal* straight line. But in the case of an instrument whose calibration has deviated significantly from the desired linear performance, the line of best fit passing through the plotted points will either have a significant slope or will reveal significant curvature. When the barograph is characterized by variable corrections as described in the previous sentence, this usually indicates that the devices for setting the ratio of the pen movement to the pressure change are not properly adjusted or that the apparatus has developed some mechanical defect (see third paragraph of sec. 6.10.0). In such an event, action should be taken to procure a replacement for the defective barograph.

Observers in the field are not authorized to adjust the devices in the barograph designed to control the ratio of pen movement to pressure change, since a person not specially trained or skilled in the art of making such adjustments may cause irreparable damage to the instrument by disturbing the delicate mechanism. The problem of carrying out the proper adjustments for these devices is to be left to the skilled and experienced technicians at the instrument laboratories where the necessary equipment and calibration standard barometers are available to permit making the adjustments in the required manner.

When a "2.5–1 barograph" has been properly adjusted and has been handled with care, it is capable of yielding results of an acceptable order of precision for meteorological observational purposes, provided that it is maintained at a fairly uniform temperature and is not subjected to mechanical shocks or jolts. Values may be read from the pressure scale of the chart to the nearest 0.005 inch of mercury or perhaps to the nearest 0.1 mb. under good conditions. In order to overcome the effects of friction, the top of the instrument case should be tapped lightly just before making a reading. With a view to achieving good conditions for the operation of the barograph, it should not be subjected to rapid or excessively large changes of temperature, keeping in mind the possibility that the temperature compensation device may not function as perfectly as desired. Owing to this fact, the instrument should neither be exposed to direct sunshine nor to sources of heat or cold, which can produce marked variations of temperature in its mechanism. While the barograph is equipped with means for damping out the effect of vibrations, this is not a protection against damage to the delicate linkages and bearings in the instrument owing to severe jars and concussions. Under conditions where such jars may occur to the base on which the barograph is installed, it is desirable to maintain it on a shock-insulating mount (see sec. A–2.21.0).

Results of the requisite absolute accuracy can be obtained with the aid of a "2.5–1 barograph" only after the foregoing precautions have been taken, while at the same time the necessary correction to the readings has been determined and applied. Therefore, the instructions contained in secs. 6.10.1

and 6.10.2 should be followed with care, in view of the need to ascertain the pertinent corrections as accurately as possible.

Good performance of a 2.5–1 barograph will be understood to imply the following characteristics regarding the instrument:

(1) It must yield a relatively fine trace.

(2) It must be responsive to changes of pressure of the order of 0.1 mb. (0.003 inch of mercury) or less.

(3) Its performance must be essentially linear over the normal operating range of pressure. In order to test for linearity of performance it is necessary first of all to compare the readings of the barograph with the air pressures observed simultaneously by means of a mercury barometer of good quality and thus to determine the corrections to the readings of the barograph over substantially its entire range. An investigation must then be made in regard to the constancy or variability of these corrections. The performance will be considered essentially linear within acceptable tolerances if a constant value of the correction is valid over the entire range, or if the deviation between corrections pertinent to readings made at increments of 0.50 inch of mercury beginning anywhere on the scale does not exceed 0.005 inch of mercury.

(4) The barograph must give repeatable results for the same conditions under calibration within a tolerance of about 0.1 mb. (0.003 inch of mercury).

(5) The barograph should be sufficiently damped so that excessive oscillation of the pen will not result when the mounting surface is under vibration.

(6) Friction of the pen with respect to the chart should not be so excessive that the pen will not return within the limits of readability to its previous reading if the pen is displaced manually the equivalent of 0.02 inch of mercury (0.6 mb.) from its initial position at any point of the scale. Similarly, if the barograph pen is displaced manually plus or minus the equivalent of 0.20 inch of mercury while the pen is in contact with the barograph chart and the pen is then allowed to return slowly toward its original position, while the barograph is free from vibration, the pen should return to within 0.02 inch of mercury (0.6 mb.) of the position it occupied before being displaced.

(7) The barograph should not suffer from excessive hysteresis; that is, corrections determined at the same readings during phases of decreasing and increasing pressure should be in close agreement, usually within 0.2 mb. (0.006 inch of mercury). See sec. 2.10, and figs. 2.10.0, 2.10.1 (a) and 2.10.1 (b).

(8) The barograph must not have any apparent mechanical defects such as might be evidenced by looseness of linkages, binding of pen-arm shaft pivots, or contact of any part of a moving linkage with any adjacent fixed portion of the instrument.

(9) The corrections determined over a period of time for the readings of the barograph should be essentially constant. If the corrections are tending toward greater and greater values at a rapid rate, this may usually be taken to signify an impairment of the pressure responsive cell, or perhaps the development of a mechanical defect.

(10) The clockwork which operates the rotation of the chart drum should yield a constant time rate in close harmony with the indications of a standard, synchronized clock. The backlash on the chart drum should not exceed the equivalent of 15 minutes on the time scale of the chart.

6.10.1 Standardization of Barographs at Land Stations.

6.10.1.0 General Information.—Barographs are to be used at field stations only under the condition that they have been adjusted at the factory or instrument laboratory to yield a linear performance as explained in sec. 6.10.0.

Subject to this condition, the following list shows the principal operational objectives relating to the standardization of barographs:

(1) Determination of the correction of the barograph at standard 6-hourly intervals as specified in the WBAN Manual of Surface Observations, Circular N. (See sec. 6.10.1.2.)

(2) Making of appropriate adjustments to the barograph so that it will indicate the true station pressure and the correct time, at least when *the barogram*

is changed and when it is found that excessive errors appear in the pressure or time indications yielded by the equipment. (See secs. 6.10.1.4 and 6.10.1.5.)

(3) Entry of necessary reference marks and other relevant data on the barogram and pertinent forms, to permit completion of the chart and to enable future users to interpret the record correctly. (See secs. 6.10.1.6, 6.10.1.8, 6.10.1.12, and 6.10.1.14.)

(4) Maintenance of the equipment in continuous, good running order. (See sec. A–2.16.3.)

(5) Proper disposition of the barograms when completed. (See sec. A–2.16.3.10.)

(6) Application of the latest appropriate barograph correction to the reading of the instrument when it is desired to obtain the corresponding station pressure. (See sec. A–2.16.3.11.)

6.10.1.1 Definition of Barograph Correction.—Let P represent the station pressure, R the reading of the barograph observed simultaneously, and C the correction to the barograph reading; then the required correction is defined as the result obtained by subtracting the reading (R) algebraically from the station pressure (P); that is,

$$C = (P - R).$$

The sign of C may be either positive (+) or negative (−). By virtue of the definition, it may be seen that when the correction has been appropriately determined, the application of the correction with its proper algebraic sign to the reading of the barograph will yield the station pressure; i.e., $P = (R + C)$, considered algebraically.

EXAMPLES $C = (P - R)$

Data	(a) in. Hg	(b) in. Hg	(c) mb.	(d) mb.
Station pressure, P	30.129	29.762	1015.9	876.4
Barograph reading, R	30.105	29.780	1015.6	876.9
Barograph correction, C	+0.024	−0.018	+0.3	−0.5
Rounded value of C	+0.025	−0.020	+0.3	−0.5

6.10.1.2 Times and Conditions for Determining Barograph Corrections.—Barograph corrections should be determined for the following times and conditions:

(a) at certain standard 6-hourly intervals as specified in circular N;[5]

(b) whenever the barogram is replaced; and

(c) whenever an adjustment is made in the barograph pen position which affects the reading.

With regard to items (b) and (c), it should be understood that readings of the barograph are to be made and corresponding barograph corrections calculated both immediately *before and after* the stated change; that is, the data will be determined for the end of an old barogram and the beginning of a new one, also before and after any adjustment is made in the pressure setting of the pen.

6.10.1.3 Posting of Barograph Correction.—A record of the latest, appropriate barograph correction should be maintained on a suitable form, card, or device kept in a well-known location at the station, preferably near the barograph. The pertinent *plus* (+) or *minus* (−) sign which applies to the particular correction must always be indicated.

6.10.1.4 Conditions for Resetting Barograph Pressure Indication.—A barograph will be adjusted (reset) to *zero correction* under each of the following two conditions: (1) when the barograph chart is replaced, and (2) when the absolute value of the barograph correction is determined to be greater than a certain limiting tolerance specified in Circular N.[6] Instructions regarding the procedure for resetting the pressure indication of barographs are presented in sec. 6.10.1.10.

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[5] The Seventh Edition of Circular N, dated October 1957, specifies that barograph corrections will be determined at the standard 6-hourly synoptic times, namely 0000, 0600, 1200, and 1800 Greenwich Civil Time, at stations which make use of Form WBAN–10.

[6] Circular N, Seventh Edition, dated October 1957, specifies the following limiting tolerances: (A) the maximum allowable error of the barograph pressure indication is 0.05 inch Hg or 1.5 mb.; and (B) the maximum allowable error in the barograph time indication is one-fourth (1/4) of one chart time division.

6.10.1.5 Conditions for Adjusting Barograph Time Indication.—The time indication of a barograph will be adjusted to yield the correct time under each of the following two conditions: (1) when the barogram is replaced, and (2) when the time indicated by the last position of the pen trace on the chart departs from the correct time by an amount greater than a certain limiting tolerance specified in Circular N.[6] Proper procedures for adjusting the barograph time indication are described in sec. 6.10.1.11.

6.10.1.6 Data and Forms Used in Computing Barograph Corrections.—When computing the barograph correction at any time, the following data will be involved: (1) time; (2) station pressure, P; (3) barograph reading, R; and (4) barograph correction, C.

The foregoing information should be recorded for all of the times and conditions specified in sec. 6.10.1.2. This is to be understood as implying that whenever a barogram is replaced or the pen reset, the data pertaining to both *before and after* the change should be recorded in some manner, either by complete entries or by implication from other known data.

Instructions given in the latest edition of WBAN Manual of Surface Observations, Circular N, should be followed with regard to the entry of the pertinent data on Form WBAN–10. A special notation is to be made whenever the barograph is reset to a zero correction, giving the time of the change.

Some of the data are to be transferred to the barogram in accordance with the provisions of sec. 6.10.1.12 and sec. 6.10.1.13.

In cases where Form WBAN–10 is not used or where the information given on that form is not sufficient to enable the observer to complete the information required on the barogram, it is essential for the observers to prepare such records of the pertinent data as will permit them to make the necessary entries on the chart after it is removed from the cylinder. Such records should be kept at least until the data entries and notations required on the barogram have been completed and checked.

The following examples indicate satisfactory methods of recording the data in cases where the pen position is reset in order to obtain a zero correction or the barogram is replaced, under the conditions stated in the last paragraph:

EXAMPLE I

Barograph, 0948E.

Before reset	After reset
P 29.872	29.872 in. Hg
R 29.925	29.870
C −.055	0

EXAMPLE II

Barogram replaced, 1500E.

Before	After
P 29.054	29.054 in. Hg
R 29.030	29.055
C +.025	0

In the examples, time is given on a local basis (E denotes Eastern Standard Time), while the other data are designated by the adopted symbols as listed in the first paragraph of this section.

6.10.1.7 Station Pressure for Computing Barograph Correction.—For this purpose the station pressure should be determined to the nearest 0.001 inch of mercury or 0.05 mb., when based on mercurial barometer observations, and to the nearest 0.005 inch Hg or 0.1 mb., when based on properly corrected readings of precision aneroid barometers or of altimeter-setting indicators. Such corrected readings of the latter instruments will be regarded as valid for computing barograph corrections only on condition that the instruments have been standardized in accordance with the provisions of secs. 6.7 and 6.8.

6.10.1.8 Barograph Readings and Time-Check Lines.—Barograph readings will be obtained to the nearest 0.005 inch Hg, when the barogram is graduated in inches, and to the nearest 0.1 mb., when it is graduated in millibars. At land stations such readings are to be taken for the times and conditions specified in Sec. 6.10.1.2, in order to enable the observer to calculate the barograph correction as illustrated in secs. 6.10.1.1 and 6.10.1.6.

In accordance with relevant instructions in WBAN Manual of Surface Observations, Circular N, a time-check line should be made on the barogram immediately after the barograph reading has been taken for the purpose of determining the barograph correction at the standard 6-hourly intervals (see fig. 6.10.0 and sec. 6.10.1.2).[7] However, a time-check line should *not* be made at the beginning of a trace or at any time the pen of the barograph has been reset to a zero correction, since such a line might, under some conditions, be misinterpreted as indicating a sudden drop in pressure and also make it difficult to verify the zero correction. In harmony with the instructions of Circular N, it is suggested that the length of the time-check line be about equal to the vertical spacing of two pressure-scale divisions on the chart, since this length is generally sufficient to permit identification of the time-check line as a mark made for the special purpose of checking time indications on the chart, with little likelihood that it will be confused with a sudden rise in the trace due to an actual sharp increase in pressure. When making a time-check line, the pen should be quickly but gently raised upward with a finger toward a higher pressure indication by the amount stated above, and then the pen is to be released so that it will return to its proper position under the existing pressure conditions.

6.10.1.9 Barograph Correction Calculated.—The barograph reading (R) is subtracted algebraically from the station pressure (P) for the same time, and the resulting algebraic difference is the barograph correction, (C), as defined in sec. 6.10.1.1. If the data are in inches of mercury, the value of the barograph correction will be generally indicated as rounded to the nearest 0.005 in. Hg; whereas if the data are in millibars, the value will generally be indicated to the nearest 0.1 mb., since these figures reveal the order of magnitude of the probable precision. When the value of the barograph correction rounds to zero under these rules, it is the general practice to enter the correction as "0" (see Circular N and sec. 6.10.1.6).

6.10.1.10 Instructions for Resetting Barograph to Zero Correction.—The following procedure will be used in adjusting the barograph so that it will indicate station pressure: The knurled, pressure-adjusting knob at the top of the housing for the pressure element should be turned until the pen point indicates the correct station pressure as determined immediately prior to the adjustment (see figs. 2.9.0, 2.9.1, and A–2.21.10 which illustrate the knob). While turning the pressure-adjusting knob as described in the preceding sentence, the case or chassis of the barograph should be tapped lightly in order to overcome any sticking in the linkage mechanism, this step being necessary until the very end of the resetting process. It is always desirable to recheck the final setting after the instrument is again lightly tapped, in order to be certain that the barograph has been accurately adjusted to a zero correction before it is left.

6.10.1.11 Adjusting Time Indication of Barograph.—The objective considered here is the adjustment of the cylinder so that the pen will indicate the correct time according to the scale of the curved vertical time lines, without there being any backlash or slack motion in the clock gear train or drive mechanism. Since the cylinder rotates clockwise, the backlash can be taken up only by turning the cylinder counterclockwise with sufficient force to override the friction drive. This means that in the last stage of the adjustment of the cylinder to obtain the correct time indication it is necessary to be turning the cylinder counterclockwise just before stopping. It does not matter if the cylinder was turned clockwise previous to this last step, provided that the cylinder is turned counterclockwise against the friction drive at the final stage of the resetting for time. Therefore, either of the following two methods may be used for the adjustment: (a) turn the barograph cylinder counterclockwise until all slack motion is removed and continue turning in this direction until the pen point indicates the correct (current) time according to the scale provided by the curved vertical time lines on the chart; or (b) turn the cylinder clockwise to a point where the time indication is say 1 to 2 hours ahead of

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[7] These instructions apply at land stations to barographs whose cases are not air-tight and can be readily opened as illustrated in figs. 2.9.0 and A–2.21.10. The instructions will not apply when use is made of the newer type of barograph as illustrated in fig. 2.9.1, provided there is need generally to maintain the air-tight case sealed and connected with a static-pressure head, as might be the situation at mountain stations. No time-check line is to be made under such conditions or when a marine-type barograph is used on shipboard.

the correct time, then finally turn the cylinder counterclockwise until the pen indicates the correct time.

6.10.1.12 Preparation of Chart Before Placing It on Barograph.—Before placing a barogram on the instrument, the observer should check whether the trimming of the form along its lower edge is along a line parallel to and about 1/4 inch below the lower, printed horizontal boundary line of the chart. If the chart has been originally cut inaccurately, the observer should carefully trim it to satisfy this requirement.

Certain data should be entered on the barogram for permanent record purposes in order to permit future users of the chart to interpret it correctly. The printed legends on the chart forms usually indicate what data are to be thus entered, and the latest edition of Circular N gives detailed operational instructions regarding the data to be entered by means of typewriter, rubber stamp, or pen and ink. Accordingly, the following list shows the data which are to be recorded by the observer on the chart prior to its being placed on the barograph cylinder:

(1) The name of the station and its type or organizational affiliation (for example, WBO, WBAS, AFB, NAS, etc.).

(2) The meridian of local standard time.

(3) The station elevation (H_p), in feet.

(4) The date of each day's record covered by the chart, to be indicated across the top of the chart on each noon line, or in the spaces provided.

(5) Figures to complete pressure values pertinent to the station, when there are missing numbers.

(6) The station pressure, the date, and the time pertinent to the instant at which the pen began making the trace on the given barogram. These data are to be entered in the space marked "ON." Pressure is to be given to the nearest 0.001 in. Hg or 0.1 mb. and time to the nearest minute Local Standard Time unless GCT is specifically authorized.

6.10.1.13 Instructions for Replacing a Barogram.—In order to replace the chart on a barograph, the following steps are taken:

(1) Open the barograph case (see figs. 2.9.0 and A–2.21.2).

(2) Push the shifting lever to hold the pen away from the cylinder.

(3) Lift the clock cylinder vertically from the shaft and remove it from the case, taking precautions to avoid smearing ink on the chart already wrapped around the cylinder.

(4) Remove the chart clip by pulling it vertically from the bottom slot and the top notch of the cylinder; then carefully remove the barogram already on the cylinder and lay it in a safe place. When handling or storing charts which have a trace, use care to prevent smearing the ink.

(5) Wind the clock. (*Caution:* This should be done before replacing the cylinder on the shaft of the instrument; when handling the cylinder, it should be held in such a manner that neither the clip nor the chart will be disturbed from its proper position. Make it a rule to have a regular winding of the clock each time that the chart is changed. Avoid forcing the winding device beyond its normal, fully wound position; stop winding if excessive tension or resistance is felt. The older types of barographs employ a winding key which is reached through the open top of the cylinder, and which must be turned in the direction indicated by the arrows beside the key. A different arrangement is used in connection with the newer type of barographs such as that pictured in fig. 2.9.1, which has its clock fastened permanently to the base plate of the instrument and is provided with separate, removable cylinder. After the cylinder is lifted from barographs of this type, the crank and ratchet device employed for winding the clock will be seen on top of the clock casing. The winding of the clock of this type is accomplished by pushing the crank a number of times forward and back in a horizontal plane. Care must be taken never to overwind the movement.)

(6) Take a new barogram on which there has already been entered the data required in accordance with the instructions in sec. 6.10.1.12, and install the barogram in the manner described below.

(7) Fit the replacement chart smoothly and tightly on the cylinder, with the bottom edge of the chart uniformly in contact with the flange at the bottom of the cylinder. Do this operation in such a manner that the actual beginning of the chart is lined up with the right-hand sides of the bottom slot and the top notch of the cylinder, while the chart is wrapped around so that its end portion laps over its left-hand margin and comes nearly up to the line of the actual beginning of the barogram trace area.

(8) Holding the chart clip so that the outside of the curve is toward the chart, insert the straight end of the clip into the slot at the bottom of the cylinder, lay the clip flat against the lapped portions of the chart, and push the hooked top down to engage the top notch of the cylinder. Check to see that the lower edge of the chart is snug against the bottom flange of the cylinder and that the chart fits smoothly and tightly.

(9) Note the local time and lower the cylinder gently over the center spindle, having it oriented so that the pen point will indicate approximately the correct time according to the corresponding curved vertical (time) lines on the chart. Next, lower the cylinder all the way gently until the gears have fully meshed in order to enable the clock gears to drive the cylinder mechanism.

(10) Fill the pen with ink by putting a drop of ink, such as would normally cling to the end of a fine wire, between the nibs of the pen. The pen barrel never should be more than 3/4 full. In order to start the ink flow, draw a piece of cellophane or lint-free paper, such as a piece of chart paper, between the nibs of the pen to wet the inside surfaces. However, care must be exercised to avoid bending, deforming or springing open the nibs, and to avoid leaving any particles of paper or lint between them. Remove any ink from the outside surfaces of the pen, since ink in that place will tend to collect dust which may cause too broad a trace. (*Note:* It is necessary to use for the barograph records a special registering ink that will remain fluid at low temperatures.)

(11) Check whether the extremities of the horizontal pressure lines match at the two ends of the chart when it is wrapped around the cylinder. Such a check may be performed by turning the cylinder on its spindle; first, so that the pen point may make contact on the left-hand side of the chart clip and, second, so that it may make contact on the right-hand side of the chart clip, observing at both places of contact the reading on the chart. If the readings at the two points are exactly the same, it may be assumed that the extremities of the pressure lines match. When it is desired to bring the pen into contact with the chart during the performance of the test or to break the contact at any stage, this is done by moving the shifting lever in the proper direction.

(12) Adjust the time indication of the barograph so that it will show the correct time, in accordance with the instructions in sec. 6.10.1.11. When making this adjustment, it must be remembered that the cylinder is to be turned counterclockwise against the friction drive of the mechanism at the very end of the operation in order to be certain that backlash is eliminated. (*Note:* It is recommended that the pen point be held away from the chart by means of the shifting lever while making any kind of adjustment, either for correct time or pressure, since the maintenance of pen point contact with the barogram under these conditions will produce horizontal or vertical marks on the barogram which could cause confusion or mar the record. Contact of the pen point with the chart

is to be made by means of the shifting lever immediately after an adjustment is made, at which stage it is necessary to check the results of the adjustment.

(13) Then, adjust the vertical position of the pen, if necessary, so that it will indicate the correct, current station pressure, being sure that contact of the pen is established at this value in accordance with the instructions given in sec. 6.10.1.10. (See also secs. 6.10.1.2 and 6.10.1.4.) It is suggested that the recommendations made in the note presented at the end of the previous paragraph be carried out in order to obviate making unnecessary or confusing pen marks on the chart as a result of adjustments.

(14) Check the results of the foregoing procedure, in order to be sure that the clock is operating and that the pen is producing a satisfactory trace, consistent with the current pressure and time.

(15) Post the pertinent barograph correction, in accordance with the instructions contained in sec. 6.10.1.3. (See also secs. 6.10.1.2 and 6.10.1.6.)

6.10.1.14 Data Entries on Completed Barograms.—After the trace has been made on a barogram for the required period of record and the chart has been removed from the cylinder, certain data must be entered on the form before it can be considered complete. Such information is essential to enable those who may use the chart in the future to give proper interpretation to the record. Printed legends on the chart indicate the data to be entered in designated spaces; while operational instructions regarding the specific entries of data necessary on the form are contained in the latest edition of Circular N. Use should be made of the typewriter, rubber stamp, or pen and ink for such purposes in order to secure a permanent record.

The following entries are necessary:

(1) On the line labeled "OFF," which refers to the instant at which the pen ends the trace, three items of pertinent information are to be written as here listed: (a) the correct, current station pressure to the nearest 0.001 in. Hg or 0.1 mb. at the time the trace was terminated; (b) the date; and (c) the time to the nearest minute at which the trace was stopped. The date and time are generally required on the basis of Local Standard Time, although in some cases the use of Greenwich Civil Time (GCT) is authorized.

(2) The barograph corrections (including the proper algebraic signs) which were determined at the standard 6–hourly intervals or at other regular times should be entered, particularly as follows: (a) beginning of trace; (b) in connection with each respective time-check line made on the chart; and (c) end of trace.

(3) Whenever an adjustment of the pressure indication of the pen is made, the items of information required to be written on the chart are as follows in connection with the times at which the pen was reset: (a) the local standard time together with an arrow indicating the point on the trace which was recorded just prior to the adjustment; (b) the correct station pressure determined at the same time; (c) the pertinent barograph correction just prior to the adjustment; and (d) the pertinent barograph correction immediately following the adjustment.

Fig. 6.10.0, taken from Circular N (Seventh Edition, October, 1957), illustrates the manner in which the foregoing entries are made in accordance with the instructions given in that publication.

In cases where the barograph cylinder covers a period of 12 hours in one rotation, special handling of the barogram is required whenever the traces for successive cycles of rotation intersect. Under that circumstance, the observer should indicate which cycle or time interval is pertinent to the two portions of the traces between points of intersection, so that the record may be properly interpreted without ambiguity at a later date. One method of doing this is to enter in a circle the day of the month or time period referred to in connection with the respective segments of the traces between points of intersection, and to use arrows as may be necessary to point from the encircled data to the pertinent segments of the traces so that they may be properly identified or associated.

6.10.2 Standardization of Marine Barographs

6.10.2.0 General Information.—The marine barograph, which is illustrated in Fig. 2.9.1, has a damper component designed to eliminate effects of vibrations, oscillations due to wind and wave action on the ship, and insignificant pressure fluctuations which result from gusts, etc. Readers will want to make reference to sec. A–2.16.4 for information relating to the installation, maintenance, and operation of the marine barograph.

Procedures for standardizing marine barographs on board ship are described in the following sections. The principal point involved in these steps is the setting of the pen to the correct time and sea-level pressure at the instant that a new chart is put into operation on the cylinder (see sec. 6.10.2.1). Certain data must also be recorded on the chart, including the ship's position at Greenwich Meridian noon for each day (see sec. 6.10.2.2).

6.10.2.1 Correct Setting of Marine Barographs.—At the time that a new chart is placed on the cylinder of the marine barograph the pen of the instrument should be set to indicate the existing sea-level pressure as determined from the properly corrected reading of a calibrated barometer, reduced to sea level. Both the actual barometer reading and the final corrected pressure value pertinent to sea level for this given time should be written out on an appropriate form used for recording Ship's Weather Observations. In addition, the time indication to which the pen is set at the instant of placing the new chart into operation must be correct on the basis of Greenwich Meridian.

6.10.2.2 Entries of Data on Marine Barograph Charts.—Before the new chart is placed on the cylinder the following data should be entered on the side of the chart:

(1) Name of ship; (2) Route terminal points (from -- and to --); (3) Date the chart was placed on cylinder; and (4) Time the chart was placed on cylinder (Greenwich Meridian).

Shortly after a chart is removed from the cylinder subsequent to obtainment of a barograph trace for some period, the following data should be entered on the side of the chart:

(1) Date the chart was removed; and (2) Time the chart was removed (Greenwich Meridian).

In addition, at the top of the chart the following items should be entered in the appropriate spaces immediately above the curved lines which represent the time 1200 Greenwich Meridian Time for each day of the barograph trace:

(1) Date; (2) Latitude; and (3) Longitude pertaining to the ship's position at 1200 GMT for each day of record.

All date and time data are to be on the basis of the Greenwich Meridian. Figure 6.10.1 illustrates the data entries on the marine barograph chart.

ANNEX TO CHAPTER 6

SPECIAL PROCEDURE FOR BAROMETER COMPARISONS

A–6.1 INTERNATIONAL COMPARISON OF BAROMETERS

The following is the text of Recommendation 15, relating to comparison of barometers for international use, as adopted by the Commission for Instruments and Methods of Observation of the World Meteorological Organization at meetings held at Toronto, Ontario, Canada, from August 10 to September 4, 1953, and approved by the Executive Committee of the World Meteorological Organization in its fourth session at Geneva, Switzerland, October 6 to 26, 1953.*

The COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATION,

NOTING the need for consistency in the standards of pressure-measuring instruments, with a view to obviating discontinuities in barometric data across international boundaries and over the reaches of the high seas;

CONSIDERING that such consistency may be best achieved by a programme of international barometer comparisons based on reference to standard barometers yielding a high order of absolute accuracy;

RECOMMENDS,

(1) That the procedure of international barometer comparisons described in the Annex should be put into effect as a recommended practice when first-order comparisons involving a relatively high degree of accuracy are desired;

(2) That the procedure of international barometer comparisons described in the following should be put into effect when second-order comparisons involving a more moderate degree of accuracy are desired, giving consideration, insofar as practicable, to the precautions outlined in the Annex;

(a) At least one portable pressure-measuring instrument of good quality should be carefully carried from one location to another, where respective standard barometers to be compared are installed;

(b) At the initial location two series of comparative readings, yielding differences, should be made between portable instrument and the standard; the first before departure, and the second after return of the portable apparatus;

(c) At the other location a single series of comparative readings, yielding another set of differences, should be made between the portable instrument and the standard;

(d) The average difference found for each of the two series referred to under (b) should be compared to determine whether any significant change has occurred in the calibration of the portable apparatus as a result of its transportation. If a significant change has occurred, the result of the experiment should be cancelled, as being unreliable;

(e) However, if no apparent significant change has occurred in the calibration of the portable apparatus, the mean of the two series of differences referred to under (b) and the mean of the single series referred to under (c) should be compared. This yields an indication of the probable disparity, if any, between the two standards;

(3) That the Secretary-General should prepare a list of instruments in categories "A" and "A_r" available for international comparison, and distribute it to the Members;

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* At the meeting of the Commission held in Paris in 1957, slight revisions in definitions of barometer categories were made, and these have been embodied in the text.

(4) That the results of international barometer comparisons should be communicated to the Secretary-General.

Annex

Recommended Practices Regarding First-Order International Comparison of Barometers

I. Nomenclature and symbols

“*A*”	denotes an absolute standard barometer capable of independent determination of pressure to an accuracy of at least ±0.05 millibars.
“A_r”	denotes a barometer of category “*A*” which has been selected by regional agreement as a reference standard for barometers of that region.
“*B*”	denotes a working standard barometer of a national Meteorological Service of a design suitable for routine pressure comparisons and with known errors which have been established by comparison with a regional standard.
“B_r”	denotes a barometer of category “*B*” in a region, which the national Meteorological Services of the Region agree to use as the reference standard barometer for the Region, in the event that a barometer of category “*A*” is unavailable in the Region,
“*C*”	denotes the fixed sub-standard barometer used for comparative purposes at field supervising stations of a national Meteorological Service,
“*M*”	denotes a portable microbarograph of good quality and accuracy,
“*N*”	denotes two or more portable precision aneroid barometers of excellent quality. (It is found desirable to have each aneroid barometer mounted in a box which may be sealed and pumped up to a fixed fiducial pressure that will be maintained until the box seal is broken. Shock mounting of the instrument would be desirable as a means of overcoming damage in transit).
“*P*”	denotes a travelling mercurial barometer of good quality and accuracy which may be carried by an observer from one country to another, or one continent to another, and still retain its calibration,
“*S*”	denotes a mercurial barometer located at an ordinary station.

II. General procedure recommended for comparison of barometers in different locations

(1) If barometer “1” is to be compared to barometer “2”, a qualified observer should carry instruments “*M*”, “*N*”, and “*P*” from barometer “1” to barometer “2”, and return to “1”, thus closing the circuit. This procedure is applicable between continents and countries, as well as within countries. Barometer “1” is usually at the central laboratory of a national standards organization or at the laboratory of a national Meteorological Service. Barometer “2” is at some other location. The carrying of “*M*” may be omitted if microbarographs of good quality are installed at the two locations, and are used in lieu of “*M*”.

(2) For standardization purposes instruments “*M*”, “*N*”, and “*P*” should be placed next to the barometer to be compared and all the instruments given equal exposure for at least 24 hours before official comparative readings are begun. An air current from an electric fan played on the instruments will aid in equalizing their temperature. The temperature of the room should be kept as uniform as practicable.

(3) Comparative readings should not be made if “*M*” shows the pressure to be fluctuating rapidly. Preference should be given to barometrically-quiet periods (i.e., pressure steady or changing slowly) for making the comparisons.

(4) Comparative readings should be made at uniform intervals of time not less than 15 minutes in duration.

(5) Experience indicates that at least five comparative readings are required for barometers at ordinary stations (category “*S*”). At least ten comparative barometer readings are required for barometers in categories “*A*”, “*B*”, “*C*”, for standardization purposes.

(6) If meteorological conditions permit, the comparative readings in the lat-

ter cases should be made at different pressures covering a range from low to high.

(7) Records should include the attached thermometer observations; the readings of instruments "*M*", "*N*", "*P*", and the barometers being compared; the wind speed, direction and gustiness; the corrections for gravity, temperature and instrumental error; the actual elevation above sea level of the zero point of the barometers; the latitude; the longitude; the name of place; and the date and time of observations.

(8) The readings of "*N*" should include the readings of the two or more precision aneroid barometers, corrected to a common basis if standardization against instruments of category "*A*" or "*B*" shows them to differ in calibration. The corrected readings of the aneroid barometers must be concordant; otherwise the comparisons will be regarded as invalid.

(9) In regard to the comparisons of instruments "*M*", "*N*" and "*P*" with barometer "1" referred to briefly in paragraph (1) above, barometer "1" should be at least the highest class of working standard available at the point of departure. For example, barometer "1" should preferably be of the quality "A_r", "*B*" or "B_r"; but generally not lower than "*C*" in the list of categories. Two comparisons of "*M*", "*N*" and "*P*" are necessary with barometer "1" namely (a) before "*M*", "*N*" and "*P*" are hand carried from the point of departure (origin) where barometer "1" is located, and (b) after "*M*", "*N*" and "*P*" have been returned to the point of origin following transit from barometer "1" to barometer "2" and return. The two comparisons ("before" and "after") shall be compared following (b). If agreement with respect to barometer "1" is within satisfactory tolerances for each one of the instruments involved ("*M*", "*N*", and "*P*"), it will be assumed that the comparisons "*M*", "*N*", and "*P*" with barometer "2" are within equal tolerances, provided there have been no mishaps in transit and that the comparative observations have been made with due precautions. However, if there is a significant disagreement or if it is known that a mishap has occurred which might have impaired the instruments or if the validity of the data is in question because of improper precautions, the comparisons should be treated as of dubious credibility and should possibly be rejected.

(10) If it is not practicable to employ a travelling mercurial barometer (class "*P*") in a stage of the programme, instruments of class "*M*" and "*N*" may be used together for the travelling instruments, but the results will be regarded as having less weight than if all three ("*M*", "*N*" and "*P*") had been employed. Then, an effort should be made to secure at least three *concordant* sets of comparisons between barometers "1" and "2" through the intermediary of "*M*" and "*N*", before firm conclusions are drawn in regard to the relationship between the readings of "1" and "2".

(11) So far as practicable, all discrepancies should finally be expressed with respect to the absolute standard readings of a single instrument of class "A_r". This will assure a common basis for all comparisons. In each case the report of comparisons should indicate the standard of reference.

Note: When a programme involving elimination of residual barometric errors is adopted there will exist a homogeneous system of barometric observational data conforming to a single absolute standard, which will permit eliminating errors that occur in horizontal pressure gradients from instrumental sources.

(12) Both before and after the mercury is cleaned or the location of a barometer changed at a laboratory or station, comparisons with other pressure-measuring instruments are necessary

to guard against overlooking development of a defect.

III. System of inter-regional comparisons

(1) Constituent services in each Region will designate a standard absolute barometer "*A*" to serve as "A_r" for the continent or Region. If an absolute standard barometer is not available in the Region, a barometer of category "*B*" will be designated jointly as the reference standard barometer for the Region, denoting the barometer so designated by the symbol "B_r".

(2) In the latter case, an observer carrying instruments of categories "*M*", "*N*", and "*P*" will travel from a central station equipped with a barometer of category "A_r" to a nearby region equipped at least with a barometer of category "*B*" (or "B_r") and make comparative readings with the aid of instruments "*M*", "*N*", and "*P*". Return to the point of origin to determine possible change of calibration of the portable barometers en route is necessary. For purposes of verification and intercomparison, it is sometimes desirable to repeat the process by comparisons involving an observer originating at some other region with a central station equipped as in the first case with a barometer of category "A_r".

(3) Copies of records obtained in the foregoing manner will be transmitted to each of the central stations equipped with barometers of category "A_r", and to the stations where the barometer "*B*" or "B_r" involved is located. Summaries of results of comparisons made in this fashion will be forwarded to all Meteorological Services in the Region where the "*B*" or "B_r" is located.

IV. System of international comparisons within a Region

(1) Each national Meteorological Service will compare its barometer of category "*B*" with a barometer of category "*A*" within the Region, if available, using the system outlined in Section III(2). Where possible, preference should be given to the barometer of category "A_r" for the Region as the standard reference instrument for the area.

(2) When a barometer of category "*A*" is not available in the Region, the recommendation of the second sentence in paragraph (1) Section III, should be followed. The barometers of category "*B*" of the respective Meteorological Services of the Region will be compared with the barometer of category "B_r" for the Region, accomplishing this, if necessary, in accord with paragraph (1), Section II.

(3) When a travelling observer carrying instruments of category "*M*", "*N*" and "*P*" is engaged in the execution of the programme outlined in the second sentence of paragraph (2) of this section, it is desirable that he make comparisons with barometers of categories "*B*" and "*C*" at locations on or near the route of his travel to and from the station where the instrument "B_r" for the Region is located.

(4) Copies of records and summaries of comparisons will be prepared and transmitted to the interested agencies in the manner outlined in paragraph (3), Section III.

V. Specifications regarding portable mercurial barometer "*P*"

The instrument considered best for barometers of category "*P*" is one so designed that the vacuum can be checked or that a good degree of vacuum can be established at the top of the tube with a vacuum pump. A check valve for sealing the tube is essential. Another desirable feature is a means of determining whether the quantity of mercury in the fixed cistern has remained constant since original filling.

Second preference for the type of instrument to be used as a travelling standard barometer is a well-built Fortin type with a tube bore of at least 9 mm., but preferably 12 mm.

The hypsometer may be considered as a portable, secondary standard pressure instrument after suitable tests have established its accuracy and precision to be within satisfactory tolerances.

The degree of accuracy as regards repeatability considered necessary for a travelling standard is about 0.1 mb. "*P*" barometers should be calibrated over a wide range of pressure and temperature, covering all possible values that may be encountered.

CHAPTER 7. REDUCTION OF PRESSURE TO SEA LEVEL, AND OTHER LEVELS

7.0 GENERAL INFORMATION ON THE HYPSOMETRIC EQUATION AND ITS TERMS, AS APPLIED TO REDUCTION OF PRESSURE

7.0.0 Introduction

This chapter describes how factors and tables may be prepared to permit reduction of pressure to sea level, and other levels. In order to provide a basis for an understanding of the subject, some pertinent definitions and discussion are presented in secs. 7.0.1 to 7.0.5.4.

Instructions regarding the preparation of factors and tables for reduction of pressure to sea level are given in the following sections:

Sec. 7.1 for station elevations below about 50 feet (depending on temperature range);
Sec. 7.2 for station elevations above about 50 feet.

Instructions given in sec. 7.3 deal with reduction of pressure either downward or upward in general. This information is useful for the calculation of data required in making comparisons of barometers relating to different elevations. The same techniques may be employed for the computation of variable removal corrections by a method alternative to and more accurate than that described in Chapter 4.

7.0.1 Temperature Scale

Procedures for reduction of pressure are conventionally based upon the use of the so-called "*hypsometric equation*" which is given below in sec. 7.0.2. This involves the assumption of an air column in which the reduction of pressure is supposed to be made. Inasmuch as the properties in this assumed air column will govern the reduction, the concepts and terms relating to this column should be understood. The most important variable property of the air column is the so-called "mean virtual temperature" (T_{mv}) which depends on the concept of "virtual temperature" (T_v), as explained a little later (see secs. 7.0.3 and 7.0.4). When used in the hypsometric equation, the mean virtual temperature (T_{mv}) is expressed in *degrees Rankine* (°R.), where this term denotes *absolute temperature in terms of units which have the size of Fahrenheit degrees.* Since the Celsius (Centigrade) degree (°C.) is 1.8 times the size of the Fahrenheit degree (°F.), the following relationships hold in regard to absolute temperature (T) on the two scales (U.S., 1948):

T, degrees Kelvin (°K.) = (273.16° + t°C.),
T, degrees Rankine (°R.) = (459.688° + t° F.),
where t = temperature, in °C. or °F., as indicated.

When expressing absolute temperatures for quantities such as T_v and T_{mv}, we will make exclusive use in this Manual of the scale in degrees Rankine (°R.) indicated by the last equation given above.

These scales were generally in effect in the United States prior to 1948. However, the Tenth General Conference on Weights and Measures which met in Paris in October 1954 agreed upon a different system based effectively on the following conventions: the value of the absolute temperature of the triple point of water is assigned as 273.16° Kelvin on the thermodynamic temperature scale, with the proviso that the ice point is defined as a temperature 0.0100 degree (Kelvin) lower than the triple point. According to these conventions, the relationships in agreement with the *thermodynamic temperature scale* of 1954 are:

T, degrees Kelvin (°K.) = (273.15° + t° C.)
T, degrees Rankine (°R.) = (459.67° + t° F.)

The reader will note that the change in conventions of the scales scarcely affects computations involving temperatures rounded to the nearest 0.1° F.

For further information the reader may consult the following references:

(a) H. F. Stimson, "The International Temperature Scale of 1948," Journal of Research of the National Bureau of Standards, vol. *42*, pp. 209–217 (1949).

(b) H. F. Stimson, "Heat Units and Temperature Scales for Calorimetry," Amer. Jour. of Physics, vol. *23*, pp. 614–622 (1955).

7.0.2 Hypsometric Equation

Consider a vertical air column, in which the effects of accelerated motion of the air and wind are negligible or absent. These limitations assume a hydrostatic condition, entailing a balance between the weight of each layer of the air column and the pressure difference between the lower and upper level surfaces confining the layer. We may think of the air column as having a base and a top. These represent two different levels.

For the present we need not restrict the level at which the base of the air column occurs. However, we shall limit our attention to air whose apparent molecular weight and composition when dry are the normal ones found at sea level (see Smithsonian Meteorological Tables, Sixth Revised Edition, 1951; pages 289 and 389; see also Appendix 8.0.1, sec. 2.1). This stipulation effectively signifies that we shall deal only with air columns, the tops of which are in a region of atmosphere below 90,000 gpm (see sec. 7.3.0).

Let

P_o = pressure at base of air column; hence when the base of the air column lies at sea level, P_o denotes the pressure reduced to sea level, or the sea-level pressure.

P = pressure at top of air column; hence when the base of the air column lies at sea level, P denotes the station pressure, or the pressure at the upper level of a column extending down to sea level.

H_{pg} = vertical extent (depth) of the air column, in geopotential meters; hence when the base of the air column lies at sea level, H_{pg} denotes the geopotential of the station to which the pressure refers. Thus, in every case involving the hypsometric equation, we may write in general, H_{pg} = (geopotential of the top of the air column *minus* geopotential of the base of the air column) in gpm.

T_{mv} = mean virtual temperature of the air column, in degrees Rankine (°R.).

K = hypsometric constant. Under the assumption that the apparent molecular weight of the dry air is normal as found at sea level, and that we use the temperature scales in effect in the United States prior to 1948 K = 0.0266895°R./gpm (see sec. 7.0.1).

$\frac{P_o}{P} = r = 10^{(KH_{pg}/T_{mv})}$, a dimensionless ratio.

Table 7.5 gives values of the ratio r as a function of H_{pg} and T_{mv}. The hypsometric equation is written as:

$$P_o = P \cdot 10^{(KH_{pg}/T_{mv})} = P \cdot r \qquad (1)$$

In terms of logarithms to the base 10, this may also be expressed

$$\log_{10} P_o = \log_{10} P + (KH_{pg}/T_{mv}) \qquad (2)$$

By means of the hypsometric equation, we are enabled to calculate the pressure reduced to sea level (P_o) depending upon two variables, P and T_{mv}; the quantity H_{pg} being a constant for a fixed station (see Chapter 1). Equations (1) and (2) are demonstrated in Appendix 7.1.

7.0.3 Virtual Temperature

The concept of "*virtual temperature*" is useful for taking account of the effect of water vapor upon the density of moist air. In this we leave out of consideration the effect of any suspended or falling particles, whether they consist of water, ice, salt, dust, mineral, or other constituents.

Consider a sample of moist air containing a definite ratio, w, of mass of water vapor (m_v) to mass of dry air (m_a) with which it is associated, so $w = m_v/m_a$, and the total mass of moist air is $m = (m_v + m_a)$. Suppose that when the moist air is at pressure

P and temperature T, its aqueous vapor pressure is e and its volume is V. Then, its density is m/V.

The "virtual temperature," T_v, of the sample of moist air is the temperature which dry air must have in order that it possess the same density as the given sample of moist air, when both moist air and dry air are maintained at the identical pressure P.

Fig. 7.0.0 illustrates the concept of virtual temperature, and the formula for it is:

$$T_v = \frac{T}{(1 - 0.378e/P)} = T\,\frac{(1 + w/0.62197)}{(1 + w)} \qquad (3)$$

Further details are given in Appendix 7.1.

For practical purposes we may consider that e, the aqueous vapor pressure of the sample of moist air, is given by the saturation vapor pressure over water corresponding to a temperature equal to the dew-point temperature of the sample (see Table 95, "Saturation Vapor Pressure Over Water," in Smithsonian Meteorological Tables, Sixth Revised Edition, 1951; see also Table 7.6.1, herein).

7.0.4 Mean Virtual Temperature of the Air Column (T_{mv})

Fig. 7.0.1 illustrates by way of contrast or comparison an actual air column in the free atmosphere and a "fictitious air column" within a plateau. The reduction of pressure to sea level from a station on land is performed on the basis of the "fictitious air column," which is assumed to extend downward to sea level from the station elevation.

Since this fictitious air column lies entirely under ground beneath the station but

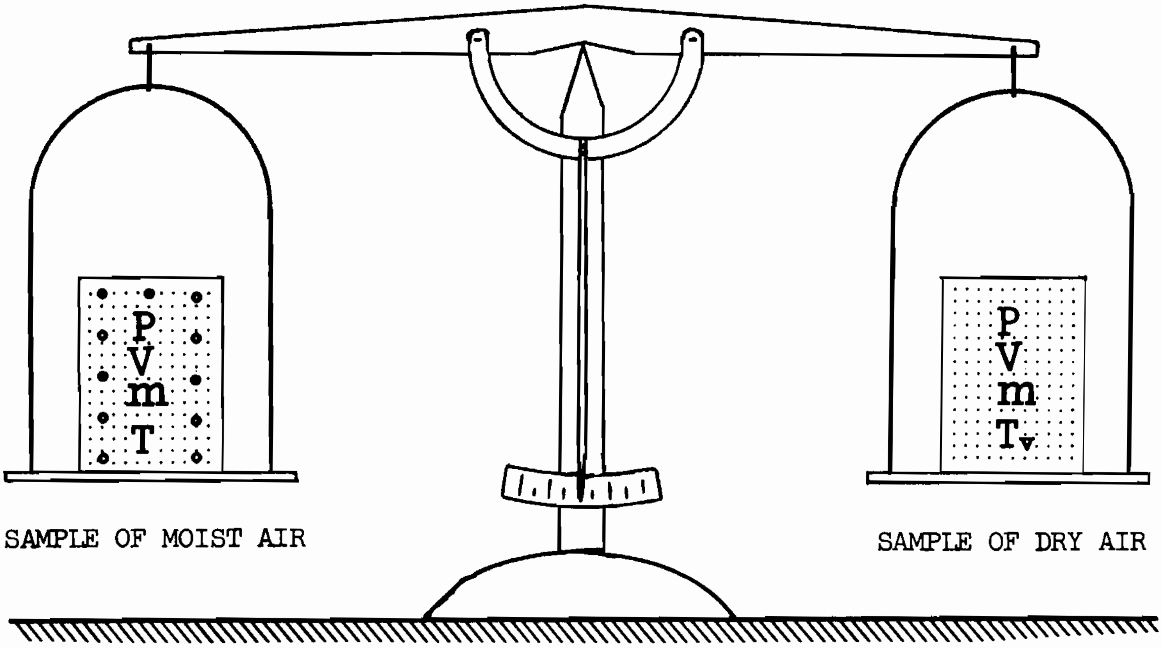

FIGURE 7.0.0. Illustration of virtual temperature of moist air.

(a) *Definition:* Virtual temperature (T_v) of a sample of moist air is the temperature at which dry air has a density equal to that of the sample of moist air whose given temperature is T when both are at the same pressure.

(b) *Condition to satisfy definition:* Balance of like boxes of equal weight and volume with air having such temperatures that the boxes contain equal masses of moist air and dry air when at the same pressure.

(c) *Symbols:* Pressure $= P$, same in both samples
Volume $= V$, same in both samples
Mass of gas $= m$, same in both samples
Moist-air temperature $= T$
Dry-air temperature $= T_v$
Density of gas $= (m/V)$, same in both samples

(d) *Note:* The value of T_v always exceeds T since the ratio of density of water vapor to that of dry air is 0.62197 when the gases are under equal pressure and temperature.

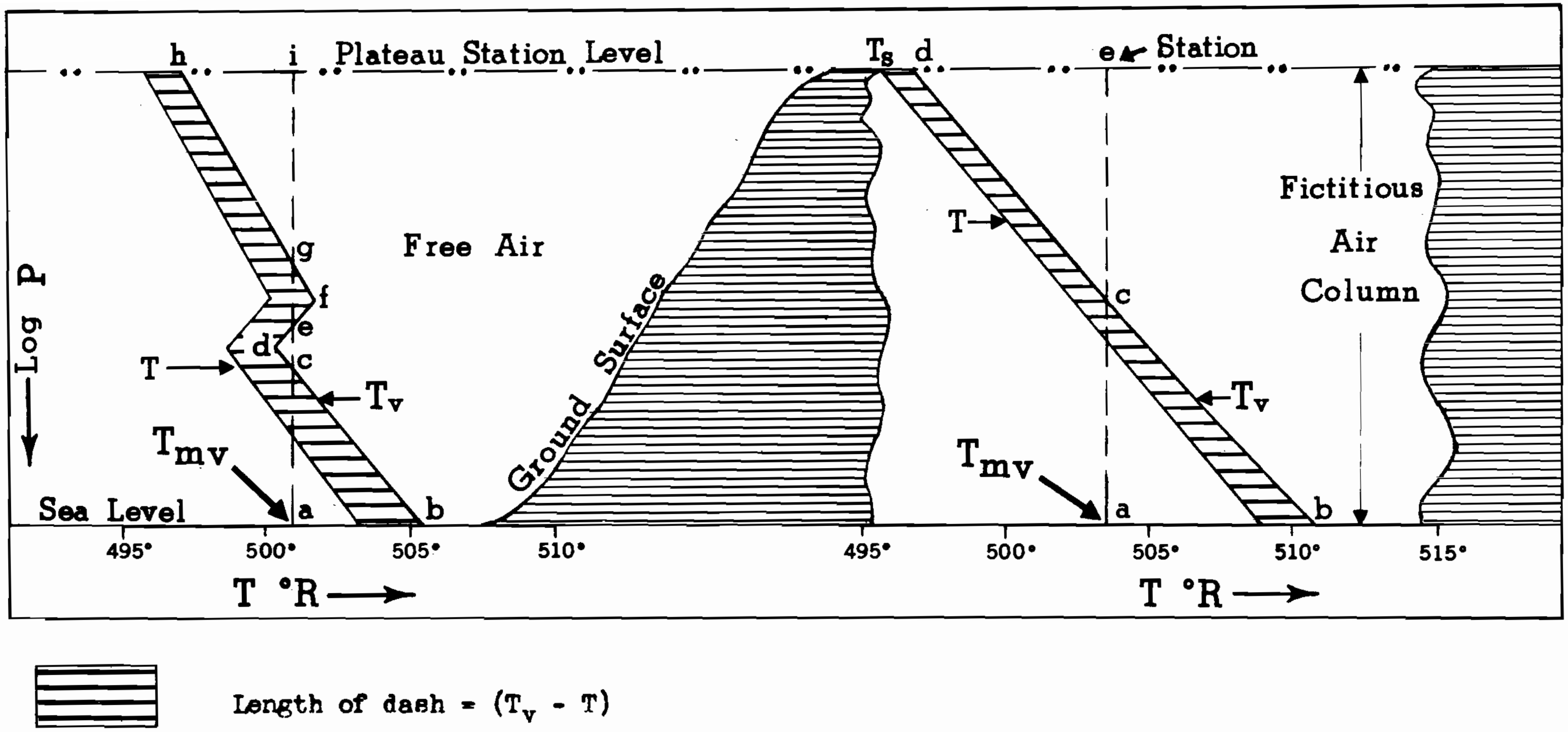

FIGURE 7.0.1. Illustration of the basic problem involved in reduction of pressure: namely, determination of the mean virtual temperature of the air column (T_{mv}).

Notes: (1) For purposes of contrast, an example of an actual free air column is shown to the left, while to the right there is presented a fictitious air column for which conditions must be assumed.

(2) Temperature and virtual temperature are plotted against logarithm of pressure.

(3) The vertical dashed lines (*ai* on left and *ae* on right) represent straight edges. When determining T_{mv} in any case, the vertical dashed line must be so placed with respect to the T_v curve that the areas confined between that curve and the dashed line within the layer shown must be distributed equally on either side of the dashed line; for example, on the left side area abc + area efg = area cde + area ghi, and on the right side area abc = area cde.

(4) Symbols: P = Pressure; T = Temperature in degrees Rankine (°R.); T_v = Virtual temperature (°R.); T_s = Station temperature argument for plateau station (°R.); T_{mv} = Mean virtual temperature of air column (°R.).

is supposed to be more or less similar to the actual air column in the free atmosphere over nearby regions of lower elevation, some of the properties of the fictitious air column must be related to observed conditions while other properties must be assumed.

The "mean virtual temperature of the fictitious air column," always denoted by the symbol T_{mv}, is called for short "mean virtual temperature" or "mean virtual temperature of the air column." When reduction of pressure to sea level is involved, it will be understood that the air column is fictitious.

Procedures adopted in this Manual of Barometry for the evaluation of T_{mv} are based on the idea that this quantity consists of various terms, some observed, some assumed, and some based on climatological data. In order to facilitate the evaluation of T_{mv}, the assumed data and many of the required climatological data are presented in various tables contained within this Manual. An effort is made to simplify the calculation of T_{mv} as much as possible by convenient arrangement of data on computation sheets (see Form WBAN 54–7.1).

Study of Fig. 7.0.1 in conjunction with the theory presented in Appendix 7.1 will reveal how the mean virtual temperature is related to virtual temperature (T_v). The quantity T_{mv} is intended to be a mean value of the virtual temperature of the air column. Thus, on the right side of fig. 7.0.1 T_{mv} corresponds to a vertical line on the temperature scale which cuts the virtual temperature curve (T_v) at a point (c) such that half of the area between the T_v curve and the vertical line lies to the left of the line and half to the right. According to the theory explained in Appendix 7.1, the vertical scale should be log P.

The terms which compose T_{mv} as computed on Form WBAN 54–7.1 are briefly explained in the next section.

7.0.5 Terms Included in T_{mv} (°R)

7.0.5.0 List of Terms Involved in T_{mv}.—The quantity T_{mv} involves the following terms as described below, all of which should be understood to be expressed in units of Fahrenheit degrees:

(1) "station temperature argument" (t_s);

(2) "standard lapse rate correction," ($aH_{pg}/2$);

(3) "humidity correction" (e_sC_h);

(4) "correction for plateau effect and local lapse rate anomaly" (F).

Form WBAN 54–7.1, Part (C), shows how the terms are combined, in accordance with the equation:

$$T_{mv} = (459.7° + t_s + aH_{pg}/2 + e_sC_h + F),$$
in degrees Rankine.

7.0.5.1 "Station Temperature Argument," t_s.—This is based on observed data.

Let

t_o = air temperature (in °F.) observed at the station at the time of the station pressure observation;

t_{-12} = air temperature (in °F.) observed at the station 12 hours previous to the time at which t_o was determined;

and

t_s = station temperature argument (in °F.).

By definition, t_s will be understood to be the average of t_o and t_{-12}, hence

$$t_s = (t_o + t_{-12})/2, \text{ in °F.}$$

For convenience in making the calculations of T_{mv} on Form WBAN 54–7.1, data are computed for values of t_s expressed as multiples of 10° F. over a suitable range. The range which must be covered depends upon the absolute minimum and maximum of temperature (extremes) determined from climatological statistics for the region in which the station is located (see Tables 7.1.2 and 7.1.3).

7.0.5.2 "Standard Lapse-Rate Correction," $aH_{pg}/2$.—Let

a = standard lapse rate, given as 0.0117° F. per gpm (which is equivalent to 0.65° C. per 100 meters assumed as the lapse rate in the troposphere region of the Standard Atmosphere; see Chapter 8),

and

H_{pg} = geopotential of the station, in geopotential meters (gpm).

The "standard lapse-rate correction" is the value of the additive quantity $aH_{pg}/2$. Use of this in computing T_{mv} amounts to saying that the mean temperature of the air column is greater than the temperature argument at the station (t_s) by the amount $aH_{pg}/2$. This is equivalent to the idea that the mean temperature is the average of t_s and the temperature at sea level, based on the assumption that the lapse rate in the fictitious air column has the standard value $a = 0.0117°$ F. per gpm.

The "standard lapse-rate correction" ($aH_{pg}/2$) is given in combination with the "humidity correction" (e_sC_h) in Table 7.3 as a function of station elevation, H_{pg} (gpm), and vapor pressure, e_s (mb.).

7.0.5.3 "Humidity Correction," e_sC_h.—Let

e_s = aqueous vapor pressure (in mb.) existing at the station at the time of the observation of station pressure;

and

C_h = known function of station elevation (in °F./mb.).

The humidity correction is the product of these two quantities, resulting in a value expressed in °F. For any station of fixed elevation, the factor C_h is a constant, which depends upon the value of H_{pg}. The relationship between H_{pg} and C_h is shown by the following table:

Station elevation H_{pg} (gpm)	Humidity correction factor C_h °F./mb.	Station elevation H_{pg} (gpm)	Humidity correction factor C_h °F./mb.
0	0.1935	1,500	0.2657
100	.1975	1,600	.2715
200	.2017	1,700	.2775
300	.2060	1,800	.2836
400	.2103	1,900	.2898
500	.2148	2,000	.2962
600	.2193	2,100	.3028
700	.2240	2,200	.3095
800	.2288	2,300	.3164
900	.2337	2,400	.3235
1,000	.2387	2,500	.3308
1,100	.2439	2,600	.3382
1,200	.2491	2,700	.3458
1,300	.2545	2,800	.3536
1,400	.2601	2,900	.3616
		3,000	.3698

The theory underlying the humidity correction is presented in Appendix 7.1. For purposes of brief explanation, it may be pointed out that the humidity correction is necessary because the density of moist air is less than the density of dry air provided the pressure and temperature, respectively, are the same in moist and dry air. This is consistent with the facts that the virtual temperature (T_v) is greater than the dry-bulb temperature (T), and that an increase of temperature acts to decrease the density of dry air maintained at constant pressure. That is, the effect of moisture in vapor form is to reduce by some amount the weight of a column of air as compared with a column of dry air of like pressure and temperature. In particular, the moisture reduces the density (or weight) of the column of moist air as compared with dry air to the same degree as would occur if the average temperature of dry air were increased by the amount e_sC_h, other conditions remaining the same. The effect of the moisture is therefore a diminution of the weight of the air column, hence of the pressure reduced to sea level.

It is intended that the quantity e_sC_h represent a correction which may be considered as the difference between the "mean virtual temperature of the fictitious air column" and the "mean (dry-bulb) temperature of the fictitious air column." Even though the quantity e_s refers to the surface, the humidity correction (e_sC_h) refers to the entire air column. This results from a property of the factor C_h as explained in Appendix 7.1.

Under the plan adopted for this Manual, the quantity e_s is treated as though it were a function of t_s, based on climatological statistics. Data giving e_s as a function of t_s for stations in various regions are presented in Tables 7.2.1, 7.2.2, 7.2.3, 7.2.4, and 7.2.5. Use is made of these data in connection with Form WBAN 54–7.1, for the purpose of calculating T_{mv} as a function of t_s.

Values of the "humidity correction" (e_sC_h) in combination with the "standard lapse-rate correction" ($aH_{pg}/2$) are given in Table 7.3 as a function of e_s and H_{pg}. Form WBAN 54–7.1 illustrates how these values are used.

7.0.5.4 "Correction for Plateau Effect and Local Lapse Rate Anomaly," *F*.—A part of the "correction for plateau effect and local lapse rate anomaly" is employed to take account of any deviation of the assumed local lapse rate from the standard lapse rate (a). Such deviation is considered to occur only at stations in North America having station elevations in excess of 305 gpm (about 1000 feet). Otherwise (i.e., at lower elevations or outside of North America), at least for this edition of the Manual, no deviation is considered to occur.

The so-called "plateau effect" is included in F to exercise a certain control upon the annual variation of pressure reduced to sea level. The correction for the "plateau effect" in a slightly different form was introduced for practical purposes by Bigelow.[1]

Appendix 7.2 presents the theory underlying the "correction for plateau effect and local lapse rate anomaly." In brief, the correction for the so-called "plateau effect" is employed so that the amplitude of the annual variation of pressure reduced to sea level shall be approximately the same at all stations in North America, regardless of elevation. If this correction were omitted, elevated plateau stations (say at 7000 feet on the western plateau region) would report mean monthly reduced pressures which were about *15 mb.* higher in January than in July. However, sea-level stations in the same latitude yield a typical difference of about *5 mb.* between these months. Use of the correction for the "plateau effect" assures that the reported differences are maintained at about the latter value in all cases.

The quantity F is given in tabular form (see Tables 7.4.1 to 7.4.8). In brief, the principles governing the determination of F *as a function of* t_s, $F(t_s)$, for stations in North America are as follows:

(1) For stations having elevations of 305 gpm or lower, the function is determined on the basis of the "annual normal" or "annual mean" station temperature (t_{sn}, in °F.). See Tables 7.4.1 and 7.4.2 giving $F(t_s)$ data for these cases. The value of t_{sn} may be obtained or estimated from Table 7.1.2 and fig. 7.2.0, or Table 7.1.3.

(2) For stations having elevations in excess of 305 gpm (about 1000 feet), the function is determined according to geographic location, elevation, and climatological conditions. See lists of stations and their coordinates in Tables 7.4.3 to 7.4.5. Values of F as functions of t_s are already tabulated for a wide selection of stations, arranged principally according to states. The actual data are presented in Tables 7.4.6 to 7.4.8 for the stations listed in Tables 7.4.3 to 7.4.5. In the case of stations not contained in the lists, it is necessary to find F by averaging data listed in regard to surrounding stations which are selected because they have more or less similar elevations and climatological regimes. Surrounding stations thus selected are termed "point-of-departure stations" for $F(t_s)$. See Form WBAN 54–7.1, Part (B), in regard to method of averaging. The mathematical symbol $F(t_s)$ is intended to denote that F is a function of t_s at any station in North America. To facilitate computations the F data are always given for values of t_s which are multiples of 10°.

Detailed instructions in regard to the preparation of data and tables to permit reduction of pressure to sea level are given in the remainder of this chapter.

7.1 INSTRUCTIONS FOR REDUCTION AT LOW STATIONS

7.1.0 General Information

When the station elevation is very low (say 50 feet or less) and the range of annual temperature variation is not extreme, it is satisfactory in most cases to calculate an additive reduction constant (see Table 7.1). This constant has the property that when added to the station pressure in the same units, it yields the pressure reduced to sea level. (See Table 7.1.4.)

Since variations of station temperature and moisture (e_s) have an effect on reduction, the constant is subject to errors (deviations) when large variations in those elements occur. It is considered permissible to allow not more than 0.005 in. Hg (nearly 0.2 mb.) deviation from the computed value of the reduction constant based on the annual normal value of t_v, where variations occur.

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[1] F. H. Bigelow, "Report on the Barometry of the United States, Canada, and the West Indies," Report of the Chief of the Weather Bureau, 1900–1901, vol. II, Washington, D.C.

The instructions describe how the computer may test whether the use of an additive reduction constant is permissible under the given conditions of temperature variation at the station. It is also possible to perform a rough test for similar purposes by means of Table 7.1.1, depending upon the difference of absolute minimum and maximum virtual temperature from the annual normal value. Should the range of these elements be very large (see Tables 7.1.2 and 7.1.3) and the test show that the use of the constant is not permissible, it will be necessary to employ the method of reduction described in sec. 7.2.

7.1.1 Determination of C_h, Humidity Correction Factor

After the geopotential of the station, H_{pg}, is known, refer to the table of "humidity correction factor," C_h, given in sec. 7.0.5.3 and determine the value of C_h corresponding to H_{pg}. This is accomplished by interpolation. Hypothetical examples given below illustrate the results.

Example I

Daytona Beach, Florida
Station elevation, $H_p = 35.1$ feet
Latitude = 29°11′ N.
Longitude = 81°03′ W.
Geopotential of station, $H_{pg} = 10.7$ gpm
According to the table in sec. 7.0.5.3, we have:

H_{pg}	C_h
gpm	°F./mb.
0	0.1935
100	0.1975

By interpolation, we find when $H_{pg} = 10.7$ gpm, $C_h = 0.1939$ °F./mb.

Example II

Old Orchard, Maine
Station elevation, $H_p = 42.9$ feet
Latitude = 43°31′ N.
Longitude = 70°22′ W.
Geopotential of station, $H_{pg} = 13.1$ gpm
By interpolation, as in Example I, we find that when $H_{pg} = 13.1$ gpm, $C_h = 0.1940$ °F./mb.

7.1.2 Determination of Absolute Extremes and Annual Normal of Temperature for the Station[2]

Refer to Table 7.1.2 or Table 7.1.3, whichever is appropriate, and locate one or more places at or near the station, for which the required temperature data are tabulated. Extract the following data for the station, interpolating if necessary on the basis of information given for nearby surrounding places, giving preference to places of nearly the same elevation:

t_{min} = absolute minimum temperature,
t_n = annual normal temperature,
t_{max} = absolute maximum temperature.

Example I

Daytona Beach, Florida
From Table 7.1.2, we find:
$t_{min} = 18°$ F.
$t_n = 70.5°$ F.
$t_{max} = 102°$ F.

Example II

Old Orchard, Maine
The place nearest to Old Orchard, Maine, for which the data are given in Table 7.1.2 is Portland, Maine. In view of the nearness, these data may be accepted. Thus, we find:
$t_{min} = -39°$ F.
$t_n = 44.5°$ F.
$t_{max} = 103°$ F.

7.1.3 Determination of Vapor Pressures (e_s) Corresponding to the Temperatures

Refer to Table 7.2.1, and by interpolation find the values of e_s for the given station, corresponding to the three temperatures specified in sec. 7.1.2. If the given station is not one of the places listed in Table 7.2.1, find one or more places in the list which are nearest to the given station, or have most nearly a similar climatological regime as regards temperature and moisture. To this end, geographical and topographic factors should be taken into account, if possible. In referring to the list, discretion and good judgment will be necessary in making the best selection of points whose data may be considered most nearly representative of those pertinent to the given station. In the case of naval or merchant marine vessels, the selection may be based upon conditions

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[2] Annual normal temperatures based on the period 1921–1950, and absolute extreme temperatures for the period of record, for stations in the United States, its possessions and trust territories, are presented in Table 7.1.2. These data were obtained from Table 10a of the 1954 Annual issue of "Climatological Data—National Summary," vol 5, No. 13, published by the U.S. Weather Bureau.

Annual mean and absolute extreme temperatures for available periods of record for stations outside the United States and its possessions are given in Table 7.1.3. Annual mean temperatures may be substituted for annual normals for locations not having 30-year normal temperatures in Table 7.1.2. The data presented in Table 7.1.3 were obtained from the sources shown at the end of that table.

existing at terminal points of their customary routes or bases of operation.

Example I

Daytona Beach, Florida
In this case the humidity data for Jacksonville, Florida, are considered most nearly representative of those for the station at Daytona Beach.

Table 7.2.1 yields the following values for Jacksonville:

t_s (°F.)	10°	20°	70°	80°	90°	100°	110°
e_s (mb.)	1.7	2.8	18.5	26.8	28.4	21.6	......

On this basis, by interpolation and extrapolation, corresponding to the temperatures specified in sec. 7.1.2, we find the following results shown in columns (1) and (2):

Col. (1)	Col. (2)	Col. (3)	Col. (4)
Vapor pressure (e_s)	Temperature	e_sC_h	Sum [col. (2)+col. (3)] virtual temperature (t_v)
mb.	°F.	°F.	°F.
2.6	$t_{min}=18°$	0.5°	19°
18.9	$t_n=70.5°$	3.7°	74.2°
20.2	$t_{max}=102°$	3.9°	106°

Example II

Old Orchard, Maine
In this case the humidity data for Portland, Maine, are considered most nearly representative of those for the station at Old Orchard, Maine.

Table 7.2.1 yields the following values for Portland:

t_s (°F.)	−40°	−30°	40°	50°	90°	100°	110°
e_s (mb.)	0.10	0.19	6.3	9.3	18.6	15.3	......

On this basis, by interpolation and extrapolation, corresponding to the temperature specified in sec. 7.1.2, we find the following results shown in columns (1) and (2):

Col. (1)	Col. (2)	Col. (3)	Col. (4)
Vapor pressure (e_s)	Temperature	e_sC_h	Sum [col. (2)+col. (3)] virtual temperature (t_v)
mb.	°F.	°F.	°F
0.11	$t_{min}=-39°$	0.0°	−39°
7.7	$t_n=44.5°$	1.5°	46.0°
14.3	$t_{max}=103°$	2.8°	106°

7.1.4 Determination of Humidity Correction (e_sC_h) and Virtual Temperature (t_v)

Multiply the value of C_h as found under sec. 7.1.1 by the vapor pressures (e_s) as found under sec. 7.1.3, thus obtaining the "humidity corrections" (e_sC_h) corresponding to the temperatures as found under sec. 7.1.2. Then, in each case add the temperature to its corresponding humidity correction, thus obtaining the virtual temperature (t_v). Examples of these steps are shown in columns (3) and (4) of the sample computation tables presented in sec. 7.1.3.

7.1.5 Determination of Additive Reduction Constant

Refer to Table 7.1, and by interpolation determine the Reduction Constants corresponding to the three values of virtual temperature defined below and specified under sec. 7.1.4, where geopotential of the station (H_{pg}) serves as one of the arguments.

We use the following notation:

$t_{v,min}$ = virtual temperature corresponding to the absolute minimum of temperature at the station;

$t_{v,n}$ = virtual temperature corresponding to the annual normal temperature at the station;

$t_{v,max}$ = virtual temperature corresponding to the absolute maximum of temperature at the station.

Example I

Daytona Beach, Florida, H_{pg} = 10.7 gpm

Virtual temperature	Reduction constant
$t_{v,min}=19°$ F.	0.041 in. Hg
$t_{v,n}=74.2°$ F.	0.037 in. Hg
$t_{v,max}=106°$ F.	0.035 in. Hg

Example II

Old Orchard, Maine, H_{pg} = 13.1 gpm

Virtual temperature	Reduction constant
$t_{v,min}=-39°$ F.	0.057 in. Hg
$t_{v,n}=46.0°$ F.	0.048 in. Hg
$t_{v,max}=106°$ F.	0.043 in. Hg

7.1.6 Criterion in Regard to Permissibility of Using Fixed Reduction Constant

When the "Reduction Constants" corresponding to $t_{v,min}$ and $t_{v,max}$ both differ by less than 0.006 inch of mercury from the

"Reduction Constant" corresponding to $t_{v,n}$, the latter may be used at the station for routine reductions of pressure to sea level. However, when the difference in either case is 0.006 inch of mercury or more, the procedure described in sec. 7.2 should be used for reduction of pressure to sea level, since in this event the use of the single "Reduction Constant" based on $t_{v,n}$ is *not* permissible.

Example I

Daytona Beach, Florida

Referring to the data tabulated under sec 7.1.5, it will be seen that the "Reduction Constant" corresponding to $t_{v,min}$ deviates from that corresponding to $t_{v,n}$ by 0.004 in. Hg, while the "Reduction Constant" corresponding to $t_{v,max}$ deviates 0.002 in. Hg. Both of these differences are less than 0.006 in. Hg. Therefore, the use of the "Reduction Constant" corresponding to $t_{v,n}$ (namely, 0.037 in. Hg for this example) will be permissible for routine reductions of pressure to sea level.

Example II

Old Orchard, Maine

A comparison is made as in the case of Example I. We find that the "Reduction Constant" corresponding to $t_{v,min}$ is 0.057 in. Hg whereas that corresponding to $t_{v,n}$ is 0.048 in. Hg, yielding an extreme difference of 0.009 in. Hg. This is greater than the tolerance of 0.005 in. Hg; hence, the use of 0.048 in. Hg is *not* permissible as the routine "Reduction Constant" in this case. Therefore, the computer should turn to sec. 7.2 for further instructions.

7.1.7 Use of Reduction Constant When Permissible

Units of station pressure and of the "Reduction Constant" must be the same. When the "Reduction Constant" is added to station pressure, it yields pressure reduced to sea level.

Example

Station: Daytona Beach, Florida
Given: Station Pressure = 29.526 in. Hg
"Reduction Constant" = +0.037 in. Hg

Pressure Reduced to Sea Level = 29.563 in. Hg

This procedure is only allowed in cases where the criterion cited in the first sentence of sec. 7.1.6 is satisfied.

Officials at low-level stations should consult Table 7.1.4. That table presents a list of certain types of low-level stations as of July 1, 1962, together with the additive reduction constants which should be employed at those points. The pertinent constant for any particular station is to remain in effect until the official in charge is directed otherwise. Since the correction in each case depends upon the pertinent value of the station elevation. H_p, the official in charge should verify that the proper value of H_p for his station is given in the table. If a different value of H_p than that listed in the table is adopted for any station after July 1, 1962, the corrections indicated in the table for the station under consideration are invalid; and under such circumstances new corrections which are appropriate for the current value of H_p should be obtained and applied.

7.2 INSTRUCTIONS REGARDING PREPARATION OF FACTORS AND TABLES FOR REDUCTION OF PRESSURE TO SEA LEVEL

7.2.0 Introduction

7.2.0.1 Forms Required.—There follows a list of the forms required in connection with the preparation of factors and tables used for reduction of pressure to sea level:

(1) Form WBAN 54–7.1 (2 pages)
(2) Form WBAN 54–7.2 (3 pages)
(3) Form WBAN 54–7.3 (1 page)
(4) Form WBAN 54–7.4. (This form is needed only if a table for reduction of pressure to sea level, in extenso, is to be prepared (see figs. 7.2.6(a) & (b) and 7.2.11(a) to (d)). When an expanded circular slide rule is available for reduction of pressure to sea level (see fig. 7.2.4), Form WBAN 54–7.4 need *not* be prepared. However, when the table in extenso is to be prepared, the computer will need to complete as many pages of Form WBAN 54–7.4 as there are lines of different station temperature argument (t_s) presented in the table.)

7.2.0.2 Significant Figures.—The numbers of significant figures to be retained in the calculations are indicated by the examples which accompany the instructions (see figs. 7.2.1(a), (b); 7.2.2(a), (b), (c); 7.2.3; 7.2.5(a), (b); 7.2.7(a), (b); 7.2.8(a), (b), (c); 7.2.9; and 7.2.10(a), (b)).

7.2.1 Preparation of Form WBAN 54–7.1

7.2.1.0 General Information and Temperature Range

7.2.1.0.0 *Purpose of Form.*—Form WBAN 54–7.1 is the form on which computations are made to determine the "mean virtual temperature" (T_{mv}, in °Rankine) as a function of "station temperature argument" (t_s).

In these instructions we shall often have occasion to use the term *"given station."* This term is used to refer to the station named at the head of the form for which the pressure is to be reduced to sea level.

7.2.1.0.1 *Parts of Form.*—Form WBAN 54–7.1 (pages 1 and 2) is composed of three parts, labeled (A), (B), and (C), as follows:

(A) Tabular values represent vapor pressure, e_s (in mb.) as a function of t_s.

(B) Tabular values represent $F(t_s)$, the correction for plateau effect and local lapse rate anomaly, as a function of t_s.

(C) Computation of T_{mv} = mean virtual temperature (°Rankine).

7.2.1.0.2 *Instructions Depending on Value of H_{pg} and Location.*—The instructions regarding the preparation of Parts (A) and (C) of Form WBAN 54–7.1 are the same for every given station, regardless of elevation and location. However, the instructions regarding the preparation of Part (B) of Form WBAN 54–7.1 are different if H_{pg} is above 305 gpm than if lower than the amount just specified, *when the given station is in North America.* On the other hand, when the given station lies outside of North America, line (f) of Part (B) is entered with the value zero (0) all the way across the form, regardless of elevation. The instructions regarding the preparation of the three parts of Form WBAN 54–7.1 are given in the text as follows: Part (A), sec. 7.2.1.2; Part (B), sec. 7.2.1.3; and Part (C), sec. 7.2.1.4.

7.2.1.0.3 *Intervals and Range of t_s.*—Data on Form WBAN 54–7.1 (pages 1 and 2) are evaluated for 10° F. multiples in regard to t_s. The appropriate range of t_s to be covered should be determined from the data on absolute extremes of temperature ("Record Lowest" and "Record Highest") presented in Tables 7.1.2 and 7.1.3. Table 7.1.2 pertains to temperature data for the United States and its possessions, while Table 7.1.3 pertains to the data for other areas of the globe.

When a computer is about to commence with Form WBAN 54–7.1, he should refer to Table 7.1.2 or 7.1.3, whichever is appropriate, and find one or more points in the tabulated list that are located reasonably close to the given station. He should preferably select points from the table which have most nearly similar climatological and topographic conditions to those of the given station. The computer should interpolate between or extrapolate from the data listed in Tables 7.1.2 or 7.1.3, in order to determine the most nearly representative values of absolute minimum temperature (t_{min}) and absolute maximum temperature (t_{max}) for the given station.

After these values have been estimated, the computer may be guided by the following principles in establishing the range of t_s to be covered on the computation forms:

(a) The lowest value of t_s should be the multiple of 10° F. nearest the estimated value of t_{min} for the given station.

(b) The highest value of t_s should be 10° F. lower than the multiple of 10° F. nearest the estimated value of t_{max} for the given station. (Where t_{min} or t_{max} end in 5° F., consider the next higher multiple of 10° F. to be the nearest.)

Examples

We may consider the cases of Daytona Beach, Florida, and Old Orchard, Maine, already dealt with in sec. 7.1.2. At Daytona Beach, we have $t_{min} = 18°$ F. and $t_{max} = 102°$ F.; therefore, if the station elevation had been significantly above 50 feet, we should make the computations on the pertinent forms for values of t_s ranging from 20° F. to 90° F. At Old Orchard, Maine, we have $t_{min} = -39°$ F. and $t_{max} = 103°$ F.; therefore, we should make the computations on the pertinent forms for values of t_s ranging from $-40°$ to 90° F.

7.2.1.1 Annual Normal Temperature of Station (t_{sn}).—Data required in the heading of Form WBAN 54–7.1 should be filled in from the best available sources. Item 4, labeled "annual normal temperature of station" (t_{sn}) can generally be determined from Table 7.1.2, fig. 7.2.0 (Isotherms of Av-

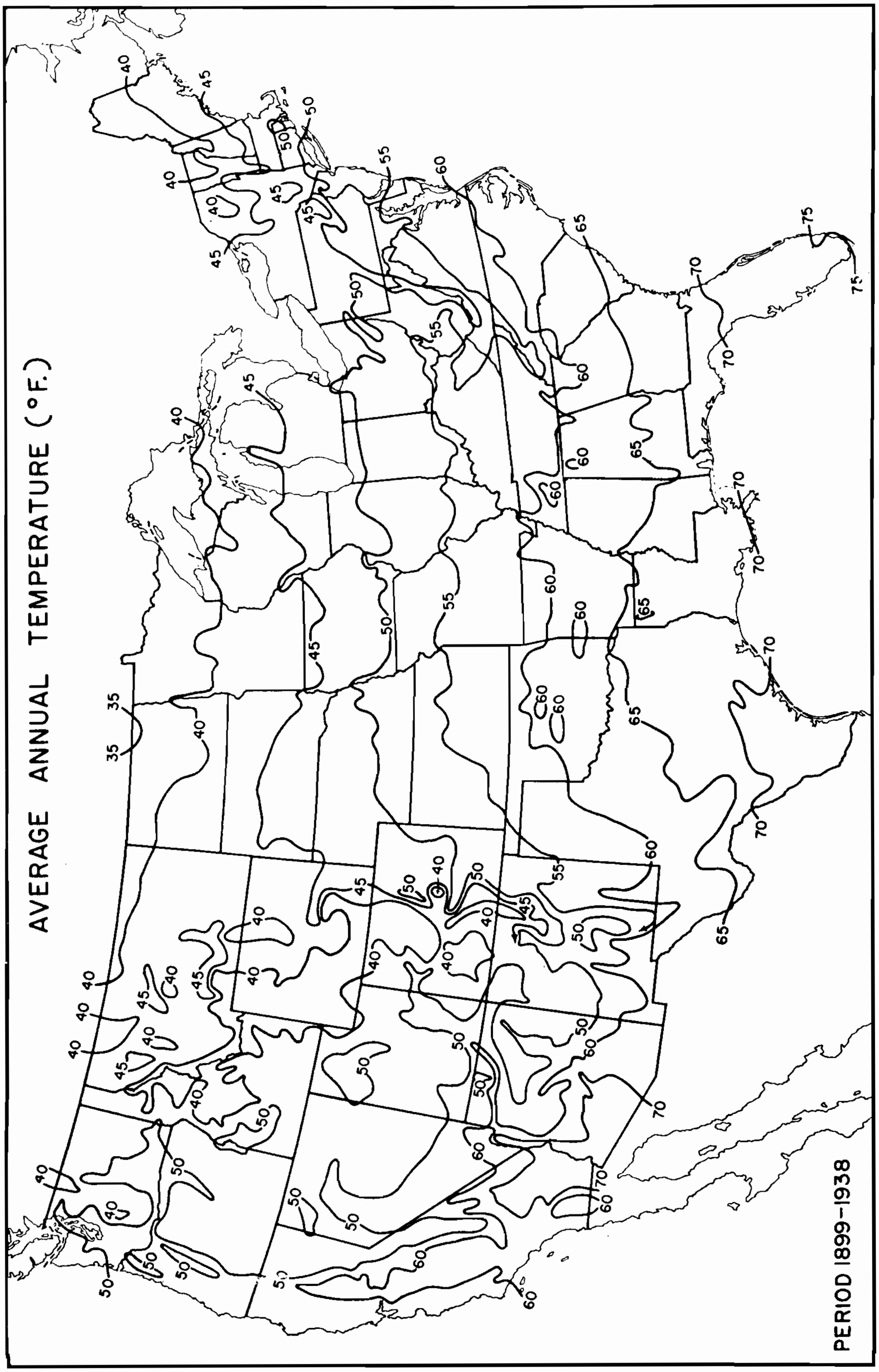


FIGURE 7.2.0. Isotherms of average annual temperature for the United States (from Yearbook of Agriculture of 1941).

erage Annual Temperature for the United States) and Table 7.1.3.

If the station is not listed in Tables 7.1.2 and 7.1.3, some interpolation between published data or extrapolation will generally be necessary to estimate t_{sn}. This can be done by considering annual normal temperatures of points listed in the tables, which are closest to the given station and have most nearly similar topography and climate.

In order to facilitate the location of points for which data are presented, the names of cities, states, countries, continents and oceans are arranged in alphabetical order in the tables.

If the value of H_p for the given station differs by over 50 feet from the elevation of any listed point whose data are to be taken from Tables 7.1.2 or 7.1.3, a correction of temperature for the difference in elevation should be made. The correction should be based upon the assumption that the lapse rate has the standard value, namely, a decrease of 0.003566° F. per foot of increase in elevation.

Example I

Suppose we require t_{sn} for Ames, Iowa, at a station elevation of 1044 feet. The latitude is 42°02′ N. and the longitude 93°39′ W. Referring to Table 7.1.2, we find that the nearest point listed is Des Moines, Iowa, whose ground elevation is 948 feet and whose annual normal temperature is 50.2° F. The elevation at Ames is 96 feet greater than that of Des Moines. Assuming the standard lapse rate, an increase of this amount in elevation should correspond to a *decrease* of $(96 \times 0.003566)^\circ$ F. in temperature, or 0.3° F. Therefore, one may estimate that at Ames, Iowa, we should expect $t_{sn} = (50.2^\circ - 0.3^\circ)$ F. $= 49.9^\circ$ F., approximately, when adjusted for the difference in elevation. Since Ames is one-half degree of latitude north of Des Moines, we must now adjust t_{sn} on the basis of the N–S horizontal temperature gradient of about 5° F. per 2° of latitude revealed in fig. 7.2.0. We thus calculate that the annual normal temperature will be less at Ames than at Des Moines by about 1.2° F. We finally conclude that at Ames, Iowa, $t_{sn} = (49.9^\circ - 1.2^\circ)$ F. $= 48.7^\circ$ F., very nearly.

Example II

On the other hand, suppose we require t_{sn} for Marshalltown, Iowa, at a station elevation of 888 feet. The latitude is 42°01′ N. and the longitude 92° 55′ W. In this case Table 7.1.2 reveals that the nearest point listed is Des Moines, Iowa, whose ground elevation is 948 feet. The elevation of Marshalltown is 60 feet lower than that of Des Moines. Again assuming the standard lapse rate, a decrease of this amount in elevation should correspond to an *increase* of $(60 \times 0.003566)^\circ$ F. in temperature, or 0.2° F. Accordingly, one may estimate that at Marshalltown, Iowa, we should have $t_{sn} = (50.2^\circ + 0.2^\circ)$ F. $= 50.4^\circ$ F., approximately, on the basis of elevation. Considering the difference in latitude between Marshalltown and Des Moines, we find it to be about 29′, that is 29/60 of one degree. From fig. 7.2.0 we estimate that the horizontal gradient of temperature pertinent to this case is about 2.5° F. per degree of latitude. Thus, we calculate that the annual normal temperature at Marshalltown should be about 1.3° F. lower than at Des Moines on the basis of difference in geographical coordinates. Accordingly, our final calculation yields for Marshalltown the value $t_{sn} = (50.4^\circ - 1.3^\circ)$ F. $= 49.1^\circ$ F., very nearly. Slightly more accurate results could be obtained by interpolation based on gradients in terms of distance on the map.

7.2.1.2 Part (A), Form WBAN 54–7.1: Vapor Pressure (e_s)

7.2.1.2.0 *"Humidity Point-of-Departure Stations"*.—The term "Humidity Point-of-Departure Station" refers to a station for which data regarding e_s are contained in Tables 7.2.1 to 7.2.5, provided that these data are considered to be fairly representative of those expected at the given station, and that the data are used in the calculations presented under Part (A) of the form.

7.2.1.2.1 *Selection of Stations for Humidity Data.*—"Humidity Point-of-Departure Stations" are to be picked on the basis of closest similarity to the given station as regards topographic and climatological conditions, especially those which affect the relation of moisture content to temperature.

Tables 7.2.1 to 7.2.5 provide values of e_s as a function of t_s on the basis of climatological studies, mainly for the United States and its possessions, and Canada. When it is desired to pick "Humidity Point-of-Departure Stations" for given stations in regions not covered by the list contained in Tables 7.2.1 to 7.2.5, the computer must use discretion and judgment based on understanding of comparative climates in making the choice of data to be compiled in Part (A).

For example, suppose the given station were outside North America in a hot, dry climate, then the computer might well select the "Humidity Point-of-Departure Stations" from points listed under states in the arid region of southwestern United States. As another example, if the given station were outside of North America in a hot, humid climate, the computer might select the "Humidity Point-of-Departure Stations" from a combination of Key West, Florida (Table 7.2.1); San Juan, P. R. (Table 7.2.4); and one or more points on Pacific Ocean Islands (Table 7.2.5). As a final example, information regarding Alaskan stations in Table 7.2.2 and Canadian stations in Table 7.2.3 will serve for data in a cold climate such as that of Greenland. Some comparative consideration of the annual normal temperatures and the absolute minimum and maximum of temperatures presented in Tables 7.1.2 and 7.1.3 will generally be helpful in choosing "Humidity Point-of-Departure Stations" for regions not covered by Tables 7.2.1 to 7.2.5.

As a rule, two or three "Humidity Point-of-Departure Stations" are picked, depending upon nearness and direction of these with respect to the given station; and also upon the estimated degree of climatological and topographic similarity.

In the case of given stations in the United States where the network of points listed in Table 7.2.1 is fairly dense, three "Humidity Point-of-Departure Stations" should, as a rule, be picked so that they form a reasonably small triangle on the map about the given station. If the given station is located at one of the points listed, this one point is sufficient for the purpose of Part (A).

7.2.1.2.2 *Evaluation of e_s Data.*—After the "Humidity Point-of-Departure Stations" are selected, the e_s data should be entered under Part (A) of Form WBAN 54–7.1 for the various values of t_s over the required range. Sums of e_s should then be indicated in line (4) for each column. The mean value of e_s should be entered in line (5) for each column, by dividing the sum by the number of e_s values listed on lines (1) to (3) of the column. (Note: These results will be used in referring to Table 7.3, in order to determine information required on line (b) of Part (C) of Form WBAN 54–7.1.)

Examples of the evaluation of e_s data as a function of t_s are presented in figs. 7.2.1(a), 7.2.1(b), 7.2.7(a), and 7.2.7(b).

7.2.1.3 Part (B), Form WBAN 54–7.1 $F(t_s)$, the Correction for Plateau Effect and Local Lapse Rate Anomaly

7.2.1.3.0 *"Point-of-Departure Stations" for $F(t_s)$.*—The term "Point-of-Departure Station" for $F(t_s)$ refers to a station for which data regarding F as a function of t_s are considered to be fairly representative of those at the given station, provided that the data are used in the calculations presented under Part (B) of the form.

7.2.1.3.1 *General Rules Regarding $F(t_s)$*

(I) When the given station lies outside of North America, we shall assume the value zero (0) for F, regardless of t_s, t_{sn}, H_{pg}, or geographic location.

(II) When H_{pg} is 305 gpm or less and the given station is in North America, the computer should refer to Tables 7.4.1 and 7.4.2 in order to find $F(t_s)$ by interpolation, depending upon the value of t_{sn} (see sec. 7.2.1.1).

(III) When H_{pg} is over 305 gpm and the given station is in North America, the computer should refer to Tables 7.4.3 to 7.4.8 in order to pick one or more appropriate "Point-of-Departure Stations" for $F(t_s)$ and to extract the data required for Part (B), Lines (a) to (d).

7.2.1.3.2 *Instructions for Determination of $F(t_s)$*

(a) *Case of Station Outside of North America.*—If the given station is located outside of North America, enter zero (0) on line (f) of Part (B), Form WBAN 54–7.1.

(b) *Case of Station in North America, and H_{pg} is 305 gpm or Less.*—If the given station is located in North America and H_{pg} is 305 gpm or less, refer to Tables 7.4.1 and 7.4.2. Using t_{sn} as an argument (see sec. 7.2.1.1), interpolate in the table to find the corresponding value of F under each column heading of t_s over the required range. Enter the interpolated data with proper algebraic sign on line (f), Part (B), Form WBAN 54–7.1.

Examples are shown in figs. 7.2.1(a) and 7.2.1(b) for Burlington, Iowa.

Form WBAN 54-7.1

7.1, p. 1 of 2

PRESSURE REDUCTION COMPUTATIONS

Computation of (A) vapor pressure (e_s); (B) correction for plateau effect and local lapse rate anomaly, $F(t_s)$; and (C) mean virtual temperature (T_{mv}); as functions of station temperature argument, t_s.

1. Name of station Burlington, Iowa 2. Latitude, ϕ = 40°47'N. Longitude, λ = 91°07'W.

3. Geopotential of station, H_{pg} = 214.0 gpm.

4. Annual normal temperature of station, t_{sn} = 51.3 °F. (See Table 7.1.2 or 7.1.3 and Figure 7.2.0).

(A) Tabular values represent vapor pressure, e_s (in mb.) as functions of t_s.

No.	Name of Humidity Point-of-Departure Station	Station temperature argument, t_s, °Fahrenheit								
		-60°	-50°	-40°	-30°	-20°	-10°	0°	+10°	+20°
(1)	Chicago, Illinois	mb.	mb.	mb.	mb. 0.19	mb. 0.34	mb. 0.60	mb. 1.0	mb. 1.7	mb. 2.8
(2)	Columbia, Mo.				0.19	0.34	0.60	1.0	1.7	2.8
(3)	Omaha, Nebr.				0.19	0.34	0.60	1.0	1.7	2.7
(4)	Sum				0.57	1.02	1.80	3.0	5.1	8.3
(5)	Mean e_s				0.19	0.34	0.60	1.0	1.7	2.8

Use data from line (5) in obtaining line (b) of (C) below.

(B) Tabular values represent $F(t_s)$, the correction for plateau effect and local lapse rate anomaly, as a function of t_s. (See Instructions, section 7.2 of Manual).

	Names of "point-of departure stations" for $F(t_s)$	Station temperature argument, t_s, °Fahrenheit								
		-60°	-50°	-40°	-30°	-20°	-10°	0°	+10°	+20°
(a)										
(b)										
(c)										
(d)										
(e)	Algebraic sum									
(f)	Mean = $F(t_s)$ for station				30.1	27.4	24.5	21.3	17.8	14.0

Transfer data from line (f) to line (d) of (C) below.

(C) Computation of T_{mv} = mean virtual temperature (°Rankine).

Obtain data for line (b) from Table 7.3 as a function of H_{pg} and e_s (see line 5 of A above).

Line	Description	Station temperature argument, t_s, °Fahrenheit								
		-60°	-50°	-40°	-30°	-20°	-10°	0°	+10°	+20°
(a)	$459.7 + t_s$	399.7	409.7	419.7	429.7	439.7	449.7	459.7	469.7	479.7
(b)	$\frac{aH_{pg}}{2} + e_sC_h$				1.3	1.4	1.4	1.5	1.6	1.8
(c)	Algebraic sum of (a) and (b)				431.0	441.1	451.1	461.2	471.3	481.5
(d)	$F(t_s)$				30.1	27.4	24.5	21.3	17.8	14.0
(e)	T_{mv} = algebraic sum of (c) and (d)				461.1	468.5	475.6	482.5	489.1	495.5

FIGURE 7.2.1(a). Form WBAN 54–7.1 (page 1) showing sample entries for determination of T_{mv} as a function of t_s, used in pressure reduction computations for a station having an elevation (H_p) of less than 305 gpm. (Example for Burlington, Iowa.)

Form WBAN 54- 7.1

7.1, p. 2 of 2

PRESSURE REDUCTION COMPUTATIONS

Computation of (A) vapor pressure (e_s); (B) correction for plateau effect and local lapse rate anomaly, $F(t_s)$; and (C) mean virtual temperature (T_{mv}); as functions of station temperature argument, t_s.

1. Name of station Burlington, Iowa 2. Latitude, ϕ = 40° 47'N Longitude, λ = 91° 07'W.
3. Geopotential of station, H_{pg} = 214.0 gpm.
4. Annual normal temperature of station, t_{sn} = 51.3 °F. (See Table 7.1.2 or 7.1.3 and Figure 7.2.0).

(A) Tabular values represent vapor pressure, e_s (in mb.) as functions of t_s.

No.	Name of Humidity Point-of-Departure Station	Station temperature argument, t_s, °Fahrenheit								
		+30°	+40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°
		mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
(1)	Chicago, Illinois	4.2	5.9	8.3	11.9	17.6	21.6	21.4	19.2	16.5
(2)	Columbia, Mo.	4.1	5.7	8.2	11.9	17.5	23.6	24.5	21.6	18.3
(3)	Omaha, Nebr.	4.1	5.8	7.8	11.2	16.7	21.9	22.7	21.1	19.0
(4)	Sum	12.4	17.4	24.3	35.0	51.8	67.1	68.6	61.9	53.8
(5)	Mean e_s	4.1	5.8	8.1	11.7	17.3	22.4	22.9	20.6	17.9

Use data from line (5) in obtaining line (b) of (C) below.

(B) Tabular values represent $F(t_s)$, the correction for plateau effect and local lapse rate anomaly, as a function of t_s. (See Instructions, section 7.2 of Manual).

	Names of "point-of-departure stations" for $F(t_s)$	Station temperature argument, t_s, °Fahrenheit								
		+30°	+40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°
(a)										
(b)										
(c)										
(d)										
(e)	Algebraic sum									
(f)	Mean = $F(t_s)$ for station	9.8	5.4	0.7	-4.4	-9.8	-15.5	-21.5	-27.7	-34.2

Transfer data from line (f) to line (d) of (C) below.

(C) Computation of T_{mv} = mean virtual temperature (°Rankine).

Obtain data for line (b) from Table 7.3 as a function of H_{pg} and e_s (see line 5 of A above).

Line	Description	Station temperature argument, t_s, °Fahrenheit								
		+30°	+40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°
(a)	$459.7 + t_s$	489.7	499.7	509.7	519.7	529.7	539.7	549.7	559.7	569.7
(b)	$\frac{aH_{pg}}{2} + e_sC_h$	2.1	2.4	2.9	3.6	4.8	5.8	5.9	5.4	4.9
(c)	Algebraic sum of (a) and (b)	491.8	502.1	512.6	523.3	534.5	545.5	555.6	565.1	574.6
(d)	$F(t_s)$	9.8	5.4	0.7	-4.4	-9.8	-15.5	-21.5	-27.7	-34.2
(e)	T_{mv} = algebraic sum of (c) and (d)	501.6	507.5	513.3	518.9	524.7	530.0	534.1	537.4	540.4

FIGURE 7.2.1(b). Form WBAN 54–7.1 (page 2) showing sample entries for determination of T_{mv} as a function of t_s, used in pressure reduction computations for a station having an elevation (H_p) of less than 305 gpm. (Example for Burlington, Iowa.)

Tables 7.4.1 and 7.4.2 serve to represent "Point-of-Departure Stations" for $F(t_s)$, without name but determined by the parameter t_{sn}, regardless of elevation, provided H_{pg} is 305 gpm or less. Table 7.4.1 applies to stations in Continental U.S., and Table 7.4.2 to stations in Alaska, when H_{pg} is less than or equal to 305 gpm.

In the case of given stations in Canada satisfying this condition regarding H_{pg}, values of $F(t_s)$ may be obtained from Table 7.4.1 or 7.4.2, depending upon the parameter t_{sn}. In this case if both Tables 7.4.1 and 7.4.2 contain data for a range of the parameter t_{sn} which includes the value of t_{sn} applicable at the given station, the computer must pick one or the other of these tables as the basis for $F(t_s)$. He will be guided in the selection by judging whether the climate of the given Canadian station most nearly resembles that of Continental U.S. stations or Alaskan stations for the given value of t_{sn}.

An example of the interpolation in regard to t_{sn} is now presented. Suppose that $H_{pg} = 301$ gpm at a given station in Continental U. S., for which $t_{sn} = 52.1°$ F. Taking data for $t_s = -40°$ F., we find from Table 7.4.1 that when $t_{sn} = 50.0°$ F., then $F(t_s) = 32.0°$; and when $t_{sn} = 55.0°$ F., then $F(t_s) = 33.9°$. Interpolating between these two values, we obtain the result that $F(t_s) = 32.8°$ corresponding to $t_{sn} = 52.1°$ F. Similarly, taking data for $t_s = 100°$ F., we obtain the result that $F(t_s) = -27.3°$ corresponding to $t_{sn} = 52.1°$ F. Care should be taken always to use the proper algebraic sign.

It should be noted that so long as H_{pg} is 305 gpm or less, $F(t_s)$ is independent of the specific value of H_{pg}, according to Tables 7.4.1 and 7.4.2.

(c) *Case of Station in North America, and H_{pg} Exceeds 305 gpm.*—If the given station is in North America and H_{pg} exceeds 305 gpm, the computer will refer to Tables 7.4.3 to 7.4.8 in order to select proper "Point-of-Departure Stations" for $F(t_s)$. He may pick from one to four such stations, depending upon their closeness to the given station. The computer, in picking the "Point-of-Departure Stations" for $F(t_s)$ should be guided by the desire to secure most nearly representative data for the given station, as may be judged from similarity of climatic and topographic conditions. Geographic coordinates and elevations are provided in Tables 7.4.3 to 7.4.5, and temperature data which are presented in Table 7.1.2 should be of assistance to the computer in selecting "Point-of-Departure Stations" for $F(t_s)$. As a rule, these stations will be so selected that they delineate a triangle or quadrilateral figure surrounding the given station on the map.

Examples are shown in figs. 7.2.7(a) and 7.2.7(b).

After the data are entered on lines (a) to (d), of Part (B), Form WBAN 54–7.1, the *algebraic sum* for each column is entered on line (e) of Part (B), and the mean is obtained by dividing the value on line (e) by the number of entries of F in lines (a) to (d) of the column. The mean is written on line (f) of Part (B). This provides a set of entries on line (f) considered to represent F as a function of t_s. Care is necessary to take proper account of signs in taking the algebraic sum for each column, and in entering the proper signs on all lines.

7.2.1.4 Part (C), Form WBAN 54–7.1: Computation of T_{mv} = Mean Virtual Temperature (°R.)

7.2.1.4.0 *General Information.*—Part (C) involves the straightforward computations to determine T_{mv} as a function of t_s.

7.2.1.4.1 *Line (b), Part (C): $(aH_{pg}/2 + e_sC_h)$.*—Refer to Table 7.3. Using H_{pg} as a fixed argument on the left-hand side and e_s as a variable argument along the top, interpolate in the body of the table to obtain the value of the quantity $(aH_{pg}/2 + e_sC_h)$, and enter the result on line (b). The variable e_s is taken from line (5), Part (A), marked "Mean e_s," under the given value of t_s.

Examples are shown in figs. 7.2.1(a) and (b), and 7.2.7(a) and (b).

7.2.1.4.2 *Line (c), Part (C): Algebraic Sum of (a) and (b).*—Compute the algebraic sum of the figures printed on line (a) and the figures entered on line (b). Write the algebraic sum on line (c).

Examples are shown in figs. 7.2.1(a) and (b), and 7.2.7(a) and (b).

7.2.1.4.3 *Line (d), Part (C): $F(t_s)$.*—Take the data from line (f), Part (B), and enter them on line (d), Part (C), under the same heading of t_s. Caution is necessary to enter the proper algebraic sign for F.

See figs. 7.2.1(a) and (b), and 7.2.7(a) and (b) for examples.

7.2.1.4.4 *Line (e), Part (C): T_{mv} = Algebraic Sum of (c) and (d).*—Take the algebraic sum of the data entered on lines (c) and (d) of the column under Part (C), and write the algebraic sum on line (e).

Figs. 7.2.1(a) and (b), and 7.2.7(a) and (b) present examples.

7.2.2 Preparation of Form WBAN 54–7.2

7.2.2.0 General Information.—When the slide rule (see fig. 7.2.4(a)) is available for reduction of pressure to sea level, entries on Form WBAN 54–7.2 need *only* be made in the columns T_{mv} and r. When it is necessary to prepare a table in extenso for reduction, columns headed $P' \cdot r$ and $(\Delta P \cdot r)$ must have entries. See secs. 7.2.2.1.3 and 7.2.2.1.5.

7.2.2.1 Instructions for Preparation of Form WBAN 54–7.2

7.2.2.1.0 *List of Data To Be Entered.*—The following data are to be entered on Form WBAN 54–7.2: P', ΔP, T_{mv}, r, $P' \cdot r$, and $(\Delta P \cdot r)$. Entries of P' and ΔP will be made in the heading above the columns; and entries of T_{mv}, r, and $(\Delta P \cdot r)$ will be made in the columns as functions of t_s. Of course the name of the station, also its elevation and geographic coordinates should be indicated at the top of the form.

7.2.2.1.1 *Column T_{mv}.*—From line (e), Part (C), of Form WBAN 54–7.2 (pages 1 and 2), transfer the values of T_{mv} corresponding to the headings of t_s printed on those forms to the corresponding proper spaces in the column headed T_{mv} on Form WBAN 54–7.2.

Examples are shown in figs. 7.2.2(a), (b), and (c); and 7.2.8(a), (b), and (c).

7.2.2.1.2 *Column r.*—Refer to Table 7.5. This yields r as a function of H_{pg} and T_{mv}. Interpolate in the table to find the values of r corresponding to constant value of H_{pg} for the given station and to the variable values of T_{mv} entered in the column headed T_{mv} on Form WBAN 54–7.2. Enter on the latter form in "Column r" the values of r thus determined on the proper lines corresponding to the specified values of T_{mv}.

Examples are shown in figs. 7.2.2(a), (b), and (c); and 7.2.8(a), (b), and (c).

7.2.2.1.3 *Entry P′.*—The symbol P' denotes the minimum station pressure to be used in the pressure reduction table in extenso.

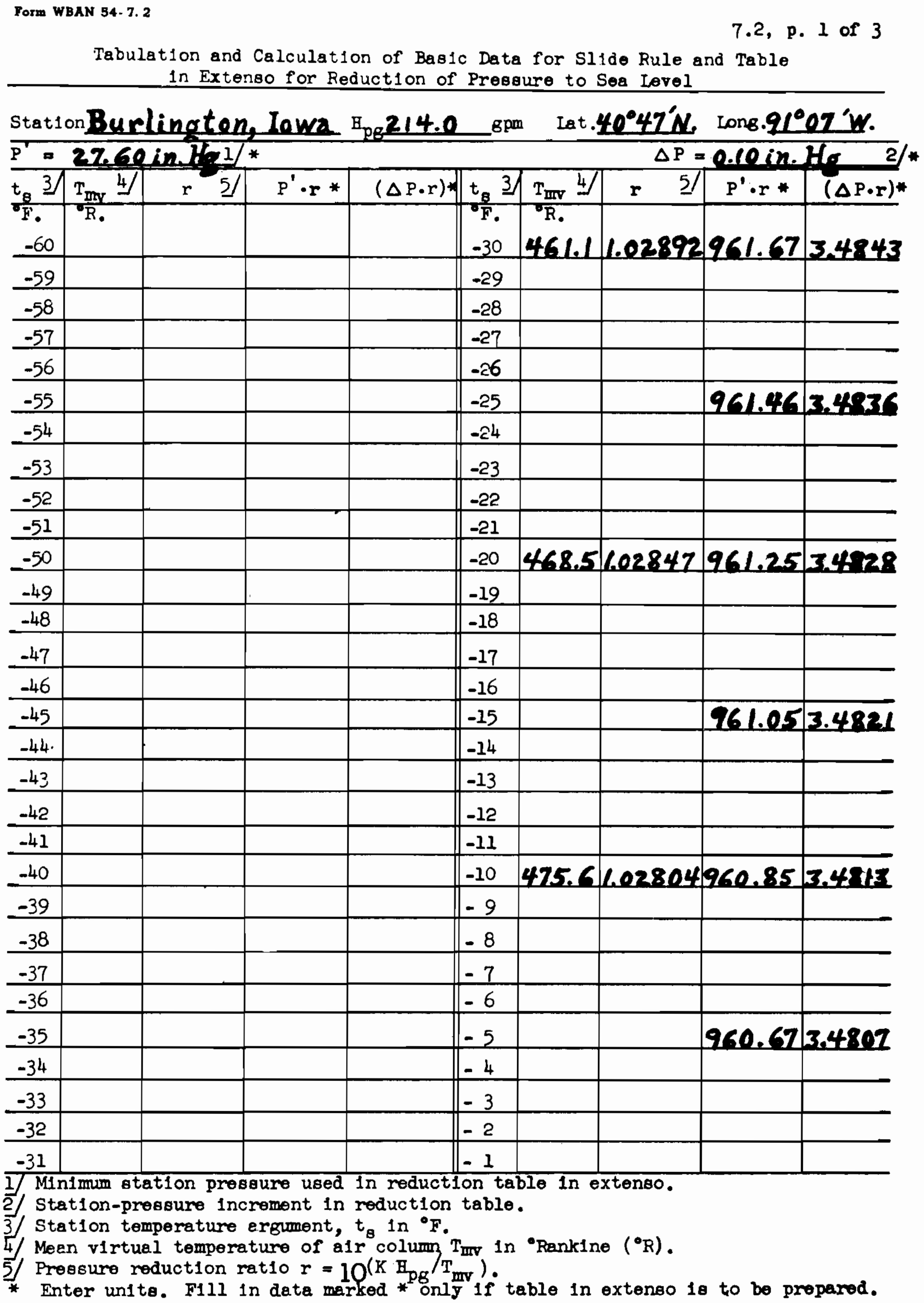
In regions where hurricanes or typhoons strike, a value of P′ will usually be chosen about 2.5 inches of mercury below the normal station pressure, which will cover roughly 98% of the storm seasons. An estimate of normal station pressure can be obtained as a function of station elevation from Table 8.1. For example, if H_p = 280 feet, it may be estimated that the normal station pressure will be about 29.62 inches of mercury; and if H_p = 1650 feet, it may be estimated that the normal station pressure is about 28.18 inches of mercury.

In parts of the world where intense extratropical cyclones occur, P' will usually be about 2.2 inches of mercury below the normal station pressure (for example, in high latitudes of both northern and southern hemispheres). In the remaining cases it is usually safe to take P' about 1.6 to 2.0 inches of mercury below the normal station pressure. Enter the value of P' thus estimated but rounded to the next lower 0.10 inch of mercury, on the line immediately above the columns of data on Form WBAN 54–7.2. If the barometer is read in millibars or millimeters of mercury, a suitable rounded value of P' in those units should be entered.

7.2.2.1.4 *Column $P' \cdot r$.*—Multiply the selected value of P' by the value of r shown under "Column r" for the given t_s, and enter the numerical value of the product $P' \cdot r$ on the line for the given t_s value. Perform the operation for every value of r which is entered, for the various arguments t_s. Interpolate vertically in this column to obtain values of $P' \cdot r$ for intermediate values of t_s, if needed.

Examples are shown in the figures cited under sec. 7.2.2.1.1.

As a rule, data are needed under the columns headed $P' \cdot r$ and $(\Delta P \cdot r)$, for the following intervals of t_s.



Form WBAN 54-7.2

7.2, p. 1 of 3

Tabulation and Calculation of Basic Data for Slide Rule and Table in Extenso for Reduction of Pressure to Sea Level

Station **Burlington, Iowa** H_{pg} **214.0** gpm Lat. **40°47′N.** Long. **91°07′W.**

P′ = **27.60 in. Hg** 1/* ΔP = **0.10 in. Hg** 2/*

t_s 3/ °F.	T_{mv} 4/ °R.	r 5/	P′·r *	(ΔP·r)*	t_s 3/ °F.	T_{mv} 4/ °R.	r 5/	P′·r *	(ΔP·r)*
-60					-30	461.1	1.02892	961.67	3.4843
-59					-29				
-58					-28				
-57					-27				
-56					-26				
-55					-25			961.46	3.4836
-54					-24				
-53					-23				
-52					-22				
-51					-21				
-50					-20	468.5	1.02847	961.25	3.4828
-49					-19				
-48					-18				
-47					-17				
-46					-16				
-45					-15			961.05	3.4821
-44					-14				
-43					-13				
-42					-12				
-41					-11				
-40					-10	475.6	1.02804	960.85	3.4813
-39					- 9				
-38					- 8				
-37					- 7				
-36					- 6				
-35					- 5			960.67	3.4807
-34					- 4				
-33					- 3				
-32					- 2				
-31					- 1				

1/ Minimum station pressure used in reduction table in extenso.
2/ Station-pressure increment in reduction table.
3/ Station temperature argument, t_s in °F.
4/ Mean virtual temperature of air column T_{mv} in °Rankine (°R).
5/ Pressure reduction ratio $r = 10^{(K\ H_{pg}/T_{mv})}$.
* Enter units. Fill in data marked * only if table in extenso is to be prepared.

FIGURE 7.2.2(a). Form WBAN 54-7.2 (page 1) showing sample entries of tabulation and calculation of basic data for slide rule and table in extenso for reduction of pressure to sea level. (Example for Burlington, Iowa.)

Form WBAN 54-7.2

7.2, p. 2 of 3

Tabulation and Calculation of Basic Data for Slide Rule and Table in Extenso for Reduction of Pressure to Sea Level

Station Burlington, Iowa H_{pg} 214.0 gpm Lat. 40°47′N. Long. 91°07′W.

P′ = 27.60 in. Hg 1/* ΔP = 0.10 in. Hg 2/*

t_s 3/	T_{mv} 4/	r 5/	P′·r *	(ΔP·r)*	t_s 3/	T_{mv} 4/	r 5/	P′·r *	(ΔP·r)*
°F.	°R.				°F.	°R.			
0	482.5	1.02764	960.48	3.4800	30	501.6	1.02657	959.48	3.4764
1					31				
2					32				
3					33				
4					34				
5			960.30	3.4794	35			959.34	3.4759
6					36				
7					37				
8					38				
9					39				
10	489.1	1.02726	960.12	3.4787	40	507.5	1.02626	959.19	3.4753
11					41				
12					42				
13					43				
14					44				
15			959.95	3.4781	45			959.05	3.4748
16					46				
17					47				
18					48				
19					49				
20	495.5	1.02689	959.78	3.4775	50	513.3	1.02595	958.90	3.4743
21					51				
22					52				
23					53				
24					54				
25			959.63	3.4770	55			958.77	3.4738
26					56				
27					57				
28					58				
29					59				

1/ Minimum station pressure used in reduction table in extenso.
2/ Station-pressure increment in reduction table.
3/ Station temperature argument, t_s in °F.
4/ Mean virtual temperature of air column T_{mv} in °Rankine (°R).
5/ Pressure reduction ratio $r = 10^{(K\ H_{pg}/T_{mv})}$.
* Enter units. Fill in data marked * only if table in extenso is to be prepared.

FIGURE 7.2.2(b). Form WBAN 54–7.2 (page 2) showing sample entries of tabulation and calculation of basic data for slide rule and table in extenso for reduction of pressure to sea level. (Example for Burlington, Iowa.)

Form WBAN 54- 7.2

7.2, p. 3 of 3

Tabulation and Calculation of Basic Data for Slide Rule and Table in Extenso for Reduction of Pressure to Sea Level

Station Burlington, Iowa H_{pg} 214.0 gpm. Lat. 40°47′N. Long. 91°07′W.

P′ = 27.60 in. Hg 1/* ΔP = 0.10 in. Hg 2/*

t_s 3/	T_{mv} 4/	r 5/	P′·r *	(ΔP·r)*	t_s 3/	T_{mv} 4/	r 5/	P′·r *	(ΔP·r)*
°F.	°R.				°F.	°R.			
60	518.9	1.02567	958.64	3.4733	90	534.1	1.02494	957.95	3.4708
61					91				
62					92				
63					93				
64					94				
65			958.51	3.4729	95			957.88	3.4706
66					96				
67					97				
68					98				
69					99				
70	524.7	1.02539	958.37	3.4724	100	537.4	1.02478	957.80	3.4703
71					101				
72					102				
73					103				
74					104				
75			958.25	3.4720	105			957.73	3.4701
76					106				
77					107				
78					108				
79					109				
80	530.0	1.02513	958.13	3.4715	110	540.4	1.02463	957.66	3.4698
81					111				
82					112				
83					113				
84					114				
85			958.04	3.4712	115				
86					116				
87					117				
88					118				
89					119				

1/ Minimum station pressure used in reduction table in extenso.
2/ Station-pressure increment in reduction table.
3/ Station temperature argument, t_s in °F.
4/ Mean virtual temperature of air column T_{mv} in °Rankine (°R).
5/ Pressure reduction ratio $r = 10^{(K\ H_{pg}/T_{mv})}$.
* Enter units. Fill in data marked * only if table in extenso is to be prepared.

FIGURE 7.2.2(c). Form WBAN 54–7.2 (page 3) showing sample entries of tabulation and calculation of basic data for slide rule and table in extenso for reduction of pressure to sea level. (Example for Burlington, Iowa.)

H_p	*Interval of* t_s
50–500 feet	10° F.
500–1000 feet	5° F.
Over 1000 feet	2° F.

These intervals assure relatively small differences of P_o between successive values of the argument t_s, for any fixed value of P.

7.2.2.1.5 *Entry* (ΔP).—The symbol (ΔP) denotes the uniform interval of station pressure for which pressures reduced to sea level are to be tabulated on the table in extenso (see fig. 7.2.11(a) to (d)). Units of ΔP must be the same as those of P and P'. When the barometer is graduated in inches, it is usually convenient to take 0.10 in. Hg for ΔP, as shown in that figure. When the barometer is graduated in millibars or millimeters of mercury, it may be convenient to take for ΔP, either 10 mb. or 10 mm. Hg.

Enter the selected value of ΔP in the space thus labeled at the head of the columns of data on Form WBAN 54–7.2.

Examples are shown in the figures cited under Section 7.2.2.1.1.

7.2.2.1.6 *Column* ($\Delta P \cdot r$).—Multiply the selected value of ΔP by the value of r shown under "Column r" for the given t_s, and enter the numerical value of the product ($\Delta P \cdot r$) on the corresponding line for t_s. Perform this operation for every value of r which is entered. Interpolate vertically in this column to obtain values of ($\Delta P \cdot r$) for intermediate values of t_s, if needed.

Examples are shown in the figures cited under Section 7.2.2.1.1.

7.2.3 Preparation of Form WBAN 54–7.3

7.2.3.0 General Information.—This form is designed to provide a compact tabulation of the pressure-reduction ratio r as a function of the station temperature argument t_s, for use with the pressure-reduction computer (circular slide rule), illustrated in fig. 7.2.4(a).

7.2.3.1 Instructions for Preparation of Form WBAN 54–7.3.—Enter on form WBAN 54–7.3 the values of r as obtained on Form WBAN 54–7.3 for the various values of t_s. Interpolate r for every intermediate degree, thus completely filling the column headed r on Form WBAN 54–7.3 over the entire range of t_s necessary for the given station. Round the values of r to four (4) decimal places on this form; *completing the interpolations before rounding.* Examples are shown in figs. 7.2.3 and 7.2.9.

7.2.4 Preparation of Form WBAN 54–7.4

7.2.4.0 General Information.—This form is to be used only if the pressure reduction table in extenso is required. The letter n denotes the number of the increment of station pressure intervals (ΔP) added to P' to obtain any desired station pressure. Thus, we may write

Station Pressure, $P = P' + \Delta P \cdot n$.

When $n = 0$, $P = P'$;

when $n = 1$, $P = P' + \Delta P$;

when $n = 2$, $P = P' + 2\Delta P$;

etc.

Since $P_o = P \cdot r$, and $P = P' + \Delta P \cdot n$, we may also write

$$P_o = (P' \cdot r) + (\Delta P \cdot r)n.$$

Therefore P_o may be calculated for a given value of r by successive addition of the increment ($\Delta P \cdot r$) to ($P' \cdot r$).

Generally speaking, pressure reduced to sea level (P_o) rarely exceeds 1070 mb. This fact forms the basis for a method of estimating the maximum value of station pressure (P) to be used in the calculation made on the form.

To estimate this value, refer to Form WBAN 54–7.2, note the quantity r corresponding to a rounded value of t_s which is about 10° to 20° F. below the annual normal temperature (t_{sn}), and calculate the quotient 1070 mb./r. This yields an approximate maximum station pressure in millibars. Convert it to inches of mercury, if necessary, and round it to the next higher multiple of 0.10 in. Hg. This may be usually taken as the maximum station pressure for the calculations on Form WBAN 54–7.4.

Example I

Burlington, Iowa

$t_{sn} = 51.3°$ F. (See form WBAN 54–7.1.)

The nearest rounded value of t_s which lies in the range of 10° to 20° F. below t_{sn} is 40° F. Referring to Form WBAN 54–7.2, we find $r = 1.02626$ corresponding to $t_s = 40°$ F. Then the maximum station pressure is approximately 1070 mb./1.02626 = 1042.6 mb. Converting this, we obtain 30.79 inches of mer-

FORM WBAN 54-7.3
(7-1-59)

U.S. DEPARTMENT OF COMMERCE - WEATHER BUREAU

Station Burlington, Iowa Station Elevation, H_p = 702.2 ft.
Location Municipal Airport Lat. 40° 47' N ;Long. 91 ° 07 ' W

t_s °F	r	t_s °F	r	t_s °F	r	t_s °F	r	t_s °F	r	t_s °F	r
-60		-30	.0289	0	.0276	+30	.0266	+60	.0257	+90	.0249
-59		-29	.0289	+ 1	.0276	31	.0265	61	.0256	91	.0249
-58		-28	.0288	+ 2	.0276	32	.0265	62	.0256	92	.0249
-57		-27	.0288	+ 3	.0275	33	.0265	63	.0256	93	.0249
-56		-26	.0287	+ 4	.0275	34	.0265	64	.0256	94	.0249
-55		-25	.0287	+ 5	.0275	35	.0264	65	.0255	95	.0249
-54		-24	.0287	+ 6	.0274	36	.0264	66	.0255	96	.0248
-53		-23	.0286	+ 7	.0274	37	.0264	67	.0255	97	.0248
-52		-22	.0286	+ 8	.0273	38	.0263	68	.0254	98	.0248
-51		-21	.0285	+ 9	.0273	39	.0263	69	.0254	99	.0248
-50		-20	.0285	+10	.0273	40	.0263	70	.0254	100	.0248
-49		-19	.0284	+11	.0272	41	.0262	71	.0254	101	.0248
-48		-18	.0284	+12	.0272	42	.0262	72	.0253	102	.0247
-47		-17	.0283	+13	.0271	43	.0262	73	.0253	103	.0247
-46		-16	.0283	+14	.0271	44	.0261	74	.0253	104	.0247
-45		-15	.0283	+15	.0271	45	.0261	75	.0253	105	.0247
-44		-14	.0282	+16	.0270	46	.0261	76	.0252	106	.0247
-43		-13	.0282	+17	.0270	47	.0260	77	.0252	107	.0247
-42		-12	.0281	+18	.0270	48	.0260	78	.0252	108	.0247
-41		-11	.0281	+19	.0269	49	.0260	79	.0252	109	.0246
-40		-10	.0280	+20	.0269	50	.0260	80	.0251	110	.0246
-39		- 9	.0280	+21	.0269	51	.0259	81	.0251	111	
-38		- 8	.0280	+22	.0268	52	.0259	82	.0251	112	
-37		- 7	.0279	+23	.0268	53	.0259	83	.0251	113	
-36		- 6	.0279	+24	.0268	54	.0258	84	.0251	114	
-35		- 5	.0278	+25	.0267	55	.0258	85	.0250	115	
-34		- 4	.0278	+26	.0267	56	.0258	86	.0250	116	
-33		- 3	.0278	+27	.0267	57	.0258	87	.0250	117	
-32		- 2	.0277	+28	.0266	58	.0257	88	.0250	118	
-31		- 1	.0277	+29	.0266	59	.0257	89	.0250	119	
-30	.0289	0	.0276	+30	.0266	60	.0257	90	.0249	120	

PRESSURE REDUCTION RATIO r (preceding 1 omitted)

FIGURE 7.2.3. Form WBAN 54–7.3 showing sample entries of pressure reduction ratio (r). (Example for Burlington, Iowa.)

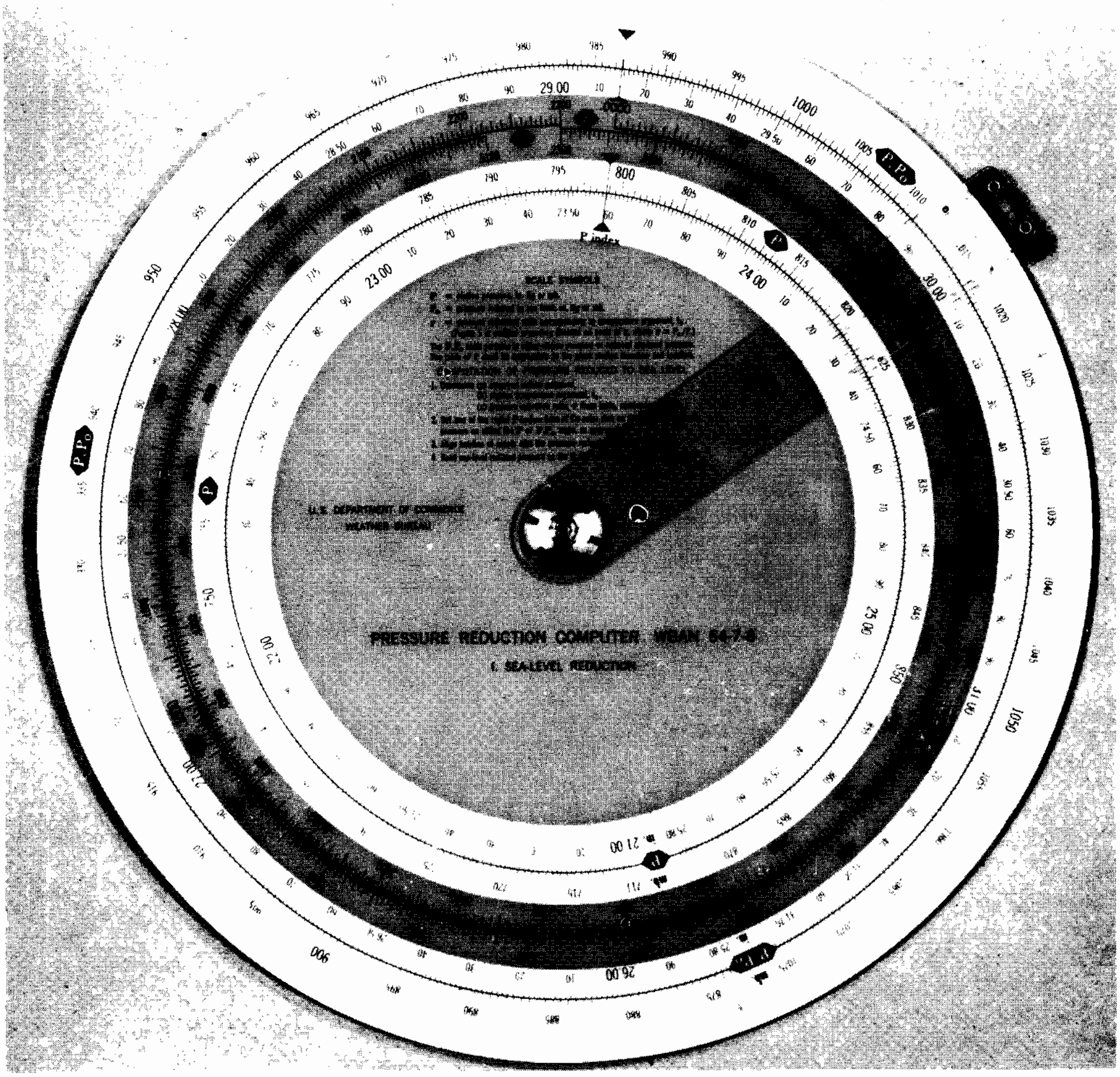


FIGURE 7.2.4(a). View of face I of Pressure Reduction Computer, used as a device to perform computations of reduction of pressure to sea level. (Device set to solve following example for Burlington, Iowa, where station elevation, H_p, is 702 ft.: Given—Station pressure, P = 29.144 in. Hg; station temperature argument, $t_s = -12°$ F. Refer to Form WBAN 54–7.3 for the station in fig. 7.2.3, and find reduction factor, $r = 1.0281$, corresponding to t_s. Operate computer according to instructions and determine pressure reduced to sea level, P_o = 1014.7 mb.)

cury. Rounding it up to the next higher multiple of 0.10 in. Hg, we secure 30.80 inches of mercury for the maximum station pressure.

Example II

Great Falls, Montana

$t_{sn} = 45.1°$ F. (See form WBAN 54–7.1)

The nearest rounded value of t_s which lies in the range 10° to 20° F. below t_{sn} is 30° F. Referring to Form WBAN 54–7.2, we find $r = 1.14686$ corresponding to $t_s = 30°$ F. Then, the maximum station pressure is approximately 1070 mb./1.14686 = 933.0 mb. Converting this, we obtain 27.55 inches of mercury. Rounding it up to the next higher multiple of 0.10 in. Hg, we secure 27.60 inches of mercury for the maximum station pressure.

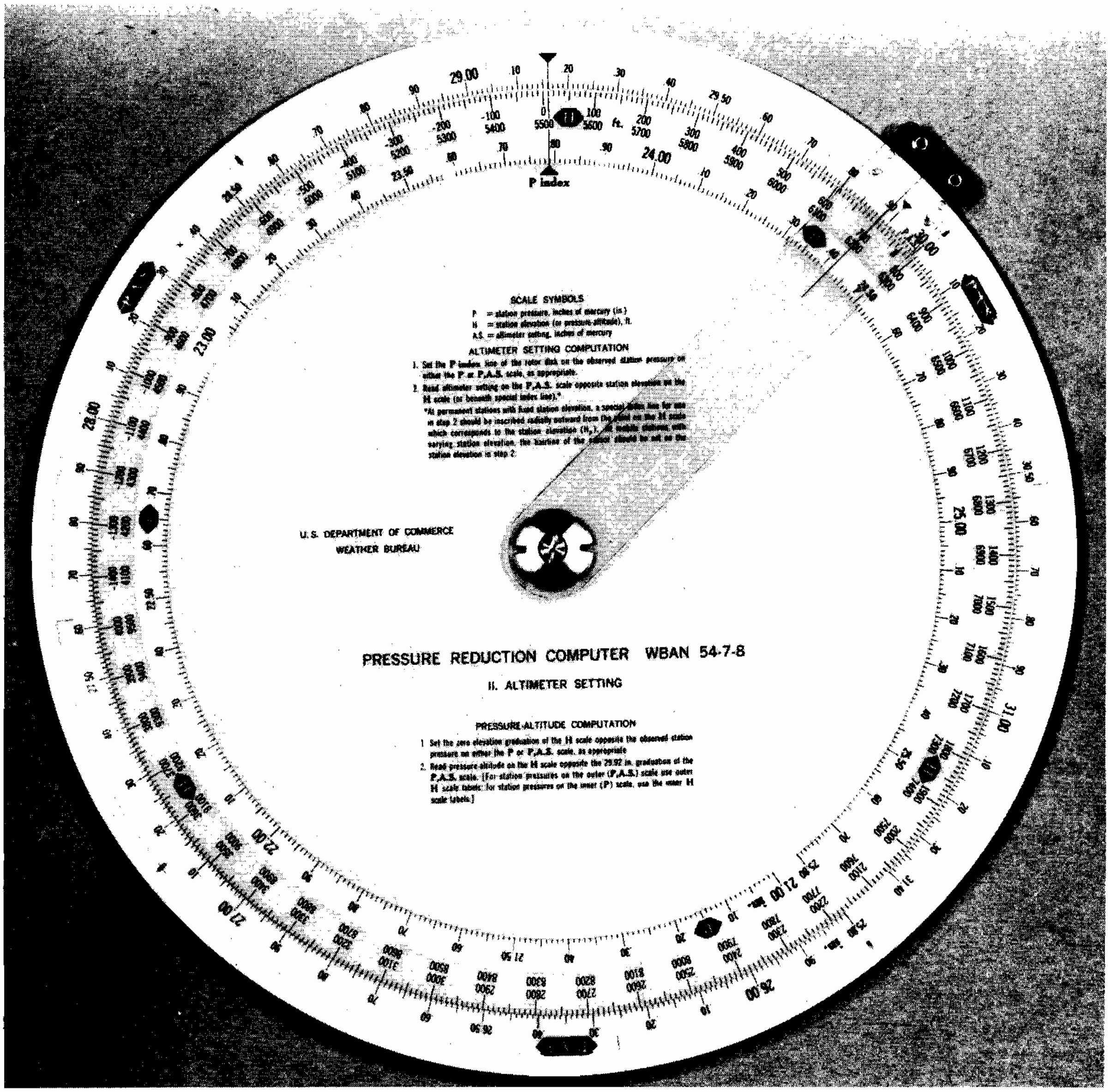
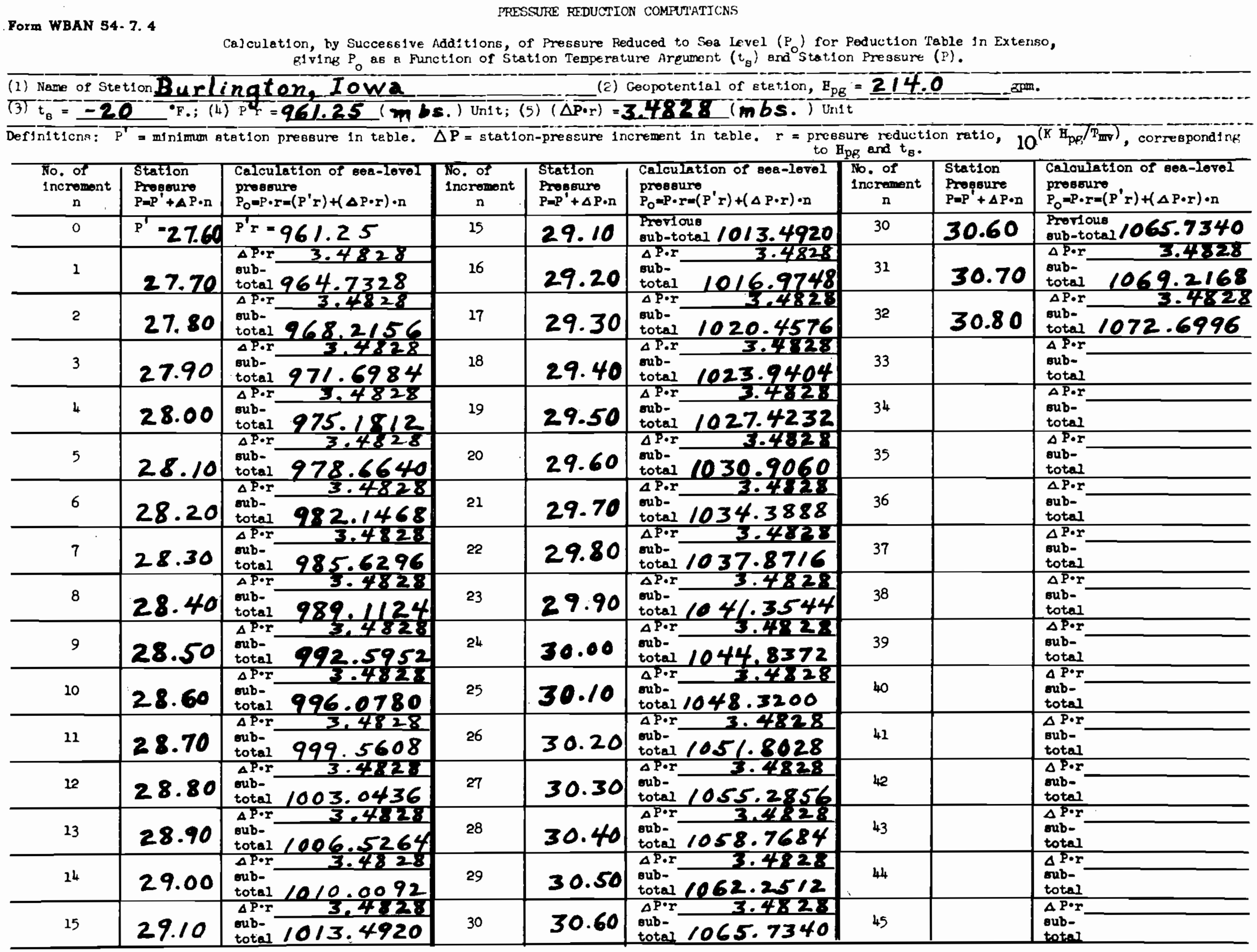


FIGURE 7.2.4(b). View of face II of Pressure Reduction Computer, which is used to compute altimeter settings. (Device set to solve following example for Burlington, Iowa, where $H_p = 702$ ft.: Given—station pressure, $P = 29.16$ in. Hg. Operate computer according to instructions and find altimeter setting, *A.S.* = 29.90 in. Hg. *Note:* Black arrow is engraved on *H* scale at a point corresponding to station elevation, H_p, for Burlington).

7.2.4.1 Instructions for Preparation of Form WBAN 54–7.4

7.2.4.1.0 *Items To Be Entered.*—A single page of Form WBAN 54–7.4 relates to a single station temperature argument t_s falling within the temperature range desired in the pressure reduction table in extenso (see figs. 7.2.6 and 7.2.11). The heading of Form WBAN 54–7.4 requires the following five constant entries: (1) name of station, (2) geopotential of station, (3) t_s, (4) $P' \cdot r$, and (5) $\Delta P \cdot r$. In the columns of the form there are required the variable entries $P = (P' + \Delta P \cdot n)$ which represents the station pressure and $P_o = (P' \cdot r) + (\Delta P \cdot r) \cdot n$ which denotes the pressure reduced to sea level. These quantities are tabulated as functions of the printed side argument n which



Form WBAN 54-7.4

PRESSURE REDUCTION COMPUTATIONS

Calculation, by Successive Additions, of Pressure Reduced to Sea Level (P_o) for Reduction Table in Extenso, giving P_o as a Function of Station Temperature Argument (t_s) and Station Pressure (P).

(1) Name of Station **Burlington, Iowa** (2) Geopotential of station, H_{pg} = **214.0** gpm.

(3) t_s = **-20** °F.; (4) P'r = **961.25** (**mbs.**) Unit; (5) (ΔP·r) = **3.4828** (**mbs.**) Unit

Definitions: P' = minimum station pressure in table. ΔP = station-pressure increment in table. r = pressure reduction ratio, $10^{(K\,H_{pg}/T_{mv})}$, corresponding to H_{pg} and t_s.

No. of increment n	Station Pressure P=P'+ΔP·n	Calculation of sea-level pressure P_o=P·r=(P'r)+(ΔP·r)·n	No. of increment n	Station Pressure P=P'+ΔP·n	Calculation of sea-level pressure P_o=P·r=(P'r)+(ΔP·r)·n	No. of increment n	Station Pressure P=P'+ΔP·n	Calculation of sea-level pressure P_o=P·r=(P'r)+(ΔP·r)·n
0	P' = 27.60	P'r = 961.25	15	29.10	Previous sub-total 1013.4920	30	30.60	Previous sub-total 1065.7340
1	27.70	ΔP·r 3.4828 sub-total 964.7328	16	29.20	ΔP·r 3.4828 sub-total 1016.9748	31	30.70	ΔP·r 3.4828 sub-total 1069.2168
2	27.80	ΔP·r 3.4828 sub-total 968.2156	17	29.30	ΔP·r 3.4828 sub-total 1020.4576	32	30.80	ΔP·r 3.4828 sub-total 1072.6996
3	27.90	ΔP·r 3.4828 sub-total 971.6984	18	29.40	ΔP·r 3.4828 sub-total 1023.9404	33		ΔP·r sub-total
4	28.00	ΔP·r 3.4828 sub-total 975.1812	19	29.50	ΔP·r 3.4828 sub-total 1027.4232	34		ΔP·r sub-total
5	28.10	ΔP·r 3.4828 sub-total 978.6640	20	29.60	ΔP·r 3.4828 sub-total 1030.9060	35		ΔP·r sub-total
6	28.20	ΔP·r 3.4828 sub-total 982.1468	21	29.70	ΔP·r 3.4828 sub-total 1034.3888	36		ΔP·r sub-total
7	28.30	ΔP·r 3.4828 sub-total 985.6296	22	29.80	ΔP·r 3.4828 sub-total 1037.8716	37		ΔP·r sub-total
8	28.40	ΔP·r 3.4828 sub-total 989.1124	23	29.90	ΔP·r 3.4828 sub-total 1041.3544	38		ΔP·r sub-total
9	28.50	ΔP·r 3.4828 sub-total 992.5952	24	30.00	ΔP·r 3.4828 sub-total 1044.8372	39		ΔP·r sub-total
10	28.60	ΔP·r 3.4828 sub-total 996.0780	25	30.10	ΔP·r 3.4828 sub-total 1048.3200	40		ΔP·r sub-total
11	28.70	ΔP·r 3.4828 sub-total 999.5608	26	30.20	ΔP·r 3.4828 sub-total 1051.8028	41		ΔP·r sub-total
12	28.80	ΔP·r 3.4828 sub-total 1003.0436	27	30.30	ΔP·r 3.4828 sub-total 1055.2856	42		ΔP·r sub-total
13	28.90	ΔP·r 3.4828 sub-total 1006.5264	28	30.40	ΔP·r 3.4828 sub-total 1058.7684	43		ΔP·r sub-total
14	29.00	ΔP·r 3.4828 sub-total 1010.0092	29	30.50	ΔP·r 3.4828 sub-total 1062.2512	44		ΔP·r sub-total
15	29.10	ΔP·r 3.4828 sub-total 1013.4920	30	30.60	ΔP·r 3.4828 sub-total 1065.7340	45		ΔP·r sub-total

FIGURE 7.2.5(a). Form WBAN 54-7.4 showing sample of computation of sea-level pressure reduction table in extenso for temperature —20° F. at Burlington, Iowa.

Form WBAN 54- 7. 4

PRESSURE REDUCTION COMPUTATIONS

Calculation, by Successive Additions, of Pressure Reduced to Sea Level (P_o) for Reduction Table in Extenso, giving P_o as a Function of Station Temperature Argument (t_s) and Station Pressure (P).

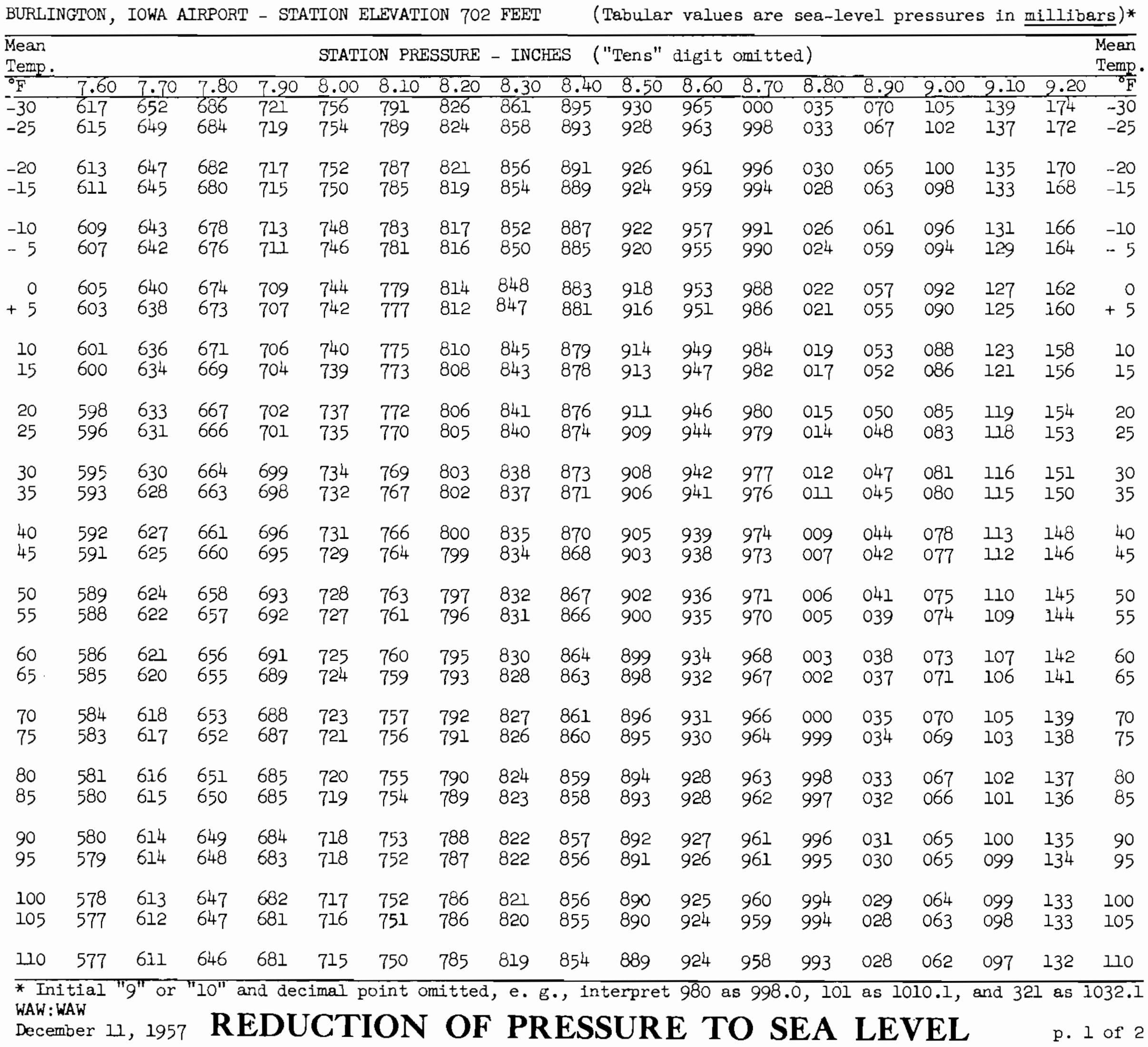
(1) Name of Station Burlington, Iowa (2) Geopotential of station, H_{pg} = 214.0 gpm.

(3) t_s = +50 °F.; (4) P'r = 958.90 (mbs.) Unit; (5) (ΔP·r) = 3.4743 (mbs.) Unit

Definitions: P' = minimum station pressure in table. ΔP = station-pressure increment in table. r = pressure reduction ratio, $10^{(K\,H_{pg}/T_{mv})}$, corresponding to H_{pg} and t_s.

No. of increment n	Station Pressure $P=P'+\Delta P\cdot n$	Calculation of sea-level pressure $P_o=P\cdot r=(P'r)+(\Delta P\cdot r)\cdot n$	No. of increment n	Station Pressure $P=P'+\Delta P\cdot n$	Calculation of sea-level pressure $P_o=P\cdot r=(P'r)+(\Delta P\cdot r)\cdot n$	No. of increment n	Station Pressure $P=P'+\Delta P\cdot n$	Calculation of sea-level pressure $P_o=P\cdot r=(P'r)+(\Delta P\cdot r)\cdot n$
0	P' 27.60	P'r = 958.90	15	29.10	Previous sub-total 1011.0145	30	30.60	Previous sub-total 1063.1290
1	27.70	ΔP·r 3.4743 sub-total 962.3743	16	29.20	ΔP·r 3.4743 sub-total 1014.4888	31	30.70	ΔP·r 3.4743 sub-total 1066.6033
2	27.80	ΔP·r 3.4743 sub-total 965.8486	17	29.30	ΔP·r 3.4743 sub-total 1017.9631	32	30.80	ΔP·r 3.4743 sub-total 1070.0776
3	27.90	ΔP·r 3.4743 sub-total 969.3229	18	29.40	ΔP·r 3.4743 sub-total 1021.4374	33		ΔP·r sub-total
4	28.00	ΔP·r 3.4743 sub-total 972.7972	19	29.50	ΔP·r 3.4743 sub-total 1024.9117	34		ΔP·r sub-total
5	28.10	ΔP·r 3.4743 sub-total 976.2715	20	29.60	ΔP·r 3.4743 sub-total 1028.3860	35		ΔP·r sub-total
6	28.20	ΔP·r 3.4743 sub-total 979.7458	21	29.70	ΔP·r 3.4743 sub-total 1031.8603	36		ΔP·r sub-total
7	28.30	ΔP·r 3.4743 sub-total 983.2201	22	29.80	ΔP·r 3.4743 sub-total 1035.3346	37		ΔP·r sub-total
8	28.40	ΔP·r 3.4743 sub-total 986.6944	23	29.90	ΔP·r 3.4743 sub-total 1038.8089	38		ΔP·r sub-total
9	28.50	ΔP·r 3.4743 sub-total 990.1687	24	30.00	ΔP·r 3.4743 sub-total 1042.2832	39		ΔP·r sub-total
10	28.60	ΔP·r 3.4743 sub-total 993.6430	25	30.10	ΔP·r 3.4743 sub-total 1045.7575	40		ΔP·r sub-total
11	28.70	ΔP·r 3.4743 sub-total 997.1173	26	30.20	ΔP·r 3.4743 sub-total 1049.2318	41		ΔP·r sub-total
12	28.80	ΔP·r 3.4743 sub-total 1000.5916	27	30.30	ΔP·r 3.4743 sub-total 1052.7061	42		ΔP·r sub-total
13	28.90	ΔP·r 3.4743 sub-total 1004.0659	28	30.40	ΔP·r 3.4743 sub-total 1056.1804	43		ΔP·r sub-total
14	29.00	ΔP·r 3.4743 sub-total 1007.5402	29	30.50	ΔP·r 3.4743 sub-total 1059.6547	44		ΔP·r sub-total
15	29.10	ΔP·r 3.4743 sub-total 1011.0145	30	30.60	ΔP·r 3.4743 sub-total 1063.1290	45		ΔP·r sub-total

FIGURE 7.2.5(b). Form WBAN 54-7.4 showing sample of computation of sea-level pressure reduction table in extenso for temperature +50° F. at Burlington, Iowa.



BURLINGTON, IOWA AIRPORT - STATION ELEVATION 702 FEET (Tabular values are sea-level pressures in millibars)*

Mean Temp.	STATION PRESSURE - INCHES ("Tens" digit omitted)																	Mean Temp.
°F	7.60	7.70	7.80	7.90	8.00	8.10	8.20	8.30	8.40	8.50	8.60	8.70	8.80	8.90	9.00	9.10	9.20	°F
-30	617	652	686	721	756	791	826	861	895	930	965	000	035	070	105	139	174	-30
-25	615	649	684	719	754	789	824	858	893	928	963	998	033	067	102	137	172	-25
-20	613	647	682	717	752	787	821	856	891	926	961	996	030	065	100	135	170	-20
-15	611	645	680	715	750	785	819	854	889	924	959	994	028	063	098	133	168	-15
-10	609	643	678	713	748	783	817	852	887	922	957	991	026	061	096	131	166	-10
- 5	607	642	676	711	746	781	816	850	885	920	955	990	024	059	094	129	164	- 5
0	605	640	674	709	744	779	814	848	883	918	953	988	022	057	092	127	162	0
+ 5	603	638	673	707	742	777	812	847	881	916	951	986	021	055	090	125	160	+ 5
10	601	636	671	706	740	775	810	845	879	914	949	984	019	053	088	123	158	10
15	600	634	669	704	739	773	808	843	878	913	947	982	017	052	086	121	156	15
20	598	633	667	702	737	772	806	841	876	911	946	980	015	050	085	119	154	20
25	596	631	666	701	735	770	805	840	874	909	944	979	014	048	083	118	153	25
30	595	630	664	699	734	769	803	838	873	908	942	977	012	047	081	116	151	30
35	593	628	663	698	732	767	802	837	871	906	941	976	011	045	080	115	150	35
40	592	627	661	696	731	766	800	835	870	905	939	974	009	044	078	113	148	40
45	591	625	660	695	729	764	799	834	868	903	938	973	007	042	077	112	146	45
50	589	624	658	693	728	763	797	832	867	902	936	971	006	041	075	110	145	50
55	588	622	657	692	727	761	796	831	866	900	935	970	005	039	074	109	144	55
60	586	621	656	691	725	760	795	830	864	899	934	968	003	038	073	107	142	60
65	585	620	655	689	724	759	793	828	863	898	932	967	002	037	071	106	141	65
70	584	618	653	688	723	757	792	827	861	896	931	966	000	035	070	105	139	70
75	583	617	652	687	721	756	791	826	860	895	930	964	999	034	069	103	138	75
80	581	616	651	685	720	755	790	824	859	894	928	963	998	033	067	102	137	80
85	580	615	650	685	719	754	789	823	858	893	928	962	997	032	066	101	136	85
90	580	614	649	684	718	753	788	822	857	892	927	961	996	031	065	100	135	90
95	579	614	648	683	718	752	787	822	856	891	926	961	995	030	065	099	134	95
100	578	613	647	682	717	752	786	821	856	890	925	960	994	029	064	099	133	100
105	577	612	647	681	716	751	786	820	855	890	924	959	994	028	063	098	133	105
110	577	611	646	681	715	750	785	819	854	889	924	958	993	028	062	097	132	110

* Initial "9" or "10" and decimal point omitted, e. g., interpret 980 as 998.0, 101 as 1010.1, and 321 as 1032.1

WAW:WAW
December 11, 1957 **REDUCTION OF PRESSURE TO SEA LEVEL** p. 1 of 2

FIGURE 7.2.6(a). Example of completed typewritten sea-level pressure reduction table in extenso for Burlington, Iowa (page 1 of 2).

may be considered to be the number of times the increment ΔP is applied to the minimum station pressure P' in expressing the station pressure argument P by successive addition.

7.2.4.1.1 *Heading Data.*—For each value of t_s on Form WBAN 54–7.2 for which entries have been made under "Column $P' \cdot r$" and "Column $(\Delta P \cdot r)$," transfer the corresponding data to Form WBAN 54–7.4, by entering them in the heading. Spaces are thus labeled: item (3) t_s; item (4) $P' \cdot r$; and item (5) $(\Delta P \cdot r)$. Indicate the units in each case.

7.2.4.1.2 *Station Pressure Data.*—Under the column headed "Station Pressure, $P = P' + \Delta P \cdot n$," enter the corresponding values of P, for the various printed values of n.

7.2.4.1.3 *Column Headed: "Calculation of Sea-Level Pressure".*—On the line for $n = 0$, under this column, enter the value of $P' \cdot r$, and on each line marked $\Delta P \cdot r$, enter the value of this quantity. Add the $\Delta P \cdot r$ value successively, entering subtotals for each number of increment n. These subtotals represent the pressure reduced to sea level corresponding to the station pressures listed in the second column, for the value of t_s indicated as item (3) on the form. *Check each tenth subtotal by successive addition of 10*

WAW:WAW
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REDUCTION OF PRESSURE TO SEA LEVEL

p. 2 of 2

Mean Temp.	STATION PRESSURE - INCHES ("Tens" digit omitted)																	Mean Temp.
°F	9.20	9.30	9.40	9.50	9.60	9.70	9.80	9.90	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	°F
-30	174	209	244	279	315	348	383	418	453	488	523	557	592	627	662	697	732	-30
-25	172	207	342	276	311	346	381	416	451	486	520	555	590	625	660	695	729	-25
-20	170	205	239	274	309	344	379	414	448	483	518	553	588	623	657	692	727	-20
-15	168	202	237	272	307	342	377	411	446	481	516	551	585	620	655	690	725	-15
-10	166	200	235	270	305	340	374	409	444	479	514	548	583	618	653	688	723	-10
- 5	164	194	233	268	303	338	372	407	442	477	512	546	581	616	651	686	721	- 5
0	162	196	231	266	301	336	370	405	440	475	510	544	579	614	649	684	718	0
+ 5	160	194	229	264	299	334	368	403	438	473	508	542	577	612	647	682	716	+ 5
10	158	193	227	262	297	332	367	401	436	471	506	540	575	610	645	680	714	10
15	156	191	226	260	295	330	365	399	434	469	504	539	573	608	643	678	712	15
20	154	189	224	259	293	328	363	398	432	467	502	537	572	606	641	676	711	20
25	153	187	222	257	292	326	361	396	431	466	500	535	570	605	639	654	719	25
30	151	186	221	255	290	325	360	394	429	464	499	533	568	603	638	672	707	30
35	150	184	219	254	289	323	358	393	428	462	497	532	567	601	636	671	706	35
40	148	183	217	252	287	322	356	391	426	461	495	530	565	600	634	669	704	40
45	146	181	216	251	285	320	355	390	424	459	494	529	563	598	633	668	702	45
50	145	180	214	249	284	319	353	388	423	458	492	527	562	597	631	666	701	50
55	144	178	213	248	282	317	352	387	421	456	491	526	560	595	630	665	699	55
60	142	177	212	246	281	316	351	385	420	455	489	524	559	594	628	663	698	60
65	141	175	210	245	280	314	349	384	419	453	488	523	558	592	627	662	696	65
70	139	174	209	243	278	313	348	382	417	452	487	521	556	591	625	660	695	70
75	138	173	207	242	277	312	346	381	416	451	485	520	555	589	624	659	694	75
80	137	171	206	241	276	310	345	380	414	449	484	519	553	588	623	657	692	80
85	136	171	205	240	275	309	344	379	413	448	483	518	552	587	622	656	691	85
90	135	170	204	239	274	308	343	378	412	447	482	517	551	586	621	655	690	90
95	134	169	204	238	273	308	342	377	412	446	481	516	551	585	620	655	689	95
100	133	168	203	237	272	307	341	376	411	446	480	515	550	584	619	654	688	100
105	133	167	202	237	271	306	341	375	410	445	480	514	549	584	618	653	688	105
110	·132	166	201	236	271	305	340	375	409	444	479	513	548	583	618	652	687	110

BURLINGTON, IOWA AIRPORT - STATION ELEVATION 702 FEET (Tabular values are sea-level pressures in millibars)*

FIGURE 7.2.6(b). Example of completed typewritten sea-level pressure reduction table in extenso for Burlington, Iowa (page 2 of 2).

$(\Delta P \cdot r)$ *to* $(P' \cdot r)$. This check is important in order to catch errors in addition.

Examples are shown in figs. 7.2.5(a) and (b), and 7.2.10(a) and (b).

If an adding or calculating machine is available, the need for Form WBAN 54–7.4 can be eliminated, and the entries of P_o can be directly written in the pressure reduction table, in extenso. The operation

$$P_o = P \cdot r = (P' \cdot r) + (\Delta P \cdot r)n$$

can be performed mechanically in either of two ways: In the first of the two methods r is used as a constant multiplier and P is used as a varying multiplicand which changes by steps equivalent to the increment ΔP. In the second of the two methods the quantity $(\Delta P \cdot r)$ is added successively to $P' \cdot r$.

7.2.5 Preparation of Pressure Reduction Table in Extenso

Fig. 7.2.11(a) to (d) illustrates a copy of such a table. The table is compiled by transferring the data from Form WBAN 54–7.4, each page of which yields P_o for a fixed value of t_s and various values of P.

7.2.6 Interpolation or Extrapolation in Tables in Extenso

By virtue of the basic relationship $P_o = P \cdot r$, linear interpolation or extrapolation with respect to station pressure, P, is valid.

Form WBAN 54-7.1 7.1, p. 1 of 2

PRESSURE REDUCTION COMPUTATIONS

Computation of (A) vapor pressure (e_s); (B) correction for plateau effect and local lapse rate anomaly, $F(t_s)$; and (C) mean virtual temperature (T_{mv}); as functions of station temperature argument, t_s.

1. Name of station Great Falls, Mont. 2. Latitude, ϕ = 47°29'N. Longitude, λ = 111° 21'W

3. Geopotential of station, H_{pg} = 1115.5 gpm.

4. Annual normal temperature of station, t_{sn} = 45.2 °F. (See Table 7.1.2 or 7.1.3 and Figure 7.2.0).

(A) Tabular values represent vapor pressure, e_s (in mb.) as functions of t_s.

No.	Name of Humidity Point-of-Departure Station	Station temperature argument, t_s, °Fahrenheit								
		-60°	-50°	-40°	-30°	-20°	-10°	0°	+10°	+20°
		mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
(1)	Havre, Mont.		0.05	0.10	0.19	0.34	0.60	1.0	1.8	2.9
(2)	Helena, Mont.		0.05	0.10	0.19	0.34	0.60	1.0	1.7	2.5
(3)										
(4)	Sum		0.10	0.20	0.38	0.68	1.20	2.0	3.5	5.4
(5)	Mean e_s		0.05	0.10	0.19	0.34	0.60	1.0	1.8	2.7

Use data from line (5) in obtaining line (b) of (C) below.

(B) Tabular values represent $F(t_s)$, the correction for plateau effect and local lapse rate anomaly, as a function of t_s. (See Instructions, section 7.2 of Manual.)

	Names of "point-of-departure stations" for $F(t_s)$	Station temperature argument, t_s, °Fahrenheit								
		-60°	-50°	-40°	-30°	-20°	-10°	0°	+10°	+20°
(a)	Havre, Mont.		34.6	31.8	28.5	25.0	21.3	17.3	13.0	8.6
(b)	Helena, Mont.		32.1	29.4	26.2	22.4	18.4	14.1	9.6	5.0
(c)	Kalispell, Mont.		28.3	26.8	24.8	22.5	19.7	16.6	13.0	9.0
(d)										
(e)	Algebraic sum		95.0	88.0	79.5	69.9	59.4	48.0	35.6	22.6
(f)	Mean = $F(t_s)$ for station		31.7	29.3	26.5	23.3	19.8	16.0	11.9	7.5

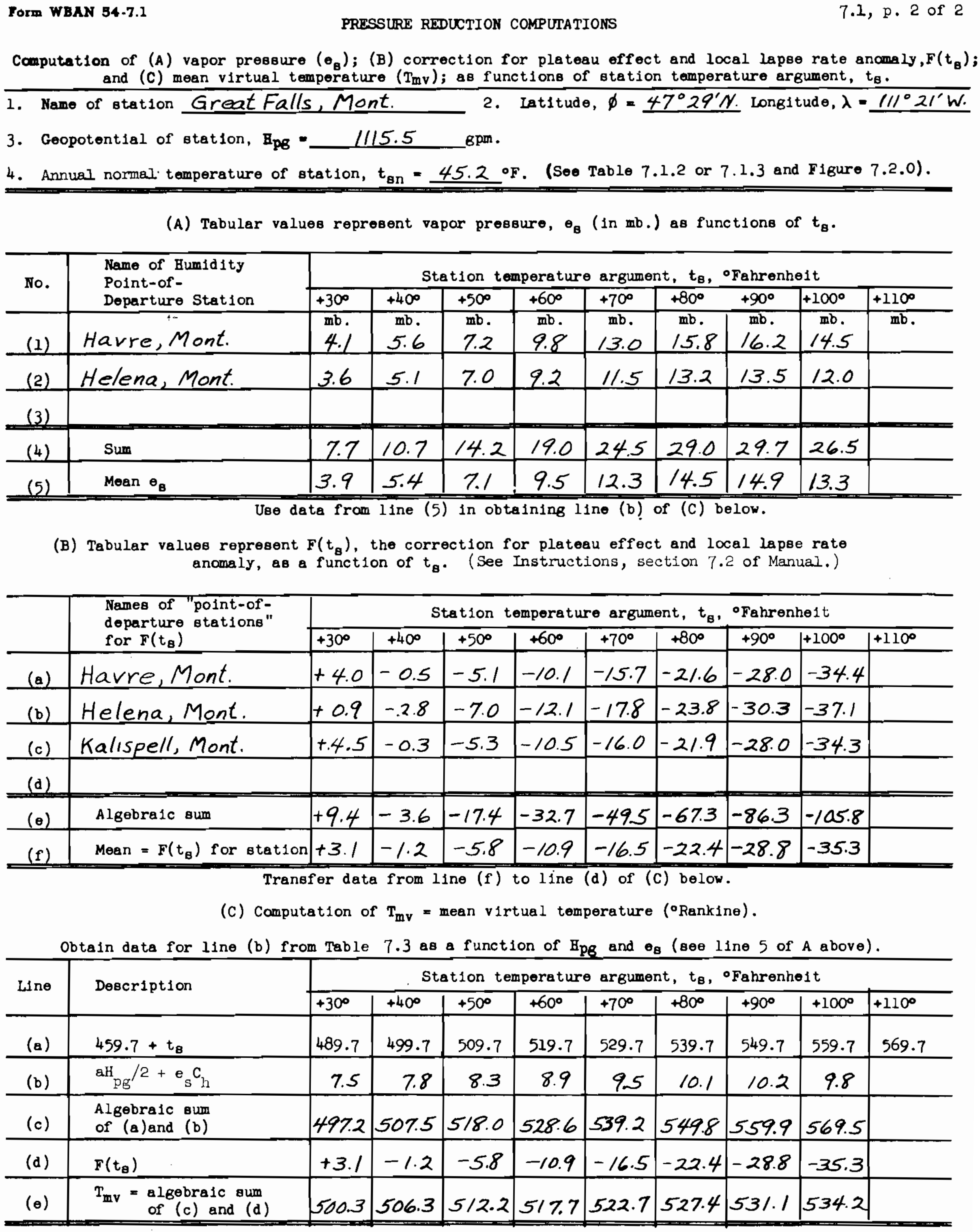
Transfer data from line (f) to line (d) of (C) below.

(C) Computation of T_{mv} = mean virtual temperature (°Rankine).

Obtain data for line (b) from Table 7.3 as a function of H_{pg} and e_s (see line 5 of A above).

Line	Description	Station temperature argument, t_s, °Fahrenheit								
		-60°	-50°	-40°	-30°	-20°	-10°	0°	+10°	+20°
(a)	459.7 + t_s	399.7	409.7	419.7	429.7	439.7	449.7	459.7	469.7	479.7
(b)	$aH_{pg}/2 + e_sC_h$		6.5	6.5	6.6	6.6	6.7	6.8	7.0	7.2
(c)	Algebraic sum of (a) and (b)		416.2	426.2	436.3	446.3	456.4	466.5	476.7	486.9
(d)	$F(t_s)$		31.7	29.3	26.5	23.3	19.8	16.0	11.9	7.5
(e)	T_{mv} = algebraic sum of (c) and (d)		447.9	455.5	462.8	469.6	476.2	482.5	488.6	494.4

FIGURE 7.2.7(a). Form WBAN 54–7.1 (page 1) showing sample entries for determination of T_{mv} as a function of t_s, used in pressure reduction computations for a station having an elevation H_p of more than 305 gpm. (Example for Great Falls, Montana.)



Form WBAN 54-7.1

7.1, p. 2 of 2

PRESSURE REDUCTION COMPUTATIONS

Computation of (A) vapor pressure (e_s); (B) correction for plateau effect and local lapse rate anomaly, $F(t_s)$; and (C) mean virtual temperature (T_{mv}); as functions of station temperature argument, t_s.

1. **Name** of station Great Falls, Mont.
2. Latitude, ϕ = 47°29'N. Longitude, λ = 111°21'W.
3. Geopotential of station, H_{pg} = 1115.5 gpm.
4. Annual normal temperature of station, t_{sn} = 45.2 °F. (See Table 7.1.2 or 7.1.3 and Figure 7.2.0).

(A) Tabular values represent vapor pressure, e_s (in mb.) as functions of t_s.

No.	Name of Humidity Point-of-Departure Station	Station temperature argument, t_s, °Fahrenheit								
		+30°	+40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°
		mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
(1)	Havre, Mont.	4.1	5.6	7.2	9.8	13.0	15.8	16.2	14.5	
(2)	Helena, Mont.	3.6	5.1	7.0	9.2	11.5	13.2	13.5	12.0	
(3)										
(4)	Sum	7.7	10.7	14.2	19.0	24.5	29.0	29.7	26.5	
(5)	Mean e_s	3.9	5.4	7.1	9.5	12.3	14.5	14.9	13.3	

Use data from line (5) in obtaining line (b) of (C) below.

(B) Tabular values represent $F(t_s)$, the correction for plateau effect and local lapse rate anomaly, as a function of t_s. (See Instructions, section 7.2 of Manual.)

	Names of "point-of-departure stations" for $F(t_s)$	Station temperature argument, t_s, °Fahrenheit								
		+30°	+40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°
(a)	Havre, Mont.	+ 4.0	- 0.5	-5.1	-10.1	-15.7	-21.6	-28.0	-34.4	
(b)	Helena, Mont.	+ 0.9	-2.8	-7.0	-12.1	-17.8	-23.8	-30.3	-37.1	
(c)	Kalispell, Mont.	+4.5	-0.3	-5.3	-10.5	-16.0	-21.9	-28.0	-34.3	
(d)										
(e)	Algebraic sum	+9.4	- 3.6	-17.4	-32.7	-49.5	-67.3	-86.3	-105.8	
(f)	Mean = $F(t_s)$ for station	+3.1	-1.2	-5.8	-10.9	-16.5	-22.4	-28.8	-35.3	

Transfer data from line (f) to line (d) of (C) below.

(C) Computation of T_{mv} = mean virtual temperature (°Rankine).

Obtain data for line (b) from Table 7.3 as a function of H_{pg} and e_s (see line 5 of A above).

Line	Description	Station temperature argument, t_s, °Fahrenheit								
		+30°	+40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°
(a)	$459.7 + t_s$	489.7	499.7	509.7	519.7	529.7	539.7	549.7	559.7	569.7
(b)	$aH_{pg}/2 + e_sC_h$	7.5	7.8	8.3	8.9	9.5	10.1	10.2	9.8	
(c)	Algebraic sum of (a) and (b)	497.2	507.5	518.0	528.6	539.2	549.8	559.9	569.5	
(d)	$F(t_s)$	+3.1	-1.2	-5.8	-10.9	-16.5	-22.4	-28.8	-35.3	
(e)	T_{mv} = algebraic sum of (c) and (d)	500.3	506.3	512.2	517.7	522.7	527.4	531.1	534.2	

FIGURE 7.2.7(b). Form WBAN 54–7.1 (page 2) showing sample entries for determination of T_{mv} as a function of t_s, used in pressure reduction computations for a station having an elevation H_p of more than 305 gpm. (Example for Great Falls, Montana.)

Form WBAN 54- 7. 2

7.2, p. 1 of 3

Tabulation and Calculation of Basic Data for Slide Rule and Table in Extenso for Reduction of Pressure to Sea Level

Station Great Falls, Mont. H_{pg} 1115.5 gpm Lat. 47°29′N. Long. 111°21′W.

P' = 24.60 in.Hg 1/ * = 833.052 mb. ΔP = 0.10 in.Hg = 3.38639 mb. 2/ *

t_s 3/ °F.	T_{mv} 4/ °R.	r 5/	P'·r *	(ΔP·r)*	t_s 3/ °F.	T_{mv} 4/ °R.	r 5/	P'·r *	(ΔP·r)*
-60					-30	462.8	1.15966	966.06	3.9271
-59					-29				
-58					-28			965.64	3.9254
-57					-27				
-56					-26			965.23	3.9237
-55					-25				
-54					-24			964.81	3.9220
-53					-23				
-52					-22			964.41	3.9204
-51					-21				
-50	447.9	1.16539	970.83	3.9465	-20	469.6	1.15718	963.99	3.9187
-49					-19				
-48			970.33	3.9444	-18			963.60	3.9171
-47					-17				
-46			969.84	3.9424	-16			963.21	3.9155
-45					-15				
-44			969.34	3.9404	-14			962.82	3.9139
-43					-13				
-42			968.85	3.9384	-12			962.43	3.9123
-41					-11				
-40	455.5	1.16241	968.35	3.9364	-10	476.2	1.15484	962.04	3.9107
-39					- 9				
-38			967.89	3.9345	- 8			961.68	3.9092
-37					- 7				
-36			967.43	3.9327	- 6			961.32	3.9078
-35					- 5				
-34			966.97	3.9308	- 4			960.95	3.9063
-33					- 3				
-32			966.51	3.9289	- 2			960.59	3.9048
-31					- 1				

1/ Minimum station pressure used in reduction table in extenso.
2/ Station-pressure increment in reduction table.
3/ Station temperature argument, t_s in °F.
4/ Mean virtual temperature of air column T_{mv} in °Rankine (°R).
5/ Pressure reduction ratio $r = 10^{(K\ H_{pg}/T_{mv})}$.
* Enter units. Fill in data marked * only if table in extenso is to be prepared.

FIGURE 7.2.8(a). Form WBAN 54–7.2 (page 1) showing sample entries of tabulation and calculation of basic data for slide rule and table in extenso for reduction of pressure to sea level. (Example for Great Falls, Montana.)

Form WBAN 54- 7.2 7.2, p. 2 of 3

Tabulation and Calculation of Basic Data for Slide Rule and Table in Extenso for Reduction of Pressure to Sea Level

Station Great Falls, Mont. H_{pg} 1115.5 gpm Lat. 47°29'N. Long. 111°21'W.

P' = 24.60 in.Hg = 833.052 mb.1/* ΔP = 0.10 in.Hg = 3.38639 mb.2/*

t_s 3/	T_{mv} 4/	r 5/	P'•r *	(ΔP•r)*	t_s 3/	T_{mv} 4/	r 5/	P'•r *	(ΔP•r)*
°F.	°R.				°F.	°R.			
0	482.5	1.15266	960.23	3.9034	30	500.3	1.14686	955.39	3.8837
1					31				
2			959.88	3.9020	32			955.09	3.8825
3					33				
4			959.54	3.9006	34			954.77	3.8812
5					35				
6			959.20	3.8992	36			954.46	3.8799
7					37				
8			958.86	3.8978	38			954.14	3.8786
9					39				
10	488.6	1.15061	958.52	3.8964	40	506.3	1.14499	953.84	3.8774
11					41				
12			958.21	3.8952	42			953.54	3.8762
13					43				
14			957.89	3.8939	44			953.24	3.8749
15					45				
16			957.58	3.8926	46			952.94	3.8737
17					47				
18			957.27	3.8913	48			952.64	3.8725
19					49				
20	494.4	1.14874	956.96	3.8901	50	512.2	1.14319	952.34	3.8713
21					51				
22			956.64	3.8888	52			952.07	3.8702
23					53				
24			956.33	3.8875	54			951.80	3.8691
25					55				
26			956.02	3.8863	56			951.54	3.8680
27					57				
28			955.71	3.8850	58			951.27	3.8670
29					59				

1/ Minimum station pressure used in reduction table in extenso.
2/ Station-pressure increment in reduction table.
3/ Station temperature argument, t_s in °F.
4/ Mean virtual temperature of air column T_{mv} in °Rankine (°R).
5/ Pressure reduction ratio $r = 10^{(K\ H_{pg}/T_{mv})}$.
* Enter units. Fill in data marked * only if table in extenso is to be prepared.

FIGURE 7.2.8(b). Form WBAN 54–7.2 (page 2) showing sample entries of tabulation and calculation of basic data for slide rule and table in extenso for reduction of pressure to sea level. (Example for Great Falls, Montana.)

Form WBAN 54- 7.2

7.2, p. 3 of 3

Tabulation and Calculation of Basic Data for Slide Rule and Table in Extenso for Reduction of Pressure to Sea Level

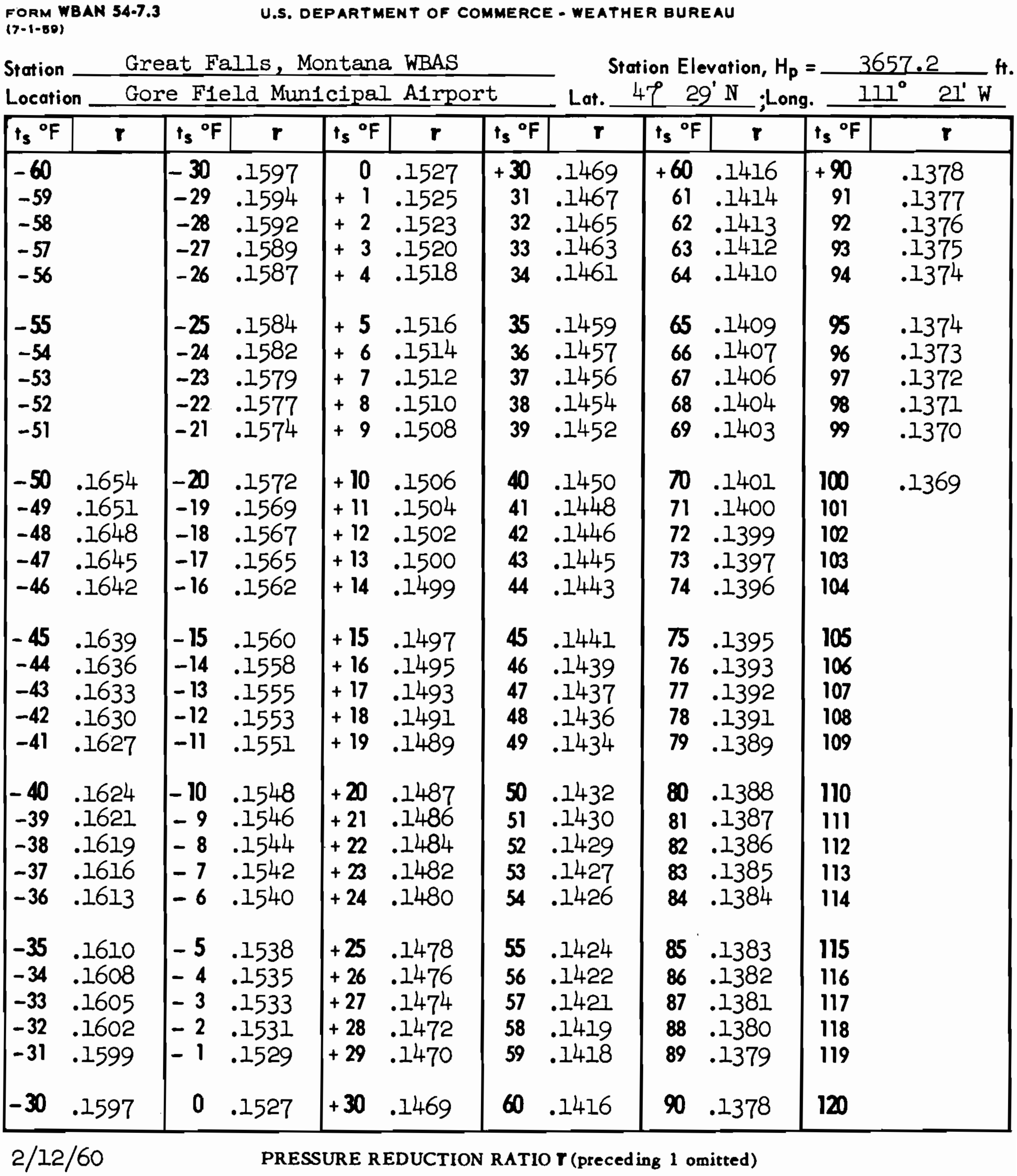
Station Great Falls, Mont. H_{pg} 1115.5 gpm. Lat. 47° 29′N. Long. 111° 21′ W.

P′ = 24.60 in Hg = 833.052 mb 1/* ΔP = 0.10 in. Hg = 3.38639 mb. 2/*

t_s 3/ °F.	T_{mv} 4/ °R.	r 5/	P′·r *	(ΔP·r)*	t_s 3/ °F.	T_{mv} 4/ °R.	r 5/	P′·r *	(ΔP·r)*
60	517.7	1.14159	951.00	3.8659	90	531.1	1.13778	947.83	3.8530
61					91				
62			950.76	3.8649	92			947.69	3.8524
63					93				
64			950.52	3.8639	94			947.55	3.8518
65					95				
66			950.28	3.8629	96			947.40	3.8512
67					97				
68			950.04	3.8619	98			947.26	3.8506
69					99				
70	522.7	1.14014	949.80	3.8610	100	534.2	1.13692	947.11	3.8501
71					101				
72			949.57	3.8600	102				
73					103				
74			949.35	3.8592	104				
75					105				
76			949.13	3.8582	106				
77					107				
78			948.91	3.8574	108				
79					109				
80	527.4	1.13881	948.69	3.8565	110				
81					111				
82			948.51	3.8557	112				
83					113				
84			948.35	3.8551	114				
85					115				
86			948.17	3.8544	116				
87					117				
88			948.00	3.8537	118				
89					119				

1/ Minimum station pressure used in reduction table in extenso.
2/ Station-pressure increment in reduction table.
3/ Station temperature argument, t_s in °F.
4/ Mean virtual temperature of air column T_{mv} in °Rankine (°R).
5/ Pressure reduction ratio $r = 10^{(K\,H_{pg}/T_{mv})}$.
* Enter units. Fill in data marked * only if table in extenso is to be prepared.

FIGURE 7.2.8(c). Form WBAN 54–7.2 (page 3) showing sample entries of tabulation and calculation of basic data for slide rule and table in extenso for reduction of pressure to sea-level. (Example for Great Falls, Montana.)



FORM WBAN 54-7.3
(7-1-59)

U.S. DEPARTMENT OF COMMERCE - WEATHER BUREAU

Station Great Falls, Montana WBAS
Station Elevation, H_p = 3657.2 ft.
Location Gore Field Municipal Airport
Lat. 47° 29' N ; Long. 111° 21' W

t_s °F	r	t_s °F	r	t_s °F	r	t_s °F	r	t_s °F	r	t_s °F	r
-60		-30	.1597	0	.1527	+30	.1469	+60	.1416	+90	.1378
-59		-29	.1594	+ 1	.1525	31	.1467	61	.1414	91	.1377
-58		-28	.1592	+ 2	.1523	32	.1465	62	.1413	92	.1376
-57		-27	.1589	+ 3	.1520	33	.1463	63	.1412	93	.1375
-56		-26	.1587	+ 4	.1518	34	.1461	64	.1410	94	.1374
-55		-25	.1584	+ 5	.1516	35	.1459	65	.1409	95	.1374
-54		-24	.1582	+ 6	.1514	36	.1457	66	.1407	96	.1373
-53		-23	.1579	+ 7	.1512	37	.1456	67	.1406	97	.1372
-52		-22	.1577	+ 8	.1510	38	.1454	68	.1404	98	.1371
-51		-21	.1574	+ 9	.1508	39	.1452	69	.1403	99	.1370
-50	.1654	-20	.1572	+10	.1506	40	.1450	70	.1401	100	.1369
-49	.1651	-19	.1569	+11	.1504	41	.1448	71	.1400	101	
-48	.1648	-18	.1567	+12	.1502	42	.1446	72	.1399	102	
-47	.1645	-17	.1565	+13	.1500	43	.1445	73	.1397	103	
-46	.1642	-16	.1562	+14	.1499	44	.1443	74	.1396	104	
-45	.1639	-15	.1560	+15	.1497	45	.1441	75	.1395	105	
-44	.1636	-14	.1558	+16	.1495	46	.1439	76	.1393	106	
-43	.1633	-13	.1555	+17	.1493	47	.1437	77	.1392	107	
-42	.1630	-12	.1553	+18	.1491	48	.1436	78	.1391	108	
-41	.1627	-11	.1551	+19	.1489	49	.1434	79	.1389	109	
-40	.1624	-10	.1548	+20	.1487	50	.1432	80	.1388	110	
-39	.1621	- 9	.1546	+21	.1486	51	.1430	81	.1387	111	
-38	.1619	- 8	.1544	+22	.1484	52	.1429	82	.1386	112	
-37	.1616	- 7	.1542	+23	.1482	53	.1427	83	.1385	113	
-36	.1613	- 6	.1540	+24	.1480	54	.1426	84	.1384	114	
-35	.1610	- 5	.1538	+25	.1478	55	.1424	85	.1383	115	
-34	.1608	- 4	.1535	+26	.1476	56	.1422	86	.1382	116	
-33	.1605	- 3	.1533	+27	.1474	57	.1421	87	.1381	117	
-32	.1602	- 2	.1531	+28	.1472	58	.1419	88	.1380	118	
-31	.1599	- 1	.1529	+29	.1470	59	.1418	89	.1379	119	
-30	.1597	0	.1527	+30	.1469	60	.1416	90	.1378	120	

2/12/60

PRESSURE REDUCTION RATIO r (preceding 1 omitted)

FIGURE 7.2.9. Form WBAN 54-7.3 showing sample entries of pressure reduction ratio (r). (Example for Great Falls, Montana.)

Form WBAN 54-7.4

PRESSURE REDUCTION COMPUTATIONS

Calculation, by Successive Additions, of Pressure Reduced to Sea Level (P_o) for Reduction Table in Extenso, giving P_o as a Function of Station Temperature Argument (t_s) and Station Pressure (P).

(1) Name of Station Great Falls, Montana (2) Geopotential of station, H_{pg} = 1115.5 gpm.

(3) t_s = −40 °F.; (4) P'r = 968.35 (mbs.) Unit; (5) (ΔP·r) = 3.9364 (mbs.) Unit

Definitions: P' = minimum station pressure in table. ΔP = station-pressure increment in table. r = pressure reduction ratio, $10^{(K\,H_{pg}/T_{mv})}$, corresponding to H_{pg} and t_s.

No. of increment n	Station Pressure P=P'+ΔP·n	Calculation of sea-level pressure P_o=P·r=(P'r)+(ΔP·r)·n	No. of increment n	Station Pressure P=P'+ΔP·n	Calculation of sea-level pressure P_o=P·r=(P'r)+(ΔP·r)·n	No. of increment n	Station Pressure P=P'+ΔP·n	Calculation of sea-level pressure P_o=P·r=(P'r)+(ΔP·r)·n
0	P' = 24.60	P'r = 968.35	15	26.10	Previous sub-total 1027.3960	30		Previous sub-total
1	24.70	ΔP·r 3.9364 sub-total 972.2864	16	26.20	ΔP·r 3.9364 sub-total 1031.3324	31		ΔP·r sub-total
2	24.80	ΔP·r 3.9364 sub-total 976.2228	17	26.30	ΔP·r 3.9364 sub-total 1035.2688	32		ΔP·r sub-total
3	24.90	ΔP·r 3.9364 sub-total 980.1592	18	26.40	ΔP·r 3.9364 sub-total 1039.2052	33		ΔP·r sub-total
4	25.00	ΔP·r 3.9364 sub-total 984.0956	19	26.50	ΔP·r 3.9364 sub-total 1043.1416	34		ΔP·r sub-total
5	25.10	ΔP·r 3.9364 sub-total 988.0320	20	26.60	ΔP·r 3.9364 sub-total 1047.0780	35		ΔP·r sub-total
6	25.20	ΔP·r 3.9364 sub-total 991.9684	21	26.70	ΔP·r 3.9364 sub-total 1051.0144	36		ΔP·r sub-total
7	25.30	ΔP·r 3.9364 sub-total 995.9048	22	26.80	ΔP·r 3.9364 sub-total 1054.9508	37		ΔP·r sub-total
8	25.40	ΔP·r 3.9364 sub-total 999.8412	23	26.90	ΔP·r 3.9364 sub-total 1058.8872	38		ΔP·r sub-total
9	25.50	ΔP·r 3.9364 sub-total 1003.7776	24	27.00	ΔP·r 3.9364 sub-total 1062.8236	39		ΔP·r sub-total
10	25.60	ΔP·r 3.9364 sub-total 1007.7140	25	27.10	ΔP·r 3.9364 sub-total 1066.7600	40		ΔP·r sub-total
11	25.70	ΔP·r 3.9364 sub-total 1011.6504	26	27.20	ΔP·r 3.9364 sub-total 1070.6964	41		ΔP·r sub-total
12	25.80	ΔP·r 3.9364 sub-total 1015.5868	27	27.30	ΔP·r 3.9364 sub-total 1074.6328	42		ΔP·r sub-total
13	25.90	ΔP·r 3.9364 sub-total 1019.5232	28	27.40	ΔP·r 3.9364 sub-total 1078.5692	43		ΔP·r sub-total
14	26.00	ΔP·r 3.9364 sub-total 1023.4596	29	27.50	ΔP·r 3.9364 sub-total 1082.5056	44		ΔP·r sub-total
15	26.10	ΔP·r 3.9364 sub-total 1027.3960	30	27.60	ΔP·r 3.9364 sub-total 1086.4420	45		ΔP·r sub-total

FIGURE 7.2.10(a). Form WBAN 54-7.4 showing sample of computation of sea-level pressure reduction table in extenso for temperature −40° F. at Great Falls, Montana.

Form WBAN 54-7.4

PRESSURE REDUCTION COMPUTATIONS

Calculation, by Successive Additions, of Pressure Reduced to Sea Level (P_o) for Reduction Table in Extenso, giving P_o as a Function of Station Temperature Argument (t_s) and Station Pressure (P).

(1) Name of Station Great Falls, Montana (2) Geopotential of station, H_{pg} = 1115.5 gpm.

(3) t_s = +50 °F.; (4) P'r = 952.34 (mb.) Unit; (5) (ΔP·r) = 3.8713 (mb.) Unit

Definitions: P' = minimum station pressure in table. ΔP = station-pressure increment in table. r = pressure reduction ratio, $10^{(K\ H_{pg}/T_{mv})}$, corresponding to H_{pg} and t_s.

No. of increment n	Station Pressure P=P'+ΔP·n	Calculation of sea-level pressure P_o=P·r=(P'r)+(ΔP·r)·n	No. of increment n	Station Pressure P=P'+ΔP·n	Calculation of sea-level pressure P_o=P·r=(P'r)+(ΔP·r)·n	No. of increment n	Station Pressure P=P'+ΔP·n	Calculation of sea-level pressure P_o=P·r=(P'r)+(ΔP·r)·n
0	P' = 24.60	P'r = 952.34	15	26.10	Previous sub-total 1010.4095	30		Previous sub-total
1	24.70	ΔP·r 3.8713 sub-total 956.2113	16	26.20	ΔP·r 3.8713 sub-total 1014.2808	31		ΔP·r sub-total
2	24.80	ΔP·r 3.8713 sub-total 960.0826	17	26.30	ΔP·r 3.8713 sub-total 1018.1521	32		ΔP·r sub-total
3	24.90	ΔP·r 3.8713 sub-total 963.9539	18	26.40	ΔP·r 3.8713 sub-total 1022.0234	33		ΔP·r sub-total
4	25.00	ΔP·r 3.8713 sub-total 967.8252	19	26.50	ΔP·r 3.8713 sub-total 1025.8947	34		ΔP·r sub-total
5	25.10	ΔP·r 3.8713 sub-total 971.6965	20	26.60	ΔP·r 3.8713 sub-total 1029.7660	35		ΔP·r sub-total
6	25.20	ΔP·r 3.8713 sub-total 975.5678	21	26.70	ΔP·r 3.8713 sub-total 1033.6373	36		ΔP·r sub-total
7	25.30	ΔP·r 3.8713 sub-total 979.4391	22	26.80	ΔP·r 3.8713 sub-total 1037.5086	37		ΔP·r sub-total
8	25.40	ΔP·r 3.8713 sub-total 983.3104	23	26.90	ΔP·r 3.8713 sub-total 1041.3799	38		ΔP·r sub-total
9	25.50	ΔP·r 3.8713 sub-total 987.1817	24	27.00	ΔP·r 3.8713 sub-total 1045.2512	39		ΔP·r sub-total
10	25.60	ΔP·r 3.8713 sub-total 991.0530	25	27.10	ΔP·r 3.8713 sub-total 1049.1225	40		ΔP·r sub-total
11	25.70	ΔP·r 3.8713 sub-total 994.9243	26	27.20	ΔP·r 3.8713 sub-total 1052.9938	41		ΔP·r sub-total
12	25.80	ΔP·r 3.8713 sub-total 998.7956	27	27.30	ΔP·r 3.8713 sub-total 1056.8651	42		ΔP·r sub-total
13	25.90	ΔP·r 3.8713 sub-total 1002.6669	28	27.40	ΔP·r 3.8713 sub-total 1060.7364	43		ΔP·r sub-total
14	26.00	ΔP·r 3.8713 sub-total 1006.5382	29	27.50	ΔP·r 3.8713 sub-total 1064.6077	44		ΔP·r sub-total
15	26.10	ΔP·r 3.8713 sub-total 1010.4095	30	27.60	ΔP·r 3.8713 sub-total 1068.4790	45		ΔP·r sub-total

FIGURE 7.2.10(b). Form WBAN 54-7.4 showing sample of computation of sea-level pressure reduction table in extenso for temperature +50° F. at Great Falls, Montana.

GREAT FALLS, MONTANA AIRPORT - STA. ELEV. 3657.2 FEET (Tabular values are sea-level pressures in <u>millibars</u>)*

Mean Temp.	STATION PRESSURE - INCHES ("Tens" digit omitted)																	Mean Temp.
°F.	4.60	4.70	4.80	4.90	5.00	5.10	5.20	5.30	5.40	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	°F.
-50	708	748	787	827	866	906	945	985	024	063	103	142	182	221	261	300	340	-50
-48	703	743	782	822	861	901	940	979	019	058	098	137	177	216	256	295	334	-48
-46	698	738	777	817	856	895	935	974	014	053	093	132	171	211	250	290	329	-46
-44	693	733	772	812	851	890	930	969	009	048	087	127	166	206	245	284	324	-44
-42	688	728	767	807	846	885	925	964	004	043	082	122	161	200	240	279	319	-42
-40	683	723	762	802	841	880	920	959	998	038	077	117	156	195	235	274	313	-40
-38	679	718	758	797	836	876	915	954	994	033	072	112	151	190	230	269	308	-38
-36	674	714	753	792	832	871	910	950	989	028	068	107	146	186	225	264	304	-36
-34	670	709	748	788	827	866	906	945	984	023	063	102	141	181	220	259	299	-34
-32	665	704	744	783	822	862	901	940	979	019	058	097	137	176	215	254	294	-32
-30	661	700	739	778	818	857	896	935	975	014	053	093	132	171	210	250	289	-30
-28	656	696	735	774	813	853	892	931	970	010	049	088	127	167	206	245	284	-28
-26	652	692	731	770	809	849	888	927	966	005	045	084	123	162	202	241	280	-26
-24	648	687	727	766	805	844	883	923	962	001	040	080	119	158	197	236	276	-24
-22	644	683	722	762	801	840	879	918	958	997	036	075	115	154	193	232	271	-22
-20	640	679	718	757	797	836	875	914	953	993	032	071	110	149	189	228	267	-20
-18	636	675	714	754	793	832	871	910	949	989	028	067	106	145	184	224	263	-18
-16	632	671	710	750	789	828	867	906	945	984	024	063	102	141	180	219	259	-16
-14	628	667	707	746	785	824	863	902	941	980	020	059	098	137	176	215	254	-14
-12	624	663	703	742	781	820	859	898	937	976	016	055	094	133	172	211	250	-12
-10	620	660	699	738	777	816	855	894	933	972	011	051	090	129	168	207	246	-10
- 8	617	656	695	734	773	812	851	890	929	969	008	047	086	125	164	203	242	- 8
- 6	613	652	691	730	769	809	848	887	926	965	004	043	082	121	160	199	238	- 6
- 4	609	649	688	727	766	805	844	883	922	961	000	039	078	117	156	195	235	- 4
- 2	606	645	684	723	762	801	840	879	918	957	996	035	075	114	153	192	231	- 2
0	602	641	680	719	758	797	836	876	915	954	993	032	071	110	149	188	227	0
+ 2	599	638	677	716	755	794	833	872	911	950	989	028	067	106	145	184	223	+ 2
4	595	634	673	712	751	790	829	868	907	946	985	024	063	103	142	181	220	4
6	592	631	670	709	748	787	826	865	904	943	982	021	060	099	138	177	216	6
8	589	628	667	706	745	783	822	861	900	939	978	017	056	095	134	173	212	8
10	585	624	663	702	741	780	819	858	897	936	975	014	053	092	131	170	209	10
12	582	621	660	699	738	777	816	855	894	933	972	011	050	088	127	166	205	12
14	579	618	657	696	735	774	813	851	890	929	968	007	046	085	124	163	202	14
16	576	615	654	693	732	770	809	848	887	926	965	004	043	082	121	160	199	16
18	573	612	650	689	728	767	806	845	884	923	962	001	040	079	117	156	195	18
20	570	609	647	686	725	764	803	842	881	920	959	998	036	075	114	153	192	20

*Initial "9" or "10" and decimal point omitted, e.g., interpret 980 as 998.0, 101 as 1010.1 and 321 as 1032.1

WAW:Da
Jan. 20, 1960

REDUCTION OF PRESSURE TO SEA LEVEL

p. 1 of 4

FIGURE 7.2.11(a). Example of completed typewritten sea-level pressure reduction table in extenso for Great Falls, Montana (page 1 of 4).

In case station pressures should be observed outside the range for which a table has been prepared, the sea-level pressure, P_o, may be determined by linear extrapolation.

Example:

Station: Great Falls, Montana
Given: Observed station pressure, $P = 24.35$ in. Hg, and $t_s = -40°$ F. Referring to fig. 7.2.11(a) which shows page 1 of the Pressure Reduction Table for Great Falls, it is seen that the minimum station pressure, P', is 24.60 in. Hg. The corresponding sea-level pressure, P_o, on the line for $t_s = -40°$ F. is (9)68.3 mb. Since $P - P' = -0.25$ in. Hg, one may determine from the table the sea-level pressure difference corresponding to this station pressure difference, as between $P = 24.60$ in. Hg and $P = 24.85$ in. Hg. The difference in P_o is found to be (9)68.3 mb. — (9)78.2 mb. $= -9.9$ mb. The sea-level pressure, P_o, corre-

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Jan. 20, 1960

REDUCTION OF PRESSURE TO SEA LEVEL

p. 2 of 4

Mean Temp.	STATION PRESSURE - INCHES ("Tens" digit omitted)																	Mean Temp.
°F.	6.20	6.30	6.40	6.50	6.60	6.70	6.80	6.90	7.00	7.10	7.20	7.30	7.40	7.50	7.60	7.70	7.80	°F.
-50	340	379	419	458	498	537	577	616	655	695	734	774	813	853	892	932	971	-50
-48	334	374	413	453	492	532	571	611	650	689	729	768	808	847	887	926	966	-48
-46	329	369	408	447	487	526	566	605	645	684	723	763	802	842	881	921	960	-46
-44	324	363	403	442	481	521	560	600	639	678	718	757	797	836	876	915	954	-44
-42	319	358	397	437	476	516	555	594	634	673	712	752	791	831	870	909	949	-42
-40	313	353	392	431	471	510	549	589	628	668	707	746	786	825	864	904	943	-40
-38	308	348	387	426	466	505	544	584	623	663	702	741	781	820	859	899	938	-38
-36	304	343	382	422	461	500	539	579	618	657	697	736	775	815	854	893	933	-36
-34	299	338	377	417	456	495	534	574	613	652	692	731	770	810	849	888	928	-34
-32	294	333	372	412	451	490	530	569	608	647	687	726	765	805	844	883	922	-32
-30	289	328	367	407	446	485	525	564	603	642	682	721	760	799	839	878	917	-30
-28	284	324	363	402	441	481	520	559	598	638	677	716	756	795	834	873	913	-28
-26	280	319	359	398	437	476	516	555	594	633	672	712	751	790	829	869	908	-26
-24	276	315	354	393	433	472	511	550	589	629	668	707	746	786	825	864	903	-24
-22	271	311	350	389	428	467	507	546	585	624	663	703	742	781	820	859	899	-22
-20	267	306	345	384	424	463	502	541	580	620	659	698	737	776	815	855	894	-20
-18	263	302	341	380	419	459	498	537	576	615	654	694	733	772	811	850	889	-18
-16	259	298	337	376	415	454	493	533	572	611	650	689	728	768	807	846	885	-16
-14	254	294	333	372	411	450	489	528	568	607	646	685	724	763	802	842	881	-14
-12	250	289	329	368	407	446	485	524	563	602	642	681	720	759	798	837	876	-12
-10	246	285	324	363	403	442	481	520	559	598	637	676	715	755	794	833	872	-10
- 8	242	281	320	360	399	438	477	516	555	594	633	672	711	750	790	829	868	- 8
- 6	238	277	317	356	395	434	473	512	551	590	629	668	707	746	786	825	864	- 6
- 4	235	274	313	352	391	430	469	508	547	586	625	664	703	742	781	820	860	- 4
- 2	231	270	309	348	387	426	465	504	543	582	621	660	699	738	777	816	855	- 2
0	227	266	305	344	383	422	461	500	539	578	617	656	695	734	773	812	851	0
+ 2	223	262	301	340	379	418	457	496	535	574	613	652	691	730	769	808	847	+ 2
4	220	259	298	337	376	415	454	493	532	571	610	649	688	727	766	805	844	4
6	216	255	294	333	372	411	450	489	528	567	606	645	684	723	762	801	840	6
8	212	251	290	329	368	407	446	485	524	563	602	641	680	719	758	797	836	8
10	209	248	287	325	364	403	442	481	520	559	598	637	676	715	754	793	832	10
12	205	244	283	322	361	400	439	478	517	556	595	634	673	712	751	790	829	12
14	202	241	280	319	358	397	436	475	513	552	591	630	669	708	747	786	825	14
16	199	238	277	315	354	393	432	471	510	549	588	627	666	705	744	783	821	16
18	195	234	273	312	351	390	429	468	507	546	584	623	662	701	740	779	818	18
20	192	231	270	309	348	387	425	464	503	542	581	620	659	698	737	776	814	20

GREAT FALLS, MONTANA AIRPORT - STA. ELEV. 3657.2 FEET (Tabular values are sea-level pressures in millibars)*

FIGURE 7.2.11(b). Example of completed typewritten sea-level pressure reduction table in extenso for Great Falls, Montana (page 2 of 4).

sponding to $P = 24.35$ in. Hg, and $t_s = -40°$ F. is thus

$$P_o = (9)68.3 \text{ mb.} - 9.9 \text{ mb.} = (9)58.4 \text{ mb.}$$

Since linear interpolation with respect to t_s is not strictly accurate, the interval of the argument t_s used in preparing the table must be taken sufficiently small in order that the error which results from linear interpolation may be less than any prescribed tolerance such as 0.003 in. Hg. Refer to sec. 7.2.2.1.4 for instructions regarding the choice of the interval of t_s.

7.2.7 Use of Pressure-Reduction Computer

Fig. 7.2.4 shows one face of the "Sea-Level Pressure Reduction and Altimeter-Setting Computer." Instructions are printed on its

GREAT FALLS, MONTANA AIRPORT - STA. ELEV. 3657.2 FEET (Tabular values are sea-level pressures in <u>millibars</u>)*

Mean Temp.	STATION PRESSURE - INCHES ("Tens" digit omitted)																	Mean Temp.
°F.	4.60	4.70	4.80	4.90	5.00	5.10	5.20	5.30	5.40	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	°F.
20	570	609	647	686	725	764	803	842	881	920	959	998	036	075	114	153	192	20
22	566	605	644	683	722	761	800	839	878	916	955	994	033	072	111	150	189	22
24	563	602	641	680	719	758	797	835	874	913	952	991	030	069	108	146	185	24
26	560	599	638	677	716	754	793	832	871	910	949	988	027	065	104	143	182	26
28	557	596	635	674	713	751	790	829	868	907	946	984	023	062	101	140	179	28
30	554	593	632	670	709	748	787	826	865	903	942	981	020	059	098	136	175	30
32	551	590	629	667	706	745	784	823	861	900	939	978	017	056	094	133	172	32
34	548	586	625	664	703	742	781	819	858	897	936	975	013	052	091	130	169	34
36	545	583	622	661	700	739	777	816	855	894	933	971	010	049	088	127	165	36
38	541	580	619	658	697	735	774	813	852	891	929	968	007	046	084	123	162	38
40	538	577	616	655	693	732	771	810	849	887	926	965	004	042	081	120	159	40
42	535	574	613	652	690	729	768	807	845	884	923	962	000	039	078	117	156	42
44	532	571	610	649	687	726	765	804	842	881	920	959	997	036	075	114	152	44
46	529	568	607	646	684	723	762	801	839	878	917	955	994	033	072	110	149	46
48	526	565	604	643	681	720	759	797	836	875	914	952	991	030	069	107	146	48
50	523	562	601	640	678	717	756	794	833	872	911	949	988	027	065	104	143	50
52	521	559	598	637	676	714	753	792	830	869	908	946	985	024	063	101	140	52
54	518	557	595	634	673	711	750	789	828	866	905	944	982	021	060	098	137	54
56	515	554	593	631	670	709	747	786	825	864	902	941	980	018	057	096	134	56
58	513	551	590	629	667	706	745	783	822	861	899	938	977	015	054	093	131	58
60	510	549	587	626	665	703	742	781	819	858	897	935	974	013	051	090	129	60
62	508	546	585	624	662	701	740	778	817	855	894	933	971	010	049	087	126	62
64	505	544	582	621	660	698	737	776	814	853	892	930	969	008	046	085	123	64
66	503	541	580	619	657	696	735	773	812	850	889	928	966	005	044	082	121	66
68	500	539	578	616	655	693	732	771	809	848	887	925	964	002	041	080	118	68
70	498	537	575	614	652	691	730	768	807	845	884	923	961	000	038	077	116	70
72	496	534	573	611	650	689	727	766	805	843	882	920	959	998	036	075	113	72
74	494	532	571	609	648	686	725	764	802	841	879	918	957	995	034	072	111	74
76	491	530	568	607	646	684	723	761	800	839	877	916	954	993	031	070	109	76
78	489	528	566	605	643	682	721	759	798	836	875	913	952	991	029	068	106	78
80	487	525	564	603	641	680	718	757	795	834	873	911	950	988	027	065	104	80
82	485	524	562	601	639	678	716	755	794	832	871	909	948	986	025	063	102	82
84	483	522	561	599	638	676	715	753	792	830	869	908	946	985	023	062	100	84
86	482	520	559	597	636	674	713	752	790	829	867	906	944	983	021	060	098	86
88	480	519	557	596	634	673	711	750	788	827	865	904	942	981	020	058	097	88
90	478	517	555	594	632	671	709	748	787	825	864	902	941	979	018	056	095	90
92	477	515	554	592	631	669	708	747	785	824	862	901	939	978	016	055	093	92
94	475	514	552	591	630	668	707	745	784	822	861	899	938	976	015	053	092	94
96	474	512	551	589	628	667	705	744	782	821	859	898	936	975	013	052	090	96
98	473	511	550	588	627	665	704	742	781	819	858	896	935	973	012	050	089	98
100	471	510	548	587	625	664	702	741	779	818	856	895	933	972	010	049	087	100

WAW:Da
Jan. 20, 1960

REDUCTION OF PRESSURE TO SEA LEVEL

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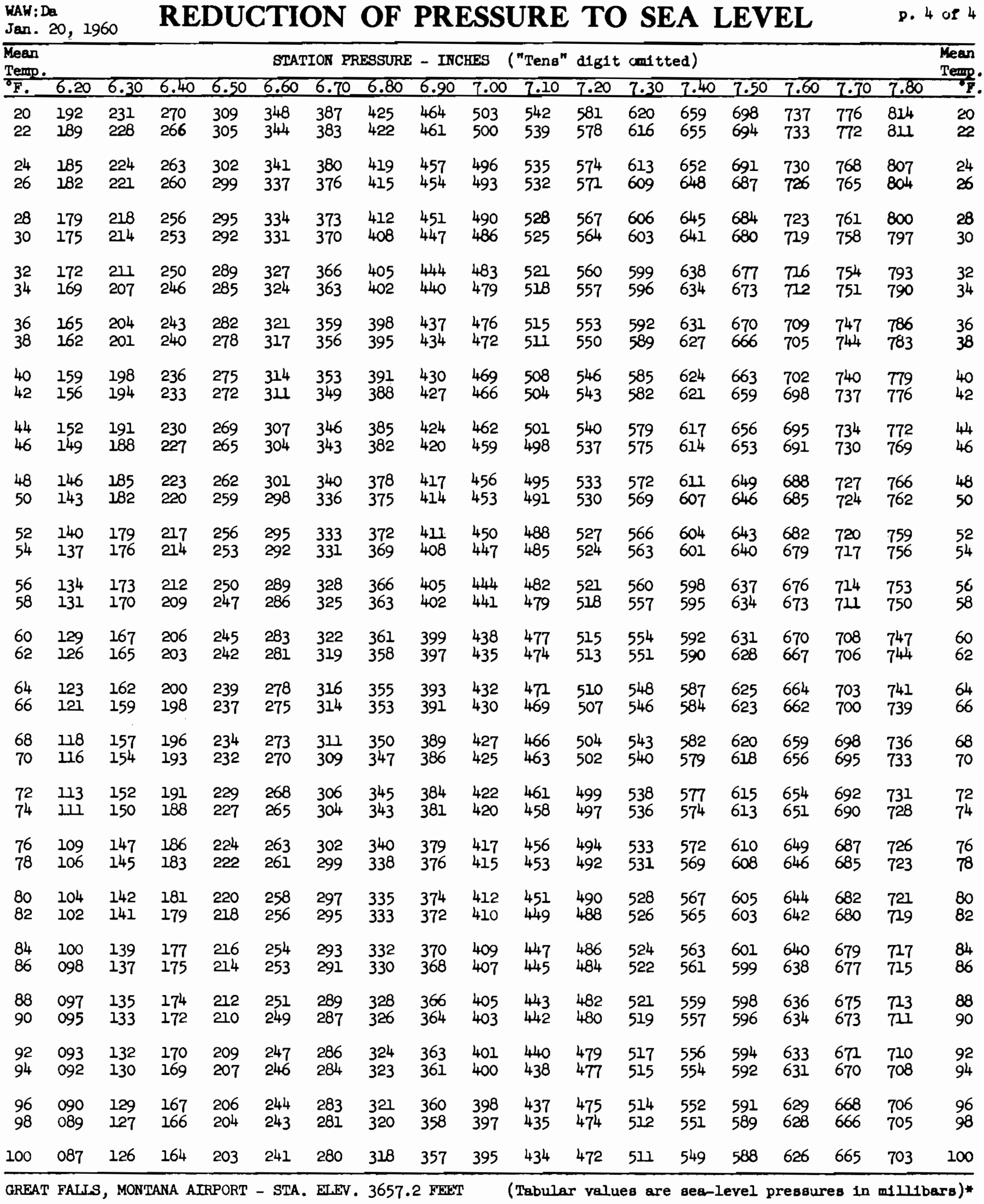
FIGURE 7.2.11(c). Example of completed typewritten sea-level pressure reduction table in extenso for Great Falls, Montana (page 3 of 4).



WAW:Da
Jan. 20, 1960

REDUCTION OF PRESSURE TO SEA LEVEL

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Mean Temp.	STATION PRESSURE - INCHES ("Tens" digit omitted)																	Mean Temp.
°F.	6.20	6.30	6.40	6.50	6.60	6.70	6.80	6.90	7.00	7.10	7.20	7.30	7.40	7.50	7.60	7.70	7.80	°F.
20	192	231	270	309	348	387	425	464	503	542	581	620	659	698	737	776	814	20
22	189	228	266	305	344	383	422	461	500	539	578	616	655	694	733	772	811	22
24	185	224	263	302	341	380	419	457	496	535	574	613	652	691	730	768	807	24
26	182	221	260	299	337	376	415	454	493	532	571	609	648	687	726	765	804	26
28	179	218	256	295	334	373	412	451	490	528	567	606	645	684	723	761	800	28
30	175	214	253	292	331	370	408	447	486	525	564	603	641	680	719	758	797	30
32	172	211	250	289	327	366	405	444	483	521	560	599	638	677	716	754	793	32
34	169	207	246	285	324	363	402	440	479	518	557	596	634	673	712	751	790	34
36	165	204	243	282	321	359	398	437	476	515	553	592	631	670	709	747	786	36
38	162	201	240	278	317	356	395	434	472	511	550	589	627	666	705	744	783	38
40	159	198	236	275	314	353	391	430	469	508	546	585	624	663	702	740	779	40
42	156	194	233	272	311	349	388	427	466	504	543	582	621	659	698	737	776	42
44	152	191	230	269	307	346	385	424	462	501	540	579	617	656	695	734	772	44
46	149	188	227	265	304	343	382	420	459	498	537	575	614	653	691	730	769	46
48	146	185	223	262	301	340	378	417	456	495	533	572	611	649	688	727	766	48
50	143	182	220	259	298	336	375	414	453	491	530	569	607	646	685	724	762	50
52	140	179	217	256	295	333	372	411	450	488	527	566	604	643	682	720	759	52
54	137	176	214	253	292	331	369	408	447	485	524	563	601	640	679	717	756	54
56	134	173	212	250	289	328	366	405	444	482	521	560	598	637	676	714	753	56
58	131	170	209	247	286	325	363	402	441	479	518	557	595	634	673	711	750	58
60	129	167	206	245	283	322	361	399	438	477	515	554	592	631	670	708	747	60
62	126	165	203	242	281	319	358	397	435	474	513	551	590	628	667	706	744	62
64	123	162	200	239	278	316	355	393	432	471	510	548	587	625	664	703	741	64
66	121	159	198	237	275	314	353	391	430	469	507	546	584	623	662	700	739	66
68	118	157	196	234	273	311	350	389	427	466	504	543	582	620	659	698	736	68
70	116	154	193	232	270	309	347	386	425	463	502	540	579	618	656	695	733	70
72	113	152	191	229	268	306	345	384	422	461	499	538	577	615	654	692	731	72
74	111	150	188	227	265	304	343	381	420	458	497	536	574	613	651	690	728	74
76	109	147	186	224	263	302	340	379	417	456	494	533	572	610	649	687	726	76
78	106	145	183	222	261	299	338	376	415	453	492	531	569	608	646	685	723	78
80	104	142	181	220	258	297	335	374	412	451	490	528	567	605	644	682	721	80
82	102	141	179	218	256	295	333	372	410	449	488	526	565	603	642	680	719	82
84	100	139	177	216	254	293	332	370	409	447	486	524	563	601	640	679	717	84
86	098	137	175	214	253	291	330	368	407	445	484	522	561	599	638	677	715	86
88	097	135	174	212	251	289	328	366	405	443	482	521	559	598	636	675	713	88
90	095	133	172	210	249	287	326	364	403	442	480	519	557	596	634	673	711	90
92	093	132	170	209	247	286	324	363	401	440	479	517	556	594	633	671	710	92
94	092	130	169	207	246	284	323	361	400	438	477	515	554	592	631	670	708	94
96	090	129	167	206	244	283	321	360	398	437	475	514	552	591	629	668	706	96
98	089	127	166	204	243	281	320	358	397	435	474	512	551	589	628	666	705	98
100	087	126	164	203	241	280	318	357	395	434	472	511	549	588	626	665	703	100

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FIGURE 7.2.11 (d). Example of completed typewritten sea-level pressure reduction table in extenso for Great Falls, Montana (page 4 of 4).

face. The factor r corresponding to t_s is determined from Form WBAN 54–7.3. The use of the slide rule is to perform the multiplication $P_o = P \cdot r$. To conserve space on the computer, the initial figure 1 preceding the decimal point is omitted; thus if $r = 1.2000$, the r scale on the computer has just the printed decimal part .2000.

Whenever necessary, the pressure reduced to sea level (P_o) may be computed by long-hand multiplication of P and r. This may be necessary if the observed value of P falls outside the range of the P-scale printed on the computer.

Example I

Station: Burlington, Iowa
Given: $P = 27.488$ in. Hg $= 930.9$ mb., and
$t_s = -10°$ F.
From completed Form WBAN 54–7.3 (fig. 7.2.3),
$r = 1.0280$
$P_o = P \cdot r = 1.0280 \times 27.488$ in. Hg $= 28.258$ in. Hg
$= 1.0280 \times 930.9$ mb. $= 957.0$ mb.

Example II

Station: Burlington, Iowa
Given: $P = 30.963$ in. Hg $= 1048.5$ mb., and
$t_s = 65°$ F.
From completed Form WBAN 54–7.3 (fig. 7.2.3),
$r = 1.0255$
$P_o = P \cdot r = 1.0255 \times 30.963$ in. Hg $= 31.753$ in. Hg
$= 1.0255 \times 1048.5$ mb. $= 1075.2$ mb.

Example III

Station: Great Falls, Montana
Given: $P = 24.439$ in. Hg $= 827.6$ mb., and
$t_s = 10°$ F.
From completed Form WBAN 54–7.3 (fig. 7.2.9),
$r = 1.1506$
$P_o = P \cdot r = 1.1506 \times 24.439$ in. Hg $= 28.120$ in. Hg
$= 1.1506 \times 827.6$ mb. $= 952.2$ mb.

Example IV

Station: Great Falls, Montana
Given: $P = 27.912$ in. Hg $= 945.2$ mb., and
$t_s = 70°$ F.
From completed Form WBAN 54–7.3 (fig. 7.2.9),
$r = 1.1401$
$P_o = P \cdot r = 1.1401 \times 27.912$ in. Hg $= 31.822$ in. Hg
$= 1.1401 \times 945.2$ mb $= 1077.6$ mb.

7.3 REDUCTION OF PRESSURE DOWNWARD OR UPWARD TO ANY LEVEL IN GENERAL

7.3.0 General Information

Let us envisage any vertical column of atmosphere fixed with reference to the earth, where the base and top of the column are at known geopotentials. If one also knew the mean virtual temperature of the air column together with the pressure at either the base or the top of the column, one could compute the pressure at the other terminus of the column. This may be accomplished on the basis of the hypsometric equation already specified in sec. 7.0.2, by making use of the data given in Table 7.5. Accordingly, reduction of pressure may be carried out either downward or upward, and it is not necessary to restrict the base of the column to sea level where the geopotential is zero (0).

It will be recalled that we wrote the hypsometric equation (sec. 7.0.2) as $P_o = P \cdot r$, where $r = 10^{KH_{pg}/T_{mv}}$.

In order to permit the use of this equation for any air column fixed with respect to the earth, the symbols must be interpreted as follows:

(A) P = pressure at the top of the air column;

(B) P_o = pressure at the base of the air column;

(C) T_{mv} = mean virtual temperature of the air column (in °R.);

(D) H_{pg} = (geopotential of the top of the air column *minus* geopotential of the base of the air column); that is, the vertical extent (depth) of the air column, in geopotential meters.

In the evaluation of the hypsometric constant ($K = 0.0266895°$ R./gpm) used in preparing Table 7.5, it was assumed that the apparent molecular weight for dry air is 28.966 grams per mole, which is considered normal for the atmosphere at sea level. Owing to mixing processes in the free atmosphere, this quantity is likely to be valid for dry air up to an altitude of about 75,000 gpm, at least to within the probable relative errors of pressure and temperature observations. At altitudes above 90,000 m. where dissociation of certain atmospheric molecular constitutents occurs, different values of K, depending upon composition of the dry air, will be required. Use of Table 7.5 must therefore be restricted to the lower altitude region characterized by complete mixing without dissociation of constituents. In applying Table 7.5, effects of wind and vertical acceleration are neglected; for these matters, see Chapters 2 and 11.

With regard to applications of reduction of pressure downward or upward in general, mention may be made of the following:

(a) For the local comparison of barometers established at different elevations, it is necessary to calculate a correction of pressure which makes due allowance for the difference in elevation between the two instruments (see sec. 6.6.2), under the given conditions of temperature, humidity, and pressure. A similar remark may be made with regard to variable removal corrections, when extreme changes in elevation are involved (see Chapter 4).

(b) If it is desired to calculate the pressure at the level of a mountain top or plateau when the pressure at the base of the neighboring valley is known, or vice versa, this may be carried out by the procedures described, neglecting effects due to wind.

The problem of reduction involves the calculation of an unknown pressure for some level in terms of a known pressure for another level. This problem may be subdivided into four stages:

(I) Determination of the vertical extent (depth) of the air column, in geopotential meters.

(II) Determination of the mean virtual temperature of the air column.

(III) Finding r from Table 7.5 as a function of the two arguments referred to under (I) and (II), above.

(IV) Calculation of the unknown pressure in terms of the known pressure and r.

The most difficult phase of the above-listed operations involves the determination of T_{mv}, which depends upon a number of factors.

In the following four sections the procedures for carrying out those operations are described.

7.3.1 Determination of H_{pg}

For the purpose of this section, the symbol H_{pg} represents the vertical extent (depth) of the air column, in geopotential meters. In order to determine H_{pg} as thus defined, ascertain the geopotentials of the top and base of the air column (in gpm), then subtract the latter from the former. That is, the formula for H_{pg} is:

$$H_{pg} = (\text{geopotential of top of air column } \textit{minus} \text{ geopotential of base of air column}). \quad (4)$$

When the elevation of either the top or base of the air column has been found by a surveyor in terms of geometric units (such as feet or meters), the elevation in either case should be converted to geopotential meters by the method described in sec. 1.3.

Example A

It is desired to compare the barometers at two nearby stations, within several miles of one another, but having elevations which differ by more than 100 feet. Station (a) at the airport, where the control (master) barometer is located, has a geopotential of 1658.7 gpm referring to pressure data taken at that point, and Station (b) at the city office has a geopotential of 1596.4 gpm referring to pressure data taken at the latter point. According to formula (4), we calculate the vertical extent of the air column as:

$$\begin{aligned} H_{pg} &= (\text{geopotential of the top of the air column } \textit{minus} \text{ geopotential of the base of the air column}) \\ &= (1658.7 - 1596.4) \text{ gpm} = 62.3 \text{ gpm.} \end{aligned}$$

Example B

This is an extension of Example (A), involving comparison of an additional barometer at Station (c). In this case, Station (c) is at a cooperative college laboratory, where the geopotential is 1699.8 gpm referring to the pressure data taken at that point. Since the control barometer is at Station (a), we obtain for the vertical extent of the air column between Stations (a) and (c) the following result, in accord with formula (4):

$$\begin{aligned} H_{pg} &= (\text{geopotential of top of air column } \textit{minus} \text{ geopotential of base of air column}) \\ &= (1699.8 - 1658.7) \text{ gpm} = 41.1 \text{ gpm.} \end{aligned}$$

Example C

At Great Falls, Montana, the geopotential of the station has been ascertained as 1115.5 geopotential meters. (See figure 1.3.1, sample computation.) This value serves as the geopotential of the base of the air column in this example. It is desired to calculate the average annual pressure at the level of the top of a nearby mountain, neglecting effects of wind. Suppose that the surveyed elevation of the mountain top is 7678 feet (2340.3 meters), at latitude 47°26′ N. This elevation by the method illustrated in fig. 1.3.1, corresponds to 2341.4 geopotential meters. The latter value corresponds to the geopotential of the top of the air column. Therefore, according to formula (4), we determine the vertical extent of the air column as:

H_{pg} = (geopotential of the top of the air column *minus* geopotential of the base of the air column)
= (2341.4 − 1115.5) gpm = 1225.9 gpm.

7.3.2 Determination of T_{mv}

7.3.2.0 General Information for Guidance

7.3.2.0.0 *Directions Regarding Instructions Covering Various Cases or Factors.*—The recommended method for determination of T_{mv} depends upon the availability of temperature, dew point, and pressure data for the air column. Basically the requirement is for values of virtual temperature (T_v) at a sufficient number of levels in the air column to permit obtaining a representative mean (T_{mv}) for the column of atmosphere (see secs. 7.0.3 and 7.0.4). In sec. 7.3.2.0.4 we describe a method of computing T_v for any location when data are available in regard to air temperature, dew point (or aqueous vapor pressure), and atmospheric pressure at the location.

We shall present recommendations concerning the determination of T_{mv} for three sets of circumstances:

(1) In secs. 7.3.2.0.1 and 7.3.2.1, we deal with the case where the vertical extent of the air column (H_{pg}) is relatively small (less than 150 gpm) and T_v can be computed from the data pertaining to the base and top of the air column.

(2) In secs. 7.3.2.0.2 and 7.3.2.2, we treat the case where the vertical extent of the air column (H_{pg}) is relatively great (say in excess of 150 gpm), and T_v can be computed from the data for a number of levels in the air column, including the base and top.

(3) In secs. 7.3.2.0.3 and 7.3.2.3, we are concerned with the case where T_v is available only for one level, either the base or the top of the air column.

Secs. 7.3.2.0.1, 7.3.2.0.2, and 7.3.2.0.3 are intended to serve as introductory summaries pertinent to the more detailed instructions contained in secs. 7.3.2.1, 7.3.2.2, and 7.3.2.3, respectively.

7.3.2.0.1 *Case of Small H_{pg} and T_v Available for Base and Top.*—When H_{pg} is less than 150 gpm, quite accurate results can usually be obtained in reductions by taking T_{mv} as the average of the existing values of T_v at the base and top of the air column.

At any single level, the quantity taken for T_v should be as representative as it is practicable to attain. This is a matter of some importance when evaluating the "correction for difference in elevation" required for barometer comparisons referring to two levels (see sec. 6.6.2). In practice, if the comparative barometer readings are made within a period of the order of one hour or less, while the temperature and humidity conditions are nearly stationary or are changing at a fairly uniform rate, it is generally satisfactory to consider T_v at a given level as the mean of the values of T_v there observed at the beginning and ending of the period of comparative readings.

7.3.2.0.2 *Case of Large H_{pg} and T_v Available for a Number of Levels.*—When H_{pg} appreciably exceeds 150 gpm and accurate results are desired, it is best to try to determine T_v at several significant intermediate levels as well as at the base and top of the air column. Then T_{mv} may be determined graphically or numerically from these data for all the levels available (see fig. 7.0.1; and secs. 7.0.4 and 7.3.2.3).

7.3.2.0.3 *Case Where T_v is Observed at Only One Level.*—When the temperature, pressure, and dew point (or vapor pressure) are obtained either at the base or top of the air column, but not both, it is necessary to make suitable assumptions regarding the vertical distribution of these elements in the air column. As a first approximation for average conditions, one may assume that the lapse rate in the air column has the value adopted for the troposphere in the standard atmosphere, namely a = 0.0117° F./gpm. Under particular conditions (such as a hot summer afternoon, or a cold, clear winter night), appropriate lapse rates must be taken into consideration, if accurate results are desired. In addition, one may assume that the vertical variation of vapor pressure in the air column is governed by some relationship such as Hann's equation [3]

$$\frac{e}{e_o} = 10^{-\frac{h}{6300}} = 10^{-0.0001587h}$$

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[3] Hann-Süring, "Lehrbuch der Meteorologie," 4th Edition, 1926.

where

e_o = vapor pressure at base of air column;

e = vapor pressure in air column at height h above the base,

where h is in meters (or equivalent gpm).

Hann's equation is merely an approximation, which holds roughly for climatological data covering a period of say a month or more, but may not be very accurate for any instant of time taken at random. Details regarding procedures which may be used to estimate T_{mv} in the case where T_v is observed at only one level are presented in sec. 7.3.2.3.

7.3.2.0.4 *Evaluation of T_v.*—According to equation (3) in sec. 7.0.3, the virtual temperature at any given level in the air column may be expressed as:

$$T_v = T/(1 - 0.378e/P) \qquad (3)$$

where

T_v = virtual temperature, in same units as T;

T = air temperature (absolute), as in °R. (see sec. 7.0.1);

e = vapor pressure of air;

P = barometric pressure (in same units as e).

It will be recalled that

$$T\ ^\circ\text{R.} = (459.7 + t\ ^\circ\text{F.}) \qquad (5)$$

where t = air temperature, in degrees Fahrenheit.

Since e/P very rarely exceeds 0.05, and under average conditions in middle latitudes is of the order of 0.025, we may write T_v to a very close degree of approximation by the equation

$$T_v = T + (0.378\ T\ e/P) \qquad (6)$$

or

$$T_v = (459.7 + t) + (0.378\ T\ e/P) \qquad (7)$$

The additive quantity ($0.378\ T\ e/P$) will be called the "correction to obtain virtual temperature," since when it is added to T it yields T_v.

Instructions follow in regard to the evaluation of T_v for any level, provided observations are available to permit calculations in accordance with equation (6) or (7). Suppose that we have observed the three basic meteorological elements for the level: dew point, barometric pressure, and temperature. The steps to compute T_v are as follows:

Step (1) Refer to Table 7.6.1 (entitled "Auxiliary Data Used in Finding 'Correction to Obtain Virtual Temperature' "). Tabular values are values of ratio e/P.

Using dew point (in °F.) and pressure (in inches of mercury or millibars) as arguments, find the corresponding value of e/P in the body of the table. Interpolate if necessary.

Step (2) Refer to Table 7.6.2 (entitled "Correction to Obtain Virtual Temperature"). Using as arguments the observed air temperature (t, in °F.) and the value of e/P found in accord with Step (1), find the corresponding value of $0.378\ T\ e/P$ in the body of this table. Interpolate if necessary.

Step (3) In accordance with equation (5), compute T in °R. as the algebraic sum of 459.7 and t, in °F.

Step (4) In accordance with equation (6), compute T_v by adding to T, as found by Step (3), the "correction to obtain virtual temperature" ($0.378\ T\ e/P$), as found by Step (2).

Data for six examples, designated as Aa (or Ba), Ab, Bc, C1, C2, and D1, are presented in the following table. These designations have been chosen to facilitate references to previous related examples given in sec. 7.3.1 and to subsequent examples. See page 7-46.

7.3.2.1 Determination of T_{mv} for a Shallow Air Column.—Instructions for the calculation of T_{mv} in the case of a shallow air column are simple, as follows:

Take the average of the virtual temperatures (T_v) at base and top of the air column as T_{mv}, the mean virtual temperature of the air column. That is,

$$T_{mv} = (T_v \text{ at base} + T_v \text{ at top})/2 \qquad (8)$$

Example A

Consider the values of T_v given under Examples Aa and Ab of the following table. Then, according to formula (8):

$$T_{mv} = (510.9^\circ\ \text{R.} + 511.7^\circ\ \text{R.})/2 = 511.3^\circ\ \text{R.}$$

Examples

[Calculations of T_v Based on Observed Dew Point, Barometric Pressure, and Temperature at Various Levels]

Line No.	Description	Example designation					
		Aa, Ba	Ab	Bc	C1	C2	D1
1	Geopotential, H_{pg} (gpm)	1658.7	1596.4	1699.8	1115.5	2341.4	1115.5
2	Dew Point (°F.)	32	33	32	32	22	46
3	Pressure (in. Hg)	24.487	24.671	24.366	26.217	22.545	25.976
4	Temperature (t, °F.)	49.8	50.5	49.3	44.9	35.8	67.1
5	e/P from Table 7.6.1	.0074	.0076	.0074	.0069	.0049	.0120
6	$0.378\ T\ e/P$ from Table 7.6.2	1.43	1.47	1.42	1.32	0.99	2.39
7	T, absolute temperature, as per eq. (5), °R.	509.5	510.2	509.0	504.6	495.5	526.8
8	T_v, as per eq. (6), in °R.	510.9	511.7	510.4	505.9	496.5	529.2

Explanation:

Line 1, Given data. See Examples A, B, and C, in sec. 7.3.1.

Lines 2, 3 and 4: Observed data.

Line 5: Based on arguments given on lines 2 and 3.

Line 6: Based on arguments given on lines 4 and 5.

Line 7: Algebraic sum of 459.7 and line 4.

Line 8: Sum of lines 6 and 7.

Example B

Consider the values of T_v given under Examples Ba(Aa) and Bc of the preceding table. Then by virtue of formula (8),

$$T_{mv} = (510.9° \text{ R.} + 510.4° \text{ R.})/2 = 510.7° \text{ R.}$$

7.3.2.2 Determination of T_{mv} for a Deep Air Column

7.3.2.2.0 *Introduction.*—Suppose that T_v has been evaluated for a number of levels, including the base and top, of the air column, as illustrated in sec. 7.3.2.0.4. Then T_{mv} may be determined graphically: (1) by Method (I) as outlined below in sec. 7.3.2.2.1 if T_v and the corresponding barometric pressure (P) are both known for various levels; and (2) by Method (II) as explained below in sec. 7.3.2.2.2 if T_v and the corresponding geopotential H_g with respect to mean sea level are both known for various levels. Formulas to permit calculation of T_{mv} by numerical procedures are also presented for each case; see eqs. (9) and (11), respectively.

7.3.2.2.1 *Determination of T_{mv} by Method (I).*

(a) Making use of semi-logarithmic paper or an adiabatic chart having a log P coordinate as illustrated on the left side of fig. 7.0.1, plot points of T_v on a linear scale against P on a logarithmic scale for the respective levels. Connect the points by a smooth curve, which represents T_v as a function of log P. (We call this the "T_v–log P curve"; indicated by b d f h in fig. 7.0.1 for the special example where the base of the air column is at sea level.)

(b) Determine T_{mv} from the curve by the process of equalizing areas as illustrated in fig. 7.0.1. This process makes use of a transparent straightedge, which must be maintained parallel to the lines of constant T_v on the graph paper. With this condition fulfilled, place the straightedge in such a position that half of the area between the T_v–log P curve and the straight edge lies to the left of the edge and half to the right. (In fig. 7.0.1 dashed line ai represents the straightedge.) When this condition is satisfied, note the point where the straightedge intersects the T_v-scale; then the value of T_v at this point corresponds to T_{mv} (see point *a* in fig. 7.0.1). In case great precision is required, the areas may be measured by means of a planimeter to verify that the areas to left and right of the straightedge are equal. (This is illustrated under note 3 of fig. 7.0.1. See also alternative method mentioned below the following equation.)

Since T_v is treated as a function of log P in Method (I), T_{mv} may also be calculated by means of numerical integration pertaining to the numerator of eq. (9), in accordance with the following formula (see Appendix 7.1):

$$T_{mv} = \frac{\int_{P_2}^{P_1} T_v \, d(\log P)}{\int_{P_2}^{P_1} d(\log P)} \qquad (9)$$

where

P_1 = barometric pressure at base of air column;

P_2 = barometric pressure at top of air column.

As an alternative to numerical integration, a planimeter can be used to measure the area represented by the numerator of eq. (9).

It will be noted that Method (I) is impracticable to use when T_v is not known as a function of log P.

7.3.2.2.2 *Determination of T_{mv} by Method (II).*

7.3.2.2.2.0 Introduction.

Before a person can apply this method, it is necessary that he know for each of a number of levels of the air column, including its base and top, the values of the virtual temperature (T_v) and the geopotential of the level (denoted here by the symbol H_g, with an additional subscript, if needed, to designate particular levels). At the same time, there must be at least one level of known geopotential (H_{gk}) for which there is also a known barometric pressure (P_k); and this usually refers either to the base or top of the air column. Generally the barometric pressures at other levels in the air column are unknown.

Suppose that for certain significant levels [4] of the air column the known data consist of three elements: air temperature (t, °F.), dew point (°F.), and geopotential (H_g in gpm) or elevation above mean sea level (in feet or meters).

Elevation above mean sea level can be converted to geopotential by the method described in sec. 1.3.6.

By means of the procedures outlined in sec. 7.3.2.0.4, the required values of T_v can be evaluated on the basis of the known data listed above; however, before this evaluation can be accomplished it is necessary to have at least a good estimate of the pressure (P) at each level. In the following we denote the estimated pressure by P_l and the geopotential of the level by H_{gl}. An estimate of the pressure P_l for the various levels of geopotential H_{gl} may be made by means of a technique described in following sec. 7.3.2.2.2.1 which involves the use of simple proportions based on Standard Atmosphere data (see Table 8.1). Actual details of the procedure for computing T_{mv} by Method II are presented in sec. 7.3.2.2.2.3.

7.3.2.2.2.1 Estimation of P for Various Levels

The following notation is employed:

P_k = known barometric pressure at known geopotential (H_{gk}).

H_{gk} = geopotential to which P_k refers. (This may pertain either to the base or the top of the air column.)

H_{gl} = geopotential of the level for which the barometric pressure is required.

P_l = estimated value of the barometric pressure at the geopotential H_{gl}.

P_{sk} = pressure in the standard atmosphere at the altitude H_{gk} (based on Table 8.1)

P_{sl} = pressure in the standard atmosphere at the altitude H_{gl} (based on Table 8.1).

We assume

$$\frac{P_l}{P_k} = \frac{P_{sl}}{P_{sk}} \qquad (10)$$

to a close degree of approximation and solve for P_l.

Example

At the base of an air column where the known geopotential is H_{gk} = 1115.5 gpm (3657 feet), the observed barometric pressure is known, in particular P_k = 26.184 inches of mercury. The problem here is to estimate the pressure P_l at the level where the geopotential is H_{gl} = 2341.4 gpm (7678 feet). (See example C2 in the table above).

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[4] A "significant level" may be defined as a level where a significant change occurs in the vertical gradient of either temperature or humidity. Clear cut examples would be: bases and tops of inversion or isothermal layers; bases and tops of moist or dry layers; etc.

Referring to Table 8.1, we find the following data:

P_{sl} = 22.500 inches of mercury corresponding to $H_{gl} = 7678$ feet, and

P_{sk} = 26.173 inches of mercury corresponding to $H_{gk} = 3657$ feet.

Since

P_k = 26.184 inches of mercury, equation (10) yields the results

$$\frac{P_l}{26.184 \text{ in. mercury}} = \frac{22.500 \text{ in. mercury}}{26.173 \text{ in. mercury}}$$

whence $P_l = 22.509$ inches of mercury, the estimated value of pressure for geopotential 2341.4 gpm.

7.3.2.2.2.2 Evaluation of T_v for the Various Levels

The foregoing means may be used to estimate the pressure for all levels for which P is unknown. Then, the procedure described in sec. 7.3.2.0.4 should be employed to evaluate T_v for each level, on the basis of the pressure thus estimated, together with the observed values of air temperature and dew point.

7.3.2.2.2.3 Determination of T_{mv} by Method (II), Final Steps

The instructions in paragraphs (1)–(4), below apply:

(1) Calculate $1/T_v$, the reciprocal of T_v, for each of the significant levels, including the base and top of the air column.

(2) Prepare a piece of graph paper with a vertical scale of H_g (geopotential) and a horizontal scale of $1/T_v$ (reciprocal of T_v). Plot $1/T_v$ against H_g for the various levels. (See fig. 7.3.0.) Connect the plotted points by a smooth curve.

(3) Use the method of equal areas to determine $1/T_{mv}$ by means of the smooth curve. That is, a transparent straightedge always maintained parallel to the H_g scale, should be placed in such a position that the area between the curve and the straightedge is divided equally; this is done by guess and trial until the area to the left of the straightedge is equal to the area to the right of the straightedge. Note the point on the scale of $1/T_v$ where the straightedge intersects when it lies in the position that equalizes the areas as outlined above. Read the value of $1/T_v$ from the scale at this point of intersection. This value represents $1/T_{mv}$.

(4) Calculate T_{mv} from this reciprocal. An example is shown in figs. 7.3.0 and 7.3.1.

If great accuracy is desired in regard to the determination of $1/T_{mv}$, this may be achieved by means of a planimeter, or by numerical integration based on the equation

$$\frac{1}{T_{mv}} = \frac{1}{H_g\,(\text{top}) - H_g\,(\text{base})} \int_{H_g\,(\text{base})}^{H_g\,(\text{top})} \frac{dH_g}{T_v} \tag{11}$$

The integral shown in the numerator of eq. (11) is illustrated in fig. 7.3.1 by the area s a b c d w v u s plus the product 0.00197 $(°\text{R})^{-1} \times (2341.4 - 1115.5)$ gpm which represents the area of a rectangle of the left of line sw extending as far as the zero axis of the $1/T_v$ scale; and the former area may be measured with the planimeter. When $1/T_v$ is assumed to be a linear function of H_g as depicted in the figure, the numerical integration can be performed simply with the aid of the trapezoidal rule.

The following itemized explanations provide information relating to the interpretation and processing of data in connection with the diagram shown in fig. 7.3.1, on a basis consistent with the use of that rule:

(1) The diagram is a plot of $1/T_v$ against H_g (geopotential).

(2) Points a, b, c, and d are based on observed temperature and dew point data, and curve abcd represents $1/T_v$ as a function of geopotential H_g.

(3) Straightedge is line efg.

(4) To determine $1/T_{mv}$ at point y, place straightedge so that area abfea = area dcfgd.

(5) Point y is on $1/T_v$ scale on extension of line efg.

7.3.2.3 Estimation and Tabulation of T_{mv} in Case Meteorological Data Are Observed at Only One Level

7.3.2.3.0 *Introduction.*—In this case suppose that the air temperature (t), dew point, and pressure (P) are observed at just one level, located either at the base or top of the air column. For any given dew point, one can readily find the corresponding vapor

	Surface (Base)	Level No. 1	Level No. 2	Level No. 3 (Top)
Geopotential (H_g, in gpm)	1115.5	1500	2000	2341.4
Geopotential (H_g, in gpft)	3660	4921	6562	7682
Temperature (t, °F), observed	44.9°	44.9°	39.8°	35.8°
Dew Point (°F), observed	31.6°	30.2	25.1	21.9°
Vapor Pressure (e, in inches of mercury)	0.17747	0.16767	0.13591	0.11883
P_k (in. Hg.) observed	26.217	----	----	----
P_{sk} (in. Hg.) from Table 8.1	26.170	----	----	----
P_{sl} (in. Hg.) from Table 8.1	----	24.970	23.475	22.497
P_l (in. Hg.), by eq. (10)	26.217	25.015	23.517	22.537
e/p, from Table 7.6.1	0.0068	0.0067	0.0058	0.0053
0.378 T e/p (°F), from Table 7.6.2	1.30	1.28	1.09	0.99
T (°R), by eq. (5)	504.6	504.6	499.5	495.5
T_v (°R), by eq. (6)	505.9	505.9	500.6	496.5
$1/T_v$ $(°R)^{-1}$*	0.001977	0.001977	0.001998	0.002014

* $1/T_v$ is plotted against H_g in Fig. 7.3.1

FIGURE 7.3.0. Computation of T_v for use in Method II.

pressure (e) by referring to Table 7.6.1. By the procedure described in sec. 7.3.2.0.4, such data enable us to evaluate T_v for the one level at which the observations have been made. Suppose that the data are unavailable for the other levels in the air column. Then, in order to accomplish the task of estimating T_{mv}, it is necessary to make suitable assumptions regarding conditions of t, P, and e in the air column at levels other than the one at which the observations have been made, in order to permit the evaluation of T_v for these other levels.

A practical scheme for estimating the conditions of t, P, and e at the top (or base) of an air column when the data have been observed at the base (or top) is given in secs. 7.3.2.3.1–7.3.2.3.3, where the notation presented in the succeeding two paragraphs is used. Sec. 7.3.2.3.4 deals with the evaluation of T_v for the various levels, and sec. 7.3.2.3.5 pertains to the determination of T_{mv}. Sec. 7.3.2.3.6 illustrates how the values of T_{mv} may be conveniently tabulated as a function of surface temperature and vapor pressure.

Let the subscript s indicate that the data pertain to the surface at which the observations of temperature, pressure, and dew point were actually made; and let the subscript l indicate that the data pertain to a level for which the conditions are being estimated.

Thus, with reference to the surface at which the observations are made, we have t_s = temperature, P_s = barometric pressure, e_s = vapor pressure corresponding to the dew point, and H_{gs} = geopotential. Also, with reference to the level for which the conditions are being estimated, we have t_l = temperature, P_l = barometric pressure, e_l = vapor pressure, and H_{gl} = geopotential.

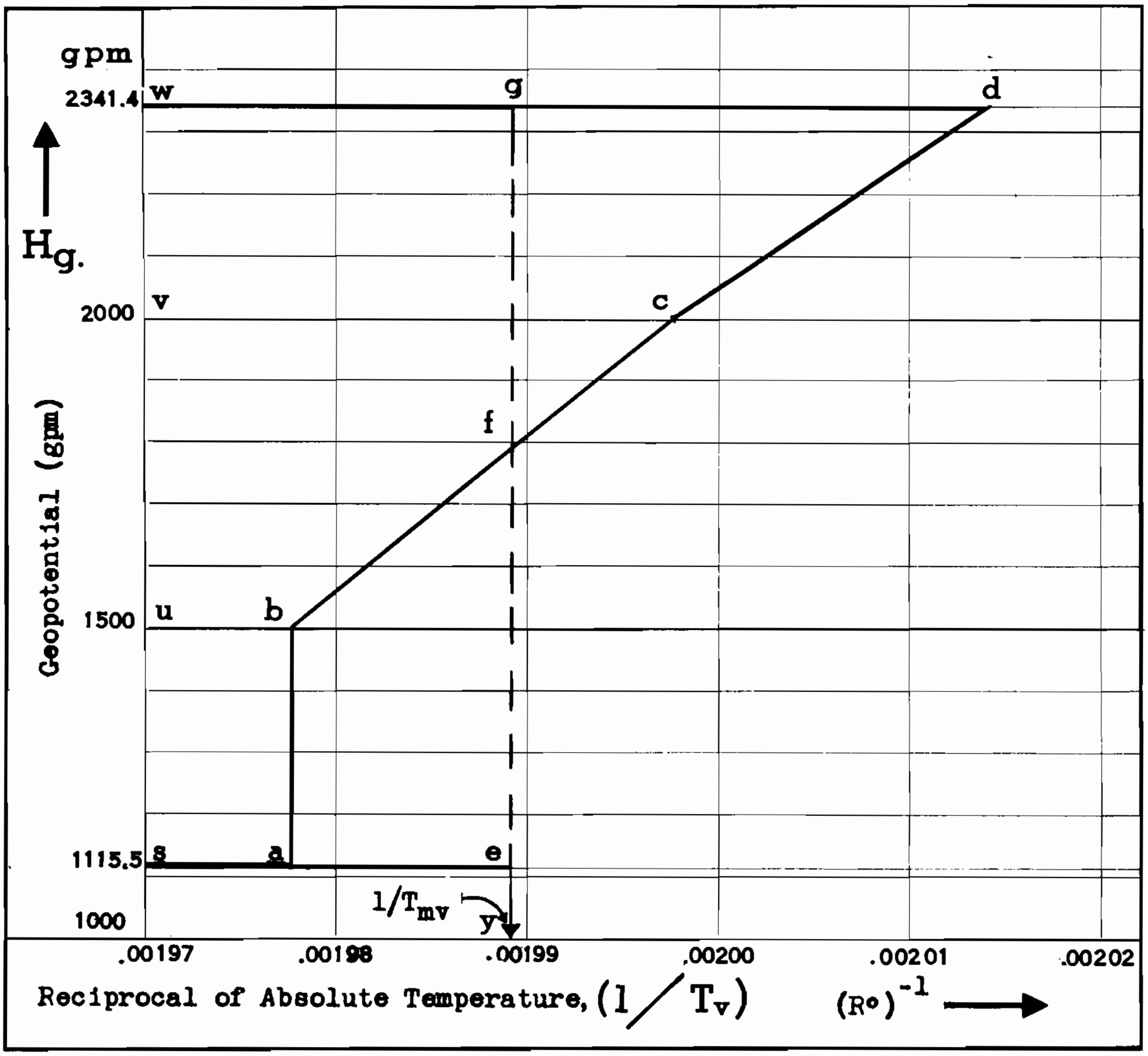

FIGURE 7.3.1. Graphical determination of $1/T_{mv}$.

7.3.2.3.1 *Estimation of Temperature* t_l.—Let a = assumed lapse rate in the air column (in °F./gpm), then by definition of lapse rate

$$\frac{t_s - t_l}{H_{gl} - H_{gs}} = a. \qquad (12)$$

$$\therefore t_l = t_s - a(H_{gl} - H_{gs}) \qquad (13)$$

When applying this equation, care must be taken to use the proper algebraic signs.

In order to estimate a reliable value for t_l, it is necessary to assume a most representative value for the lapse rate (a). Since t_s, H_{gl}, and H_{gs} are given, one can compute t_l by means of equation (13).

Under average conditions covering both day and night jointly over a considerable period of time, in middle latitudes, the value of a which is generally assumed for an air column within the troposphere is $a = 0.0117°$ F./gpm. In the summer, on a hot afternoon, the value of a may be of the order of 0.018° F./gpm. It may be slightly more near the ground under these circumstances. An overcast sky will tend to make the value less in the daytime. At night, in the close vicinity of the surface, an inversion layer may form; hence in this layer, the value of a is *negative.* Inversions are most common during the winter night, and will often yield values of a ranging from about —0.003 to —0.036° F./gpm, the latter especially over snow covered ground under clear skies in high latitudes. The inversion will be less marked under an overcast sky.

Example (D)

Given

$t_s = 67.1°$ F.
$H_{gs} = 1115.5$ gpm
$H_{gl} = 2341.4$ gpm

To find t_l under average conditions.

Assuming these conditions, $a = 0.0117°$ F./gpm.

According to equation (13)

$t_l = t_s - a(H_{gl} - H_{gs}) = 67.1°$ F.
− (0.0117°F./gpm)(2341.4 − 1115.5 gpm)
= 67.1° F.− 14.3° F. = 52.8° F. (estimated value at 2341.4 gpm).

Example (E)

Given

$t_s = -20.7°$ F. (clear winter night)
$H_{gs} = 1115.5$ gpm
$H_{gl} = 1425.6$ gpm

To find t_l, on a clear winter night in middle latitudes.

Assuming an inversion, such that the lapse rate is given by

$a = -0.02°$ F./gpm, we have, in accord with equation (13)

$t_l = t_s - a(H_{gl} - H_{gs})$
$t_l =$ −20.7° F. −(−0.02° F./gpm) × (1425.6 gpm − 1115.5 gpm)
= −20.7° F. + 6.2° F. = −14.5° F. (estimated value for 1425.6 gpm).

Example (F)

Observations were made of temperature, yielding $t_s = 88.6°$ F., on top of a hill at geopotential $H_{gs} = 529$ gpm during a hot summer afternoon; to find the estimated temperature (t_l) at the foot of the hill where the geopotential is represented by $H_{gl} = 257$ gpm.

Assuming that the lapse rate is given by $a = 0.018°$ F./gpm under these conditions, we have in accordance with equation (13)

$t_l = t_s - a(H_{gl} - H_{gs}) = 88.6°$ F.
− (0.018° F./gpm)(257 gpm − 529 gpm)
= 88.6° F. − (0.018° F./gpm)(−272 gpm)
= 88.6° F. + 4.9° F. = 93.5° F.

7.3.2.3.2 *Estimation of Barometric Pressure* P_l.—The method based on equation (10), sec. 7.3.2.2.2.1, should be used in estimating P_l for various levels, when P_s, H_{gs}, and H_{gl} are given.

7.3.2.3.3 *Estimation of Vapor Pressure* e_l.—When the dew point has been observed, the corresponding vapor pressure, e_s, may be determined by referring to Table 7.6.1. (For example: If the observed dew point is 46° F., then according to Table 7.6.1, the corresponding vapor pressure is 0.31185 inches of mercury, which represents e_s.)

Assuming that Hann's equation holds for the variation of vapor pressure with height, we have as a basis for estimating e_l the relationship

$$e_l = e_s\, 10^{-0.0001587(H_{gl} - H_{gs})} \quad . \qquad (14)$$

In this equation H_{gl} and H_{gs} must be expressed in units of geopotential meters (although a sufficiently good approximation for present purposes is secured by using geometric meters). The terms e_s and e_l must always be written in identical units, such as inches of mercury (or millibars).

Table 7.7 presents values of the factor $10^{-0.0001587(H_{gl} - H_{gs})}$ for both positive and negative values of the term $(H_{gl} - H_{gs})$; hence, equation (14) can be evaluated with the aid of this table. In referring to Table 7.7 for purposes of obtaining the given factor, it is important to take proper consideration of the sign of the term $(H_{gl} - H_{gs})$.

Example D′

Given:

Dewpoint = 46° F.,
hence $e_s = 0.31185$ inch of mercury
$H_{gs} = 1115.5$ gpm
$H_{gl} = 2341.4$ gpm

To find e_l by means of Hann's equation (14).

We have $(H_{gl} - H_{gs}) =$ (2341.4 gpm − 1115.5 gpm) = +1225.9 gpm.

Referring to Table 7.7, we find by interpolation that the corresponding value of the factor is $10^{-0.0001587(H_{gl} - H_{gs})} = 0.6389$.

According to equation (14), we obtain

$e_l = e_s\, 10^{-0.0001587(H_{gl} - H_{gs})}$
= (0.31185 inch of mercury)(0.6389)
= 0.1992 inch of mercury.

Example F′

The dew point was observed to be 65° F. on top of a hill at geopotential $H_{gs} = 529$ gpm on a hot summer afternoon; to find the estimated vapor pressure, e_l, at the foot of the hill where the geopotential is $H_{gl} = 257$ gpm.

According to Table 7.6.1, the vapor pressure at the top of the hill corresponding to the observed dew point of 65° F. is given by $e_s = 0.62209$ inch of mercury.

Also $(H_{gl} - H_{gs}) =$ (257 gpm − 529 gpm) = −272 gpm.

Referring to Table 7.7, we find by interpolation that the value of the factor for the corresponding value of $(H_{gl} - H_{gs})$ is $10^{-0.0001587(H_{gl} - H_{gs})} = 1.1045$.

Thus, on the basis of equation (14), we have for the estimated vapor pressure at the foot of the hill:

$e_l = e_s\, 10^{-0.0001587(H_{gl} - H_{gs})}$
= (0.62209 inch of mercury) × (1.1045)
= 0.6871 inch of mercury

7.3.2.3.4 *Evaluation of T_v for Various Levels.*— After the quantities t_l, P_l, and e_l have been estimated for the various levels, as required, by the methods described above, the corresponding values of T_v for these levels may be evaluated by the procedures already presented in sec. 7.3.2.0.4. We shall denote the values of T_v thus obtained by the symbol T_{vl}, in general. When there is need to distinguish the values for a number of levels, we shall use the designations T_{v1}, T_{v2}, $T_{v3}, \ldots T_{v(n-1)}$, T_{vn}.

7.3.2.3.5 *Determination of T_{mv}.*—Suppose that observations have been made at the base (or top) of the air column, yielding data which permits the evaluation of T_{vs}; and suppose further that by the methods of estimation outlined above, it becomes possible to evaluate T_{v1}, referring to the top (or base) of the air column.

Then suppose the air column is treated as a single layer, for whose base and top one has values of T_v. Under these circumstances, we may determine T_{mv} by means of the equation:

$$1/T_{mv} = (1/T_{vs} + 1/T_{v1})/2 \qquad (15)$$

This relationship is consistent with equation (11) and Method (II), assuming that $1/T_v$ is a linear function of H_g. It yields good results when T_{v1} is accurately estimated and the air column is fairly shallow.

On the other hand, when the air column is deep and it is possible to make reasonably accurate estimates of T_v for several levels in the air column, a more precise formula for calculating T_{mv} may be used. We may employ equation (11) for the purpose (sec. 7.3.2.2.2.3), since it has generality, being valid in all cases (see figures 7.3.0 and 7.3.1). However, in the special case where the air column has been subdivided into a whole number (n) of layers of *equal* vertical extent (depth in gpm) and T_v has been estimated or observed for the base and top of each of the layers, then in practice it is convenient to use formula (16) or (17) below. These are based on equation (11), under the assumption that $1/T_v$ is a linear function of geopotential, where T_{vs}, T_{v1}, T_{v2}, $T_{v3}, \ldots T_{v(n-1)}$, T_{vn} represent the virtual temperatures at the successive levels:

$$\frac{1}{T_{mv}} = \frac{1}{n}\left\{\frac{1}{2}\left(\frac{1}{T_{vs}} + \frac{1}{T_{v1}}\right) + \frac{1}{2}\left(\frac{1}{T_{v1}} + \frac{1}{T_{v2}}\right) + \cdots + \frac{1}{2}\left(\frac{1}{T_{v(n-1)}} + \frac{1}{T_{vn}}\right)\right\} \qquad (16)$$

or

$$\frac{1}{T_{mv}} = \frac{1}{n}\left\{\frac{1}{2}\left(\frac{1}{T_{vs}} + \frac{1}{T_{vn}}\right) + \frac{1}{T_{v1}} + \frac{1}{T_{v2}} + \cdots + \frac{1}{T_{v(n-1)}}\right\} \qquad (17)$$

Example

An air column which is 1225.9 gpm in depth and has a base at 1115.5 gpm with top at 2341.4 gpm, is subdivided into four layers of equal vertical extent. Therefore, $n = 4$, and the vertical thickness of each of these layers is 1225.9 gpm/4 = 306.5 gpm. We are thus concerned with data for five levels. Suppose that the values of T_v and their reciprocals have been evaluated as follows:

SAMPLE COMPUTATION

H_g Geopotential of level (gpm)	Designation of T_v	Value of T_v	Value of $1/T_v$
		° *R.*	(°*R.*)$^{-1}$
1115.5......	T_{vs}	505.9	0.001977
1422.0......	T_{v1}	505.9	0.001977
1728.5......	T_{v2}	503.5	0.001986
2034.9......	T_{v3} ($=T_{vn-1}$)	500.2	0.001999
2341.4......	T_{v4} ($=T_{vn}$)	496.5	0.002014

According to equation (17),

$$\frac{1}{T_{mv}} = \frac{1}{4}\left\{\frac{1}{2}(0.001977 + 0.002014) + 0.001977 + 0.001986 + 0.001999\right\}$$

$$\frac{1}{T_{mv}} = 0.001990\ (°\text{R.})^{-1}, \text{ whence } T_{mv} = 502.5°\text{ F.}$$

7.3.2.3.6 *Tabulation of T_{mv} as a Function of Surface Temperature and Dew Point (or Vapor Pressure).*—There are many situations in which the problem of reducing pressure arises repeatedly. Commonly the temperature (t_s), the barometric pressure (P_s), and the dew point are observed at the surface. From the dew point, one can obtain the corresponding vapor pressure (e_s); see Table 7.6.1. Whenever the similar data for the other levels in the air column are unknown, they may be estimated by the procedures described in the foregoing.

When the problem of performing the reduction must be dealt with many times or at frequent intervals, a saving of time accrues if the estimates are made in advance covering the range of conditions likely to be observed in regard to t_s and e_s. With regard to P_s, it is usually sufficiently accurate for purposes of evaluating T_v to assume that P_s has the normal annual value at the surface. If the latter is unknown, it may be estimated with the aid of the Standard Atmosphere data; see Table 8.1, taking account of the elevation of the surface. On the basis of the information thus assembled, it is possible to calculate in advance the values of T_{mv} corresponding to the observed surface quantities t_s and dew point (or e_s), under various conditions that might govern the assumed lapse rate (a). After the values of T_{mv} have been thus computed, they can be compiled in the form of tables giving T_{mv} as a function of observed surface data t_s and dew point (or e_s), over a suitable range. In some cases the assumed lapse rate (a) may be treated as a function of t_s, so that in these circumstances the function may be embodied in the table. Otherwise different tables of T_{mv} as a function of t_s and dew point (or e_s) may be constructed for different respective values of the lapse rate (a), taken as a fixed parameter for each table.

Such tables serve as useful adjuncts in facilitating the operations. An example of a portion of such a table in skeleton form is illustrated in fig. 7.3.2, where. the assumed value of the lapse rate (a) is 0.0117° F./gpm. For other values of the parameter a different tables would have to be consulted.

7.3.3 Compilation of Ratio *r* as a Function of T_{mv}, for Given H_{pg}

After T_{mv} has been determined, refer to Table 7.5 and extract r as a function of T_{mv}, for the given vertical extent of the air column, H_{pg}, in geopotential meters. When the argument T_{mv} is taken by multiples of 5° F. (such as 410°, 415°, 420°, ... 550°, 555°, 560°) as shown at the head of Table 7.5, interpolation must be made only with respect to H_{pg}. But when the argument T_{mv} is taken for every whole °R. over a suitable range, interpolation must be made both with respect to H_{pg} and T_{mv}. An example showing an extract of Table 7.5 together with results of such interpolations is presented in fig. 7.3.3.

In order to facilitate further use of the data, a table of the results should be compiled presenting r as a function of T_{mv} on the basis of the values thus obtained by interpolation. Fig. 7.3.4 illustrates examples of such tables showing r as a function of T_{mv} for certain fixed values of H_{pg}. Data such as those presented in fig. 7.3.4 for the appropriate values of H_{pg} are necessary for the obtainment of the final data in regard to reduction of pressure.

7.3.4 Reduction of Pressure: Final Stage

7.3.4.0 Recapitulation and Introduction. —To recapitulate: As indicated in sec. 7.0.2 the basic equation used for reduction of pressure is

$$\frac{P_o}{P} = r = 10^{KH_{pg}/T_{mv}}. \qquad (1)$$

Inspection of the right-hand member of eq. (1) reveals that we are initially concerned with two quantities, H_{pg} and T_{mv}, which may vary. With regard to the first of these, it will be recalled that sec. 7.3.1 describes how H_{pg} may be obtained after: (a) the necessary surveys have been made to determine elevation (see sec. 1.2.3.7); and (b) the geopotentials corresponding to the top and base of the air column have been computed (see sec. 1.3.6). It will be recalled that H_{pg} represents the difference between those two geopotentials, and is always a positive quantity as dealt with in this Manual. With regard to T_{mv}, it will be remembered from sec. 7.3.2 that T_{mv} may be determined under various circumstances, depending upon the levels at which temperature, dew point, and pressure (or elevation) have been observed.

Thus for any problem of reduction, we may consider that both H_{pg} and T_{mv} will be appropriately ascertained to fit the circumstances. In the case where surface temperature (t_s) and dew point have been observed at only one level (as at base or top of the air column), we have illustrated in sec. 7.3.2.3 how T_{mv} may be tabulated as a function of t_s and e_s (surface vapor pressure). Finally, with the aid of Table 7.5, the ratio r may be ascertained as a function of H_{pg} and T_{mv}, where H_{pg} is a known constant for any

Name of station: Great Falls, Montana

Geopotential of station: H_{pg} = 1115.5 gpm

Reduction to level of geopotential: 1422 gpm

Assumed lapse rate, $\underline{a}$ = 0.0117° F./gpm

(Tabular data are values of T_{mv} in °R.)

Surface Temperature	Surface Vapor Pressure (e_s), inch of mercury				
t_s	0.0	0.1	0.2	0.3	0.4
°F.	°R.	°R.	°R.	°R.	°R.
0					
10					
20					
30					
40					
50			509.3	510.0	510.7
60			519.3	520.0	520.8
70			529.4	530.1	530.8
80					
90					
100					

FIGURE 7.3.2. Sample tabulation of T_{mv} as a function of t_s and e_s.

given problem. In fig. 7.3.4, of sec. 7.3.3 we have illustrated how the values of r thus found can be tabulated as a function of T_{mv}, results being shown for three different values of H_{pg}, which refer to three specific examples (A, B, C).

From the foregoing it will be apparent that once H_{pg} is known and T_{mv} determined, it is an easy matter to find the corresponding value of r.

Now when we consider any particular problem of reduction, we also have the pressure observed at some level. Two cases of this problem enter into consideration: (a) downward reduction; and (b) upward reduction.

Example A:

H_{pg}	T_{mv} = Mean Virtual Temperature (°R.)					
gpm	470°	471°	472°	473°	474°	475°
60	1.00788					1.00779*
62.3	1.00819	1.00817	1.00815	1.00813	1.00811	1.00809#
70	1.00921					1.00909*

Example B:

H_{pg}	T_{mv} = Mean Virtual Temperature (°R.)					
gpm	515°	516°	517°	518°	519°	520°
40	1.00478					1.00473*
41.1	1.00491	1.00490	1.00489	1.00488	1.00487	1.00486#
50	1.00598					1.00594*

Example C:

H_{pg}	T_{mv} = Mean Virtual Temperature (°R.)					
gpm	480°	481°	482°	483°	484°	485°
1220	1.16904					1.16719*
1225.9	1.16993	1.16956	1.16918	1.16881	1.16843	1.16806#
1230	1.17055					1.16866*

Notes:

Geopotentials:	Example A	Example B	Example C
Top of Air Column =	1658.7 gpm	1699.8 gpm	2341.4 gpm
Base of Air Column =	1596.4 gpm	1658.7 gpm	1115.5 gpm
Difference, H_{pg} =	62.3 gpm	41.1 gpm	1225.9 gpm

(Reference: See Section 7.3.1)

*Values of r on this line extracted from Table 7.5.
#Interpolated values of r shown on this line.

FIGURE 7.3.3. Examples of some values of r extracted from Table 7.5, with certain additional values obtained by interpolation; on the basis of given arguments H_{pg} and T_{mv} where H_{pg} = vertical extent of air column, in gpm.; and T_{mv} = mean virtual temperature of air column, in °R.

T_{mv}	H_{pg}			T_{mv}	H_{pg}		
°R.	62.3 gpm	41.1 gpm	1225.9 gpm	°R.	62.3 gpm	41.1 gpm	1225.9 gpm
		Example				Example	
	A	B	C		A	B	C
410°	1.00939	1.00617	1.20172	485°	1.00792	1.00522	1.16806
411°	1.00937	1.00615	1.20119	486°	1.00791	1.00521	1.16769
412°	1.00934	1.00614	1.20065	487°	1.00789	1.00520	1.16732
413°	1.00932	1.00613	1.20012	488°	1.00788	1.00519	1.16694
414°	1.00930	1.00612	1.19959	489°	1.00786	1.00518	1.16657
415°	1.00927	1.00611	1.19905	490°	1.00785	1.00517	1.16620
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.
470°	1.00819	1.00539	1.17386	515°	1.00747	1.00491	1.15752
471°	1.00817	1.00537	1.17346	516°	1.00745	1.00490	1.15720
472°	1.00815	1.00536	1.17306	517°	1.00744	1.00489	1.15687
473°	1.00813	1.00535	1.17267	518°	1.00742	1.00488	1.15655
474°	1.00811	1.00534	1.17227	519°	1.00741	1.00487	1.15623
475°	1.00809	1.00533	1.17187	520°	1.00739	1.00486	1.15590
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.
480°	1.00801	1.00526	1.16993	555°	1.00692	1.00455	1.14539
481°	1.00800	1.00525	1.16956	556°	1.00691	1.00455	1.14511
482°	1.00798	1.00525	1.16918	557°	1.00690	1.00454	1.14483
483°	1.00796	1.00524	1.16881	558°	1.00689	1.00454	1.14455
484°	1.00794	1.00523	1.16843	559°	1.00688	1.00453	1.14427
485°	1.00792	1.00522	1.16806	560°	1.00687	1.00453	1.14399

FIGURE 7.3.4. Tabular values representing r as a function of T_{mv} for the three examples, A, B, and C of sec. 7.3.1. These pertain to the reduction of pressure involving different data in regard to the vertical extent of air column (H_{pg}, in gpm.) as indicated in heading.

Case (a): Downward Reduction:
When the pressure is observed at the top of the air column, we have P given by observation, and the problem of reduction is to compute P_o which represents the pressure at the base of the air column.

Case (b): Upward Reduction:
When the pressure is observed at the base of the air column, we have P_o given by observation, and the problem of reduction is to compute P which represents the pressure at the top of the air column.

Equation (1) is valid for both cases (a) and (b), assuming H_{pg} and T_{mv} to be determined appropriately to fit the circumstances, thus permitting the corresponding value of r to be ascertained with the aid of Table 7.5. In the following we explain how eq. (1) is applied in the two cases.

7.3.4.1 Case (a): Downward Reduction.—Equation (1) may be written

$$P_o = Pr. \qquad (1A)$$

Subtracting P from both left- and right-hand members of eq. (1A), we obtain

$$(P_o - P) = Pr - P = P(r - 1). \; (1B)$$

For this problem of downward reduction we have P as given for the top of the air column and can find r on the basis of H_{pg} and T_{mv}. Thus, with the aid of eq. (1A) we can readily compute the desired pressure P_o which pertains to the base of the air column. Eq. (1A) is convenient to use when the problem arises only occasionally, or when one has a calculator or slide rule to perform the indicated multiplication.

Eq. (1B) is most convenient to use when the results are desired in the form of a correction, $P(r - 1)$; for one can see obviously from eq. (1B) that it has the following application:

$$P_o = P + (P_o - P) = P + P\,(r - 1). \qquad (1C)$$

That is, the correction, $P(r - 1)$, applied to the pressure P existing at the top of the air column, yields the pressure P_o referring to the base of the air column.

By virtue of eq. (1A) we may obviously compute a table presenting P_o as a function of P and r; also, by virtue of eq. (1B) we may compute a table showing the correction $(P_o - P)$ as a function of P and r. However, we can go a step further when r is

T_{mv} °R	Station pressure (in inches of mercury) at geopotential 1658.7 gpm.									
	23.00	23.10	23.20	→ etc. →	24.50	24.60	→ etc. →	25.80	25.90	26.00
	in. Hg.	in Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.
410°	23.216	23.317	23.418	→ etc. →	24.730	24.831	→ etc. →	26.042	26.143	26.244
411°	23.216	23.316	23.417		24.730	24.831		26.042	26.143	26.244
412°	23.215	23.316	23.417		24.729	24.830		26.041	26.142	26.243
413°	23.214	23.315	23.416		24.728	24.829		26.040	26.141	26.242
414°	23.214	23.315	23.416		24.728	24.829		26.040	26.141	26.242
415°	23.213	23.314	23.415		24.727	24.828		26.039	26.140	26.241
etc.										
470°	23.188	23.289	23.390		24.701	24.801		26.011	26.112	26.213
471°	23.188	23.289	23.390		24.700	24.801		26.011	26.112	26.212
472°	23.187	23.288	23.389		24.700	24.800		26.010	26.111	26.212
473°	23.187	23.288	23.389		24.699	24.800		26.010	26.111	26.211
474°	23.187	23.287	23.388		24.699	24.800		26.009	26.110	26.211
475°	23.186	23.287	23.388		24.698	24.799		26.009	26.110	26.210
etc.										
485°	23.182	23.283	23.384		24.694	24.795		26.004	26.105	26.206
486°	23.182	23.283	23.384		24.694	24.795		26.004	26.105	26.206
487°	23.181	23.282	23.383		24.693	24.794		26.004	26.104	26.205
488°	23.181	23.282	23.383		24.693	24.794		26.003	26.104	26.205
489°	23.181	23.282	23.382		24.693	24.793		26.003	26.104	26.204
490°	23.181	23.281	23.382		24.692	24.793		26.003	26.103	26.204
etc.										
515°	23.172	23.273	23.373		24.683	24.784		25.993	26.093	26.194
516°	23.171	23.272	23.373		24.683	24.783		25.992	26.093	26.194
517°	23.171	23.272	23.373		24.682	24.783		25.992	26.093	26.193
518°	23.171	23.271	23.372		24.682	24.783		25.991	26.092	26.193
519°	23.170	23.271	23.372		24.682	24.782		25.991	26.092	26.193
520°	23.170	23.271	23.371		24.681	24.782		25.991	26.091	26.192
etc.										
555°	23.159	23.260	23.361		24.670	24.770		25.979	26.079	26.180
556°	23.159	23.260	23.360		24.669	24.770		25.978	26.079	26.180
557°	23.159	23.259	23.360		24.669	24.770		25.978	26.079	26.179
558°	23.158	23.259	23.360		24.669	24.769		25.978	26.078	26.179
559°	23.158	23.259	23.360		24.669	24.769		25.978	26.078	26.179
560°	23.158	23.259	23.359		24.668	24.769		25.977	26.078	26.179

FIGURE 7.3.5. Example *A*. Tabular values are pressures (in inches of mercury) reduced to the level of geopotential 1596.4 gpm.

Example A

T_{mv} °R	Station pressure (in inches of mercury) at geopotential 1658.7 gpm.									
	23.00	23.10	23.20	→etc.→	24.50	24.60	→etc.→	25.80	25.90	26.00
	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.
410°	0.216	0.217	0.218	→etc.→	0.230	0.231	→etc.→	0.242	0.243	0.244
411°	0.216	0.216	0.217		0.230	0.231		0.242	0.243	0.244
412°	0.215	0.216	0.217		0.229	0.230		0.241	0.242	0.243
413°	0.214	0.215	0.216		0.228	0.229		0.240	0.241	0.242
414°	0.214	0.215	0.216		0.228	0.229		0.240	0.241	0.242
415°	0.213	0.214	0.215		0.227	0.228		0.239	0.240	0.241
etc.										
470°	0.188	0.189	0.190		0.201	0.201		0.211	0.212	0.213
471°	0.188	0.189	0.190		0.200	0.201		0.211	0.212	0.212
472°	0.187	0.188	0.189		0.200	0.200		0.210	0.211	0.212
473°	0.187	0.188	0.189		0.199	0.200		0.210	0.211	0.211
474°	0.187	0.187	0.188		0.199	0.200		0.209	0.210	0.211
475°	0.186	0.187	0.188		0.198	0.199		0.209	0.210	0.210
etc.										
485°	0.182	0.183	0.184		0.194	0.195		0.204	0.205	0.206
486°	0.182	0.183	0.184		0.194	0.195		0.204	0.205	0.206
487°	0.181	0.182	0.183		0.193	0.194		0.204	0.204	0.205
488°	0.181	0.182	0.183		0.193	0.194		0.203	0.204	0.205
489°	0.181	0.182	0.182		0.193	0.193		0.203	0.204	0.204
490°	0.181	0.181	0.182		0.192	0.193		0.203	0.203	0.204
etc.										
515°	0.172	0.173	0.173		0.183	0.184		0.193	0.193	0.194
516°	0.171	0.172	0.173		0.183	0.183		0.192	0.193	0.194
517°	0.171	0.172	0.173		0.182	0.183		0.192	0.193	0.193
518°	0.171	0.171	0.172		0.182	0.183		0.191	0.192	0.193
519°	0.170	0.171	0.172		0.182	0.182		0.191	0.192	0.193
520°	0.170	0.171	0.171		0.181	0.182		0.191	0.191	0.192
etc.										
555°	0.159	0.160	0.161		0.170	0.170		0.179	0.179	0.180
556°	0.159	0.160	0.160		0.169	0.170		0.178	0.179	0.180
557°	0.159	0.159	0.160		0.169	0.170		0.178	0.179	0.179
558°	0.158	0.159	0.160		0.169	0.169		0.178	0.178	0.179
559°	0.158	0.159	0.160		0.169	0.169		0.178	0.178	0.179
560°	0.158	0.159	0.159		0.168	0.169		0.177	0.178	0.179

FIGURE 7.3.6. Example *A*. Tabular values are pressure corrections, $(P_o - P)$, in inches of mercury, to reduce pressure from a station whose geopotential is 1658.7 gpm. to a level of geopotential 1596.4 gpm.

tabulated as a function of T_{mv} as indicated by the three examples in sec. 7.3.3, for given values of H_{pg}. Thus, under these circumstances we may prepare a table showing P_o or $(P_o - P)$ as functions of P and T_{mv} (see figs. 7.3.5 and 7.3.6). To accomplish this, for each line of the table pertaining to a given value of T_{mv}, one must employ the corresponding appropriate value of r, for the given parameter H_{pg}, and apply eq. (1A) or eq. (1B), whichever is required. These operations yield final tables such as those illustrated in figs. 7.3.5 and 7.3.6, in skeleton form, with reference to the Example A referred to in secs. 7.3.1 and 7.3.3. This example refers to downward reduction from a station whose geopotential is 1658.7 gpm to another level whose geopotential is 1596.4 gpm, which yields the amount 62.3 gpm as the vertical extent of the air column.

A table such as that shown in fig. 7.3.6 is useful in connection with the comparison of barometers observed at different levels in a given neighborhood (see secs. 6.5.11 and 6.6.2; also Example A, sec. 7.3.1).

As an illustration of the use of the table such as Fig. 7.3.6, consider Example A, sec. 7.3.1, in the case of the arguments where the station pressure (P) at geopotential 1658.7 gpm is 24.500 inches of mercury (in. Hg) and $T_{mv} = 285°$ R. From Fig. 7.3.6 we find that $(P_o - P) = 0.194$ inch of mercury (in. Hg) under these conditions. Therefore, in accord with eq. (1C), we obtain the result

T_{mv} °R.	B [1/r]	C [1/r]	T_{mv} °R.	B [(r-1)/r]	C [(r-1)/r]
410°	0.99387	0.83214	410°	0.006132	0.167859
411°	0.99389	0.83251	411°	0.006112	0.167492
412°	0.99390	0.83288	412°	0.006103	0.167118
413°	0.99391	0.83325	413°	0.006093	0.166750
414°	0.99392	0.83362	414°	0.006083	0.166382
415°	0.99393	0.83399	415°	0.006073	0.166006
etc.			etc.		
470°	0.99464	0.85189	470°	0.005361	0.148110
471°	0.99466	0.85218	471°	0.005341	0.147819
472°	0.99467	0.85247	472°	0.005331	0.147529
473°	0.99468	0.85275	473°	0.005322	0.147245
474°	0.99469	0.85305	474°	0.005312	0.146954
475°	0.99470	0.85334	475°	0.005302	0.146663
etc.			etc.		
485°	0.99481	0.85612	485°	0.005193	0.143880
486°	0.99482	0.85639	486°	0.005183	0.143608
487°	0.99483	0.85666	487°	0.005173	0.143337
488°	0.99484	0.85694	488°	0.005163	0.143058
489°	0.99485	0.85721	489°	0.005153	0.142786
490°	0.99486	0.85749	490°	0.005143	0.142514
etc.			etc.		
515°	0.99511	0.86392	515°	0.004886	0.136084
516°	0.99512	0.86415	516°	0.004876	0.135845
517°	0.99513	0.86440	517°	0.004866	0.135599
518°	0.99514	0.86464	518°	0.004856	0.135359
519°	0.99515	0.86488	519°	0.004846	0.135120
520°	0.99516	0.86513	520°	0.004836	0.134873
etc.			etc.		
555°	0.99547	0.87307	555°	0.004529	0.126935
556°	0.99547	0.87328	556°	0.004529	0.126721
557°	0.99548	0.87349	557°	0.004519	0.126508
558°	0.99548	0.87371	558°	0.004519	0.126294
559°	0.99549	0.87392	559°	0.004510	0.126080
560°	0.99549	0.87413	560°	0.004510	0.125866

FIGURE 7.3.7. Illustration of skeleton tables which give as tabular values the factors $[1/r]$ and $[(r-1)/r]$ as functions of T_{mv} pertinent to Examples B and C for upward reduction: ($H_{pg} = 41.1$ gpm. for B, and $H_{pg} = 1225.9$ gpm. for C).

$$\begin{aligned} P_o &= P + (P_o - P) \\ &= 24.500 \text{ in. Hg} + (0.194 \text{ in. Hg}) \\ &= 24.694 \text{ inches of mercury.} \end{aligned}$$

This is in agreement with the result yielded by the table in Fig. 7.3.5 for the same two arguments.

7.3.4.2 Case (b): Upward Reduction.—In the case of upward reduction, we have given P_o the pressure observed at the base of the air column; and it is necessary to compute P, the pressure at the top of the air column. The latter then must be regarded as a "reduced pressure," based on the process of

EXAMPLE B

T_{mv} °R	P_o = Pressure at base of air column, inches of mercury.									
	23.00	23.10	23.20 →	etc. →	24.50	24.60 →	etc. →	25.80	25.90	26.00
	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.
410°	22.859	22.958	23.058 →	etc. →	24.350	24.449 →	etc. →	25.642	25.741	25.841
411°	22.859	22.959	23.058		24.350	24.450		25.642	25.742	25.841
412°	22.860	22.959	23.058		24.351	24.450		25.643	25.742	25.841
413°	22.860	22.959	23.059		24.351	24.450		25.643	25.742	25.842
414°	22.860	22.960	23.059		24.351	24.450		25.643	25.743	25.842
415°	22.860	22.960	23.059		24.351	24.451		25.643	25.743	25.842
etc.										
485°	22.881	22.980	23.080		24.373	24.472		25.666	25.766	25.865
486°	22.881	22.980	23.080		24.373	24.473		25.666	25.766	25.865
487°	22.881	22.981	23.080		24.373	24.473		25.667	25.766	25.866
488°	22.881	22.981	23.080		24.374	24.473		25.667	25.766	25.866
489°	22.882	22.981	23.081		24.374	24.473		25.667	25.767	25.866
490°	22.882	22.981	23.081		24.374	24.474		25.667	25.767	25.866

EXAMPLE C

T_{mv} °R	P_o = Pressure at base of air column, inches of mercury									
	24.60	24.70	24.80 →	etc. →	26.20	26.30 →	etc. →	27.60	27.70	27.80
	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.
410°	20.471	20.554	20.637 →	etc. →	21.802	21.885 →	etc. →	22.967	23.050	23.134
411°	20.480	20.563	20.646		21.812	21.895		22.977	23.060	23.144
412°	20.489	20.572	20.655		21.821	21.905		22.987	23.071	23.154
413°	20.498	20.581	20.665		21.831	21.914		22.998	23.081	23.164
414°	20.507	20.590	20.674		21.841	21.924		23.008	23.091	23.175
415°	20.516	20.600	20.683		21.851	21.934		23.018	23.102	23.185
etc.										
485°	21.061	21.146	21.232		22.430	22.516		23.629	23.715	23.800
486°	21.067	21.153	21.238		22.437	22.523		23.636	23.722	23.808
487°	21.074	21.160	21.245		22.444	22.530		23.644	23.729	23.815
488°	21.081	21.166	21.252		22.452	22.538		23.652	23.737	23.823
489°	21.087	21.173	21.259		22.459	22.545		23.659	23.745	23.830
490°	21.094	21.180	21.266		22.466	22.552		23.667	23.752	23.838

FIGURE 7.3.8. Illustration of skeleton tables which give as tabular values P, the pressure at the top of the air column, as a function of T_{mv} and P_o, the pressure at the base of the air column, pertinent to Examples B and C of sec. 7.3.1 (cases of upward reduction).

upward reduction. As a basis for this process, we divide the left- and right-hand members of eq. (1A) by the ratio r, thus obtaining

$$P = P_o/r = P_o[1/r]. \qquad (1D)$$

Substituting eq. (1D) in the right-hand member of eq. (1B), and multiplying the result by (—1), we secure the result

$$[-(P_o - P)] = -P_o(r-1)/r = -P_o[(r-1)/r]. \qquad (1E)$$

The application of eq. (1E) is shown by the following relationship:

$$P = P_o + [-(P_o - P)] = P_o + [-P_o(r-1)/r]. \qquad (1F)$$

The term represented in eq. (1E) is a correction, and it is always negative.

For any problem of upward reduction we can find r on the basis of H_{pg} and T_{mv} by referring to Table 7.5, thus obtaining results such as those illustrated in fig. 7.3.4. Examples B and C of sec. 7.3.1 involve upward reduction, and fig. 7.3.4 shows the quantity r corresponding to T_{mv} over a certain range, based on appropriate values of H_{pg} for these examples.

Equations (1D and (1E) obviously require division by r. However, one finds that on being faced with the problem of applying these relationships repeatedly, as when making computations by means of a calculating machine, an advantage is gained by using the forms of those equations which involve the expressions in brackets. That is,

EXAMPLE B

T_{mv}	P_o = Pressure at base of air column, inches of mercury.									
°R.	23.00	23.10	23.20	→ etc →	24.50	24.60	→ etc →	25.80	25.90	26.00
	in.Hg.	in.Hg.	in.Hg.	in.Hg.	in.Hg.	in.Hg.	in.Hg.	in.Hg.	in.Hg.	in.Hg.
410°	-0.141	-0.142	-0.142	→ etc →	-0.150	-0.151	→ etc. →	-0.158	-0.159	-0.159
411°	-0.141	-0.141	-0.142		-0.150	-0.150		-0.158	-0.158	-0.159
412°	-0.140	-0.141	-0.142		-0.150	-0.150		-0.157	-0.158	-0.159
413°	-0.140	-0.141	-0.141		-0.149	-0.150		-0.157	-0.158	-0.158
414°	-0.140	-0.141	-0.141		-0.149	-0.150		-0.157	-0.158	-0.158
415°	-0.140	-0.140	-0.141		-0.149	-0.149		-0.157	-0.157	-0.158
etc.										
485°	-0.119	-0.120	-0.120		-0.127	-0.128		-0.134	-0.134	-0.135
486°	-0.119	-0.120	-0.120		-0.127	-0.128		-0.134	-0.134	-0.135
487°	-0.119	-0.119	-0.120		-0.127	-0.127		-0.133	-0.134	-0.134
488°	-0.119	-0.119	-0.120		-0.126	-0.127		-0.133	-0.134	-0.134
489°	-0.119	-0.119	-0.120		-0.126	-0.127		-0.133	-0.133	-0.134
490°	-0.118	-0.119	-0.119		-0.126	-0.127		-0.133	-0.133	-0.134

EXAMPLE C

T_{mv}	P_o = Pressure at base of air column, inches of mercury.									
°R.	24.60	24.70	24.80	→ etc →	26.20	26.30	→ etc. →	27.60	27.70	27.80
	in.Hg.	in.Hg.	in.Hg.	in.Hg.	in.Hg.	in.Hg.	in.Hg.	in.Hg.	in.Hg.	in.Hg.
410°	-4.129	-4.146	-4.163	→ etc →	-4.398	-4.415	→ etc. →	-4.633	-4.650	-4.666
411°	-4.120	-4.137	-4.154		-4.388	-4.405		-4.623	-4.640	-4.656
412°	-4.111	-4.128	-4.145		-4.378	-4.395		-4.612	-4.629	-4.646
413°	-4.102	-4.119	-4.135		-4.369	-4.386		-4.602	-4.619	-4.636
414°	-4.093	-4.110	-4.126		-4.359	-4.376		-4.592	-4.609	-4.625
415°	-4.084	-4.100	-4.117		-4.349	-4.366		-4.582	-4.598	-4.615
etc.										
485°	-3.539	-3.554	-3.568		-3.770	-3.784		-3.971	-3.985	-4.000
486°	-3.533	-3.547	-3.561		-3.763	-3.777		-3.964	-3.978	-3.992
487°	-3.526	-3.540	-3.555		-3.755	-3.770		-3.956	-3.970	-3.985
488°	-3.519	-3.534	-3.548		-3.748	-3.762		-3.948	-3.963	-3.977
489°	-3.513	-3.527	-3.541		-3.741	-3.755		-3.941	-3.955	-3.969
490°	-3.506	-3.520	-3.534		-3.734	-3.748		-3.933	-3.948	-3.962

FIGURE 7.3.9. Illustration of skeleton tables which give as tabular values $[-(P_o - P)]$, which is the correction to reduce pressure from the base to the top of the air column pertinent to Examples *B* and *C* of sec. 7.3.1 (cases of upward reduction). The correction is shown as a function of T_{mv} and P_o, pressure at the base of the air column.

the factors shown as terms in brackets may be computed first by division; and then the equations (1D) and (1E) with these factors are set up to yield the required results by multiplication.

Fig. 7.3.7 illustrates a skeletonized tabulation of the factors $[1/r]$ and $[(r-1)/r]$ as functions of T_{mv} to suit the values of H_{pg} applicable to Examples B and C, sec. 7.3.1.

Fig. 7.3.8 illustrates tables for upward reduction based on the application of eq. (1D), where use is made of the factors $[1/r]$ given in fig. 7.3.7 with regard to Examples B and C. Thus, fig. 7.3.8 discloses particular cases where P is presented as a function of P_o and T_{mv}, for these two examples.

Fig. 7.3.9 illustrates tables for upward reduction where the correction $[-(P_o - P)]$ is given as a function of P_o and T_{mv}, with reference to the same two examples. This figure is based on the application of eqs. (1E) and (1F), use being made of the factors $[(r-1)/r]$ tabulated in fig. 7.3.7 with regard to Examples B and C. It should be noted by virtue of eq. (1F) that the correction $[-(P_o-P)]$ must be applied *algebraically* to the quantity P_o in order to obtain P.

For example, if $P_o = 24.500$ inches of mercury, and $T_{mv} = 485°$ R., we have in the case of Example B that the factor $[(r-1)/r]$ has the value 0.00519. Therefore, according to eq. (1F) the correction for this set of conditions is the expression $[-(P_o - P)] = -P_o[(r-1)/r] = -0.127$ as revealed by the data in fig. 7.3.9. Hence it follows on the basis of eq. (1F) that

$P = 24.500$ in. Hg $+ (-0.127$ in. Hg), i.e.
$P = 24.373$ inches of mercury.

A similar result is obtained directly by reference to fig. 7.3.8, where use is made of the same arguments for P_o and T_{mv}.

As a further case of upward reduction consider Example C, sec. 7.3.1; in this instance we shall take as arguments the following values: $P_o = 26.200$ inches of mercury (in. Hg) and $T_{mv} = 490°$ R. Table 7.3.7 yields for the factor $[1/r]$ the value 0.85749; and for the factor $[(r-1)/r]$ the value 0.14251; corresponding to the argument $T_{mv} = 490°$ R. According to Table 7.3.9, the correction $[-(P_o - P)]$ corresponding to the two specified arguments is represented by the quantity —3.734 inches of mercury. On the basis of eq. (1F), we therefore obtain

$$P = P_o + [-(P_o - P)]$$
$$P = 26.200 \text{ in. Hg} + (-3.734 \text{ in. Hg})$$
$$P = 22.466 \text{ inches of mercury.}$$

Reference to fig. 7.3.8 indicates that on using equivalent arguments P_o and T_{mv} the same result is secured directly for the quantity P, in accord with eq. (1D).

A table like that presented in fig. 7.3.9 is extremely useful as an aid when barometer readings made at different levels are to be compared (see secs. 6.5.11 and 6.6.2; also Example B, sec. 7.3.1).

Since $[-(P_o - P)] = (P - P_o)$, the *minus* sign preceding the numerical values in the body of the sample table presented in fig. 7.3.9 simply indicates that the pressure at the top of the air column is less than the pressure at the bottom of the air column.

CHAPTER 8. ALTIMETRY

8.0 GENERAL INFORMATION

8.0.0 Introduction

This chapter is intended to provide information on the subject of sensitive pressure altimeters, their applications for the measurement and control of altitude in aviation, and related matters. Little will be said concerning the maintenance or the mechanical features of altimeters, for these items are left to be treated in manuals dealing with maintenance of aeronautical instruments. Emphasis, rather, is placed here upon the meteorological factors which affect altimeters and which must be taken into consideration in making a sound interpretation of their readings. Various sources of error are discussed, briefly in certain cases and at some length in others, depending upon their significance and relevance from the standpoint here adopted.

Since altimeters are calibrated in accordance with the Standard Atmosphere, Appendix 8.0.1 on the subject of this atmosphere is included under Chapter 12, while a brief summary of certain items connected with this matter is presented in sec. 8.0.2. Inasmuch as a good deal of special terminology pertinent to the matter is currently being used, a section is devoted to a collection of definitions of relevant terms such as altimeter setting, pressure altitude, density altitude, etc.

Instructions for computing these quantities are set forth.

Figs. 8.0.1, 8.0.2, 8.0.3, 8.0.4, and 8.0.5 illustrate views of the faces of five different sensitive pressure altimeters.

8.0.1 Functions of Altimeters

Altimeters are used principally for the following purposes which require the measurement or control of the altitude of aircraft with respect to sea level or some other reference surface:

(1) landing at an airport;

(2) vertical separation between aircraft flying in different directions on an airway, or elsewhere;

(3) vertical clearance of terrain under instrument flying conditions;

(4) miscellaneous aircraft operations that require a knowledge of pressure altitude and other parameters; for example, the setting of engine controls for power or thrust on the basis of pressure altitude and air temperature; establishment of optimum cruising speed by means of density altitude which depends upon the two factors last mentioned; air navigation conducted to take account of pressure pattern flying, that is, by cruising on minimum time routes, determined with the aid of the pressure altitude, air temperature, and other factors which are involved; etc.

Altimeters may also be used to compare the elevations of two or more points on the surface, within an area of limited extent. Accordingly, they are often applied to measure the height of mountains; but this application is really a case of hypsometry (see Chapter 9), for which purpose temperature corrections must be taken into account if accurate results are desired.

8.0.2 Standard Atmosphere and Pressure Altitude

8.0.2.0 General Information.—The Standard Atmosphere has been established by international agreement to provide primarily a standard relationship between pressure and altitude for the calibration of pressure altimeters.[1]

Standard density of air computed on the basis of the correlated pressure and temperature in this atmosphere has also been utilized in the calibration of airspeed indicators, and for the correction of readings to determine true airspeed. Additionally, the Standard Atmosphere has been defined to serve as a fixed standard of reference in

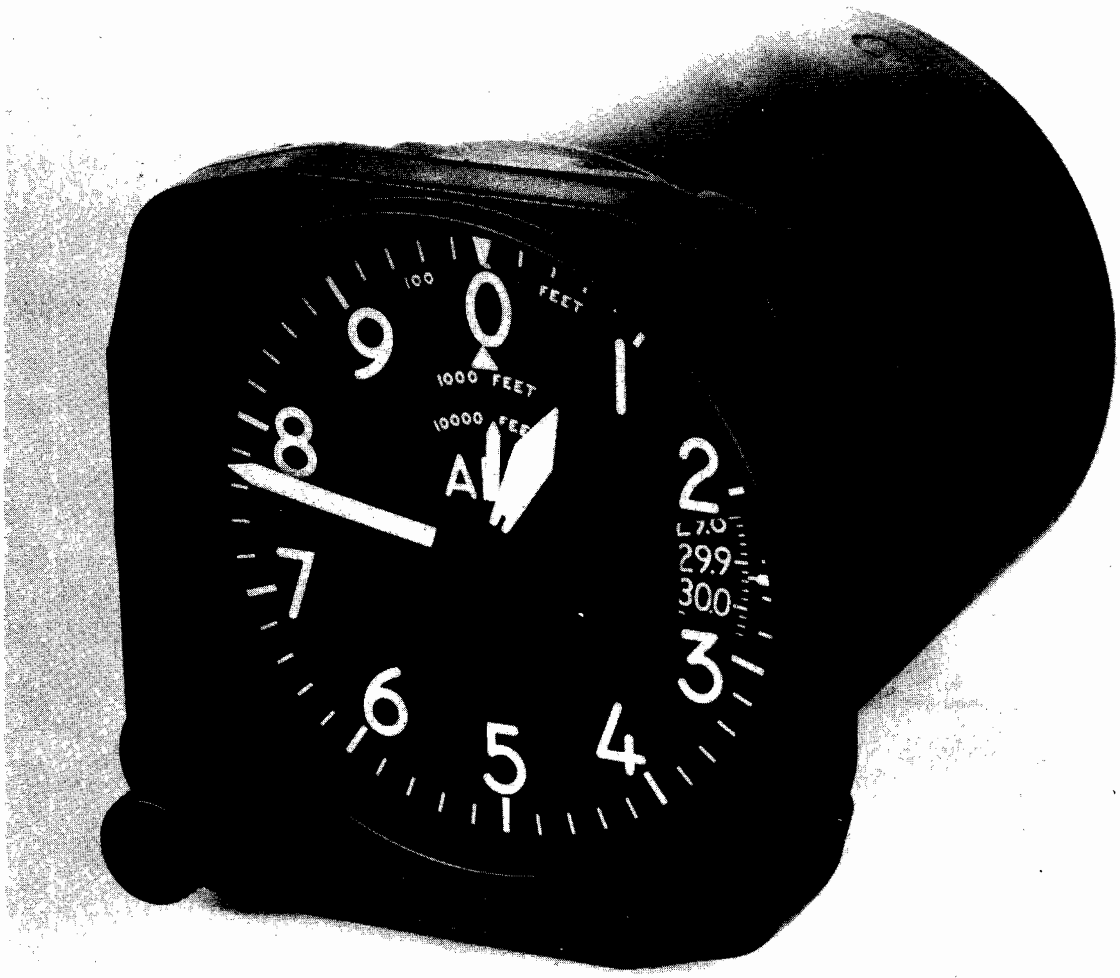

Figure 8.0.1. Altimeter, sensitive pressure. This illustrates the old standard altimeter having 3 concentrically mounted pointers all reading in feet with reference to a single uniformly graduated scale. A large pointer indicates hundreds of feet and makes one revolution for each 1000 feet of altitude, an intermediate pointer indicates thousands of feet and makes one revolution for each 10,000 feet, and a small pointer indicates tens of thousands of feet. The indicated altitude shown in this figure is about 800 feet. The altimeter setting scale which is controlled by a setting knob is visible through a window in the dial. The altimeter setting illustrated is 29.92 inches of mercury.

terms of which to represent or compare atmospheric conditions existent during aeronautical tests or under any specified circumstances of observation.

Detailed specifications regarding the ICAO Standard Atmosphere are published by the International Civil Aviation Organization[1] and by the U.S. National Advisory Committee for Aeronautics (NACA).[2]

Appendix 8.0.1 of this Manual of Barometry contains an account of the basic specifications for the convenience of readers.

The ICAO Standard Atmosphere is now official for the United States in view of the action by the ICAO Council on November 7, 1952, to approve it, and the adoption of this standard by the National Advisory Committee for Aeronautics on November 20, 1952. The previous U.S. Standard Atmosphere defined in NACA Report 218 is superseded by

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[1] International Civil Aviation Organization, "Manual of ICAO Standard Atmosphere," Doc. 7488, Montreal, Canada (May 1954).

[2] National Advisory Committee for Aeronautics, "Standard Atmosphere—Tables and Data for Altitudes to 65,800 Feet," NACA Report No. 1235, Washington, D.C. (1955).

Figure 8.0.2. Altimeter, pressure (modified dial presentation) type MA-1. A large pointer indicates hundreds of feet and makes one revolution for each 1000 feet of altitude, and an intermediate pointer indicates thousands of feet and makes one revolution for each 10,000 feet. In addition, a small pointer indicating tens of thousands of feet is painted on a black disk with an extension line terminating in a triangular section. This provides a conspicuous indication which the pilot can use to get his approximate altitude at a quick glance. In addition, a sixty degree section marked with alternate diagonal fluorescent and black markings is provided at the bottom of the dial above the digit "5." The striped warning area is visible between zero altitude and 17,000 feet. This provides a conspicuous warning of the approach to lower altitude.

the ICAO Standard Atmosphere which has international acceptance.

It is worthy of note that the National Advisory Committee for Aeronautics accepted and adopted for use in altimetry and airspeed computations, the following conversion factors which had been adopted by the ICAO:[2]

1 inch = 2.54 centimeters (exactly)

1 pound = 0.4535923 kilogram (exactly)

The following list represents a brief summary of the principal meteorological features of the standard atmosphere as assumed under the specifications:

(1) Standard pressure at sea level, $P_o =$ 1013.250 mb. (29.921 in. Hg)

(2) Standard temperature at sea level, $t_o =$ 15° C. (59° F.; 518.688° R.; 288.16° K.)

(3) Standard lapse rate of troposphere, $a = 0.0065°$ C. per m′

(4) Standard temperature of tropopause and isothermal portion of stratosphere, $t^* = -56.5°$ C. (−69.7° F.; 389.988° R.; 216.66° K.)

(5) Standard altitude (geopotential) of tropopause, $H^* =$ 11,000 m′ (36,089 ft′)

(6) Upper altitude limit of standard isothermal portion of stratosphere[3] = 20,000 m′.

Fig. 8.0.6(A) illustrates graphically these assumptions on which the standard atmos-

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[3] See Appendix 8.0.1 and reference 19, p. 8-67.

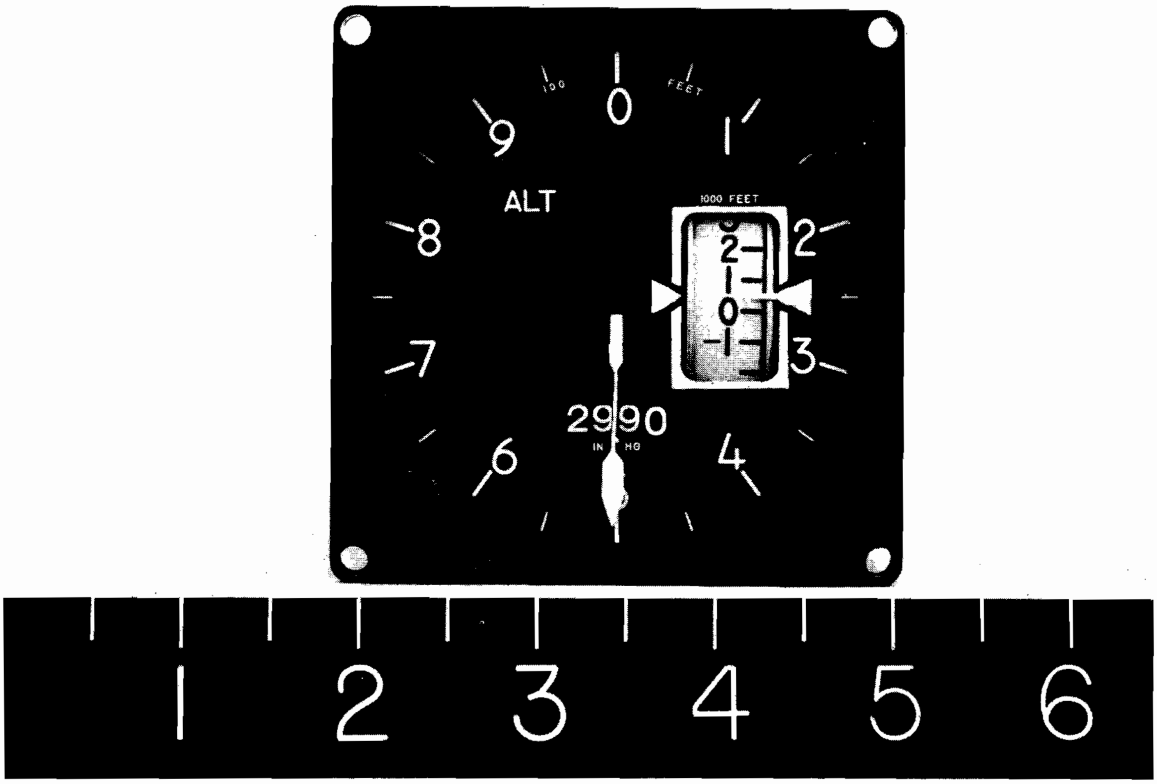

FIGURE 8.0.3. Drum-Pointer type altimeter. In an effort to simplify the altimeter display and to eliminate reading error, a "Drum-Pointer" type altimeter is proposed. This altimeter is comparable in size and weight to the present standard altimeter. The "Drum-Pointer" type altimeter provides indications of thousands of feet on a drum, visible through a vertical window in the dial. Indication of hundreds of feet is obtained from a single pointer on the main dial. In addition, improved presentation of the barometric pressure scale is accomplished by use of a 4 digit "Veeder" type counter in lieu of the window type. It is believed that the use of the "Drum-Pointer" type altimeter display will materially reduce the incidence of erroneous altimeter interpretation by pilots.

phere is based, except that there are shown certain revisions and an extension in respect to altitude as recommended to ICAO by the United States in 1962. More details concerning the original ICAO Standard Atmosphere adopted in 1952 will be found in NACA Report 1235 and in Appendix 8.0.1. As outlined in the Notes following par. 2.11 of Appendix 8.0.1, the U.S. Committee on Extension of the Standard Atmosphere in 1962 proposed revisions in the specifications of the standard atmosphere and an extension of the data pertaining to the altitude range.

Height above sea level in the standard atmosphere is expressed in terms of geopotential, using special units, either metric or English. In metric measures the unit is called "the standard geopotential meter" (symbol m′); while in English measures the unit is termed "the standard geopotential foot" (symbol ft′). The sizes of these units have been so chosen that if one measures the vertical distance between two points in the lower atmosphere, the distance in geometric meters (or feet) as determined by tape measure would very nearly be the same as the difference in geopotential between the two points, expressed in terms of the above mentioned units, m′ (or ft′). The data in fig. 8.0.7 illustrate how closely the geopotentials expressed in ft′ agree in numerical value with the geometric altitudes in feet, at three different latitudes.

Inasmuch as many people are not familiar with the concept of geopotential (see sec. 1.3.1–1.3.6; and Appendix 1.3.1) and owing to the fact that the numerical values in ft′ (or m′) agree closely with those in feet (or

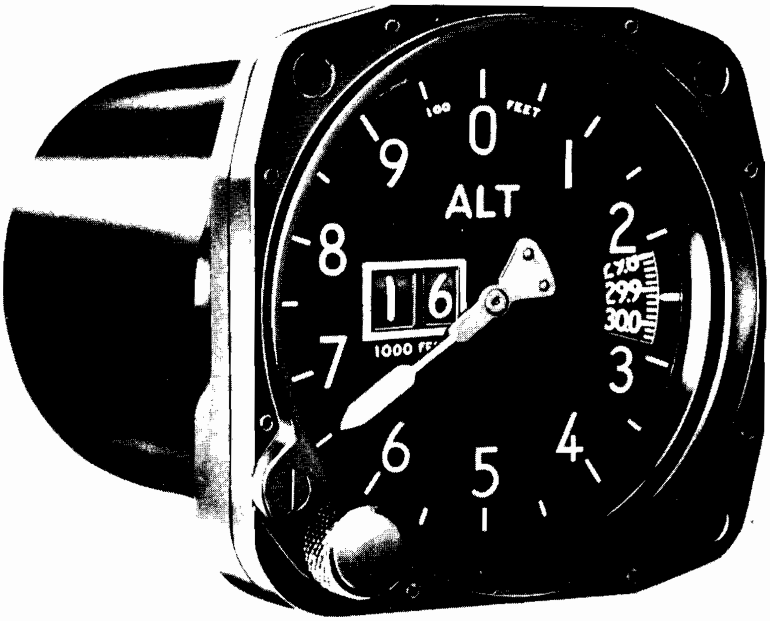

FIGURE 8.0.4. Counter-Pointer altimeter MIL–A–19679. Pointer indicates hundreds of feet, making one revolution per thousand feet. Counter digits indicate thousands and tens of thousands of feet. (Altimeter in illustration reads 16,650 feet). Tolerances and performance requirements are essentially the same as the standard MIL–A–6863 altimeter.

meters) users of the data often disregard the distinction between geopotential and geometric altitude. Going a step further, it is conventional practice among aeronautical engineers and aviators to employ the term "*pressure altitude*" in referring to the geopotential which corresponds to any given pressure in the standard atmosphere. We shall adhere to this practice.

Appendix 8.0.1 sets forth the "pressure-altitude relationships" pertaining to the standard atmosphere, and indicates their mathematical derivation.

8.0.2.1 Definition of "Pressure Altitude." —The term "Pressure Altitude" is used to represent the height above sea level in the standard atmosphere at which a given pressure occurs. In this case "height above sea level" will be understood to be expressed on the basis of standard geopotential units, ft′ or m′.

Owing to this definition, the "pressure altitude" (H, in ft′ or m′) for any particular situation is determined by the pressure (P), which must always be specified. That is, for each value of P there is a corresponding "pressure altitude", since H is a function of P, as indicated by the equations (Ib) and (IIb), Appendix 8.0.1. See also sec. 8.4.

Table 8.1 which stems from this basis, contains values of "pressure altitude" corresponding to various pressures, over the range from 15.00 to 32.90 inches of mercury. Tables in NACA Report 1235 should be consulted if different units or values covering a wider range are involved.

In applying the pressure-altitude data to altimetry, it is often necessary to use these tables either directly or inversely as illustrated below; and the user must always keep in mind that when P is *less than* 29.921 in. Hg (1013.25 mb.), H is positive, but when P is *greater than* 29.921 in. Hg, H is negative.

Examples

Direct use of Table 8.1		Inverse use of Table 8.1	
Given: *P* pressure (in. Hg)	To find: *H* pressure altitude	Given: *H* pressure altitude	To find: *P* pressure
	ft.′	*ft.′*	*in. Hg*
17.57	14,010	10,000	20.577
29.69	215	775	29.093
29.921	0	0	29.921
30.12	−183	−380	30.334
30.58	−604	−796	30.792

It is often convenient to recall from these data that for pressures within about an inch of mercury greater and less than 29.921 in. Hg, a pressure change of 1 in. Hg produces a change of 925 ft′ in pressure altitude. Considering this relationship in round numbers, a pressure change of 0.10 in. Hg produces a change of nearly 100 ft′ in pressure altitude, or 0.01 in. Hg corresponds to roughly 10 ft′.

Fig. 8.0.6(B) illustrates that when *H* is plotted against *P* it yields a curve. This curve is a graphical representation of the basis on which the pressure altimeter is calibrated.

8.0.2.2 Definition of "Density Altitude."—The term "density altitude" pertaining to any point in the actual atmosphere for which the existing air density is known denotes the altitude above sea level in the standard atmosphere characterized by the known air density.

When the air temperature, pressure, and humidity are observed at any point, the air density pertinent to these data may be readily computed. (See equation 12, Appendix 7.1; also Smithsonian Meteorological Tables, Sixth Revised Edition, R. J. List, Editor; First Reprint, published by the Smithsonian Institution, Washington, D. C., 1958, pages 290–301.)

In order to determine the density altitude which corresponds to the air density thus computed, one may refer to tables which show density as a function of altitude in the standard atmosphere, and thereby find the required density altitude from the tables as the height above sea level at which the given density occurs. Tables of this kind have been published.[4]

An alternative method of ascertaining the density altitude is to make use of a specially designed chart which indicates density altitude for various values of pressure and temperature (see Smithsonian Meteorological Tables, p. 285, or fig. 8.0.6(C) herein where such a chart is presented).

8.0.3 Fundamental Basis of Altimeter Operation

8.0.3.0 Introduction.—In this section the treatment of the subject is predicated on the assumption that the altimeter is free from all sources of error and is perfectly calibrated. Information regarding various sources of error is presented in a later section.

8.0.3.1 Models Illustrating Basis of Altimeter.—Pressure altimeters contain an internal mechanism which is essentially an aneroid barometer calibrated in accordance with the pressure-altitude relationships of the standard atmosphere. The pointers of the typical altimeter are actuated by changes of pressure exerted on the aneroid element. Consequently, the pointers show deflections with respect to the base of the internal mechanism as the ambient pressure varies. This mechanism will be understood to include suitable cams, gears, levers, and other devices, designed for a special purpose. The primary purpose is to permit the calibration on a uniform scale of pressure altitude when the instrument is set on the standard

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[4] National Advisory Committee for Aeronautics, Report 1235, "Standard Atmosphere—Tables and Data for Altitudes to 65,800 Feet," published by the U.S. Government Printing Office, Washington 25, D.C., 1955. (See pages 8–13, and 64–72.)

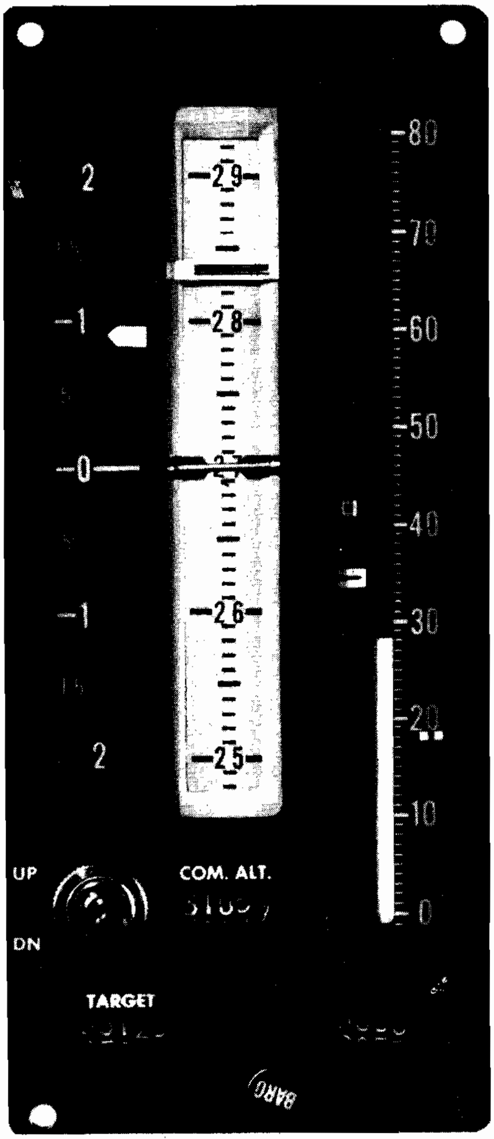

FIGURE 8.0.5. Altimeter—vertical speed indicator (WCLC–56–134). This illustrates a type of altitude—vertical speed indicator. Command and target altitudes are presented by means of translational motions of symbols along vertical scales as well as indication on five digit counters. Sensitive altitude is presented by means of moving scales against fixed index marks. Gross altitude is presented by means of a thermometer type band, indicating against a fixed altitude scale. Cabin pressure altitude is presented by means of a moving marker indicating against a fixed altitude scale. Vertical speed, between 0 and 2000 feet per minute ascent and descent, are presented by a moving pointer against a fixed scale. Rates in excess of 2000 feet per minute are presented by means of moving scales against fixed index marks.

altimeter setting of 29.921 inches of mercury. That is, with this setting, the pointer on a properly calibrated, perfect altimeter should indicate altitude corresponding to the ambient pressure, in accord with the standard atmosphere relationship of pressure-to-altitude, as given in Appendix 8.0.1 and illustrated in fig. 8.0.8. The mechanism must permit this relationship to hold despite the fact that uniform steps of increasing altitude correspond to gradually decreasing, nonuniform steps of pressure (see Table 8.1). The reader can grasp the basic concept by carefully studying figs. 8.0.8, 8.0.9, 8.0.10, and 8.0.11.

In these figures, models of the fundamental principle of the operation of the sensitive pressure altimeter are shown. While most actual altimeters do not have a "built-in altitude scale" as implied by figs. 8.0.8 and 8.0.9, such a scale, even though fictitious, is nevertheless useful to an understanding of the principle. By imagining that the "built-in altitude scale" is real, it may be seen that the aneroid mechanism (*AM*) must contain the necessary devices to translate pressure (*P*) to pressure altitude (*H*) from the nonlinear pressure scale to the linear (uniform) altitude scale in agreement with the curve revealed by fig. 8.0.6 (B).

By comparing fig. 8.0.9 with fig. 8.0.8, it is clear that rotation of the disk on which the internal mechanism is mounted will cause the pointer to shift with respect to the outside, fixed altitude scale. This rotation is accomplished by turning a knob on the actual altimeters (see figs. 8.0.1–8.0.5).

In the model shown by figs. 8.0.8 and 8.0.9, the reader may conceive of the "window" (w) as a rectangular frame supported by a cantilever "bridge" (b). This bridge is fastened rigidly to the outside, fixed altitude scale. It is placed in such a manner that the outer end of its central index line lies at the point marked by 0 (zero) altitude, and it must rise slightly above the plane of the figure. Thus, the bridge is clear of concentric rings which include scales S_2 and S_3 on the disk. With this arrangement the disk of radius AC_2 may be rotated about axis A without interference from bridge b. Hence, as the disk is rotated, we may think of the graduations

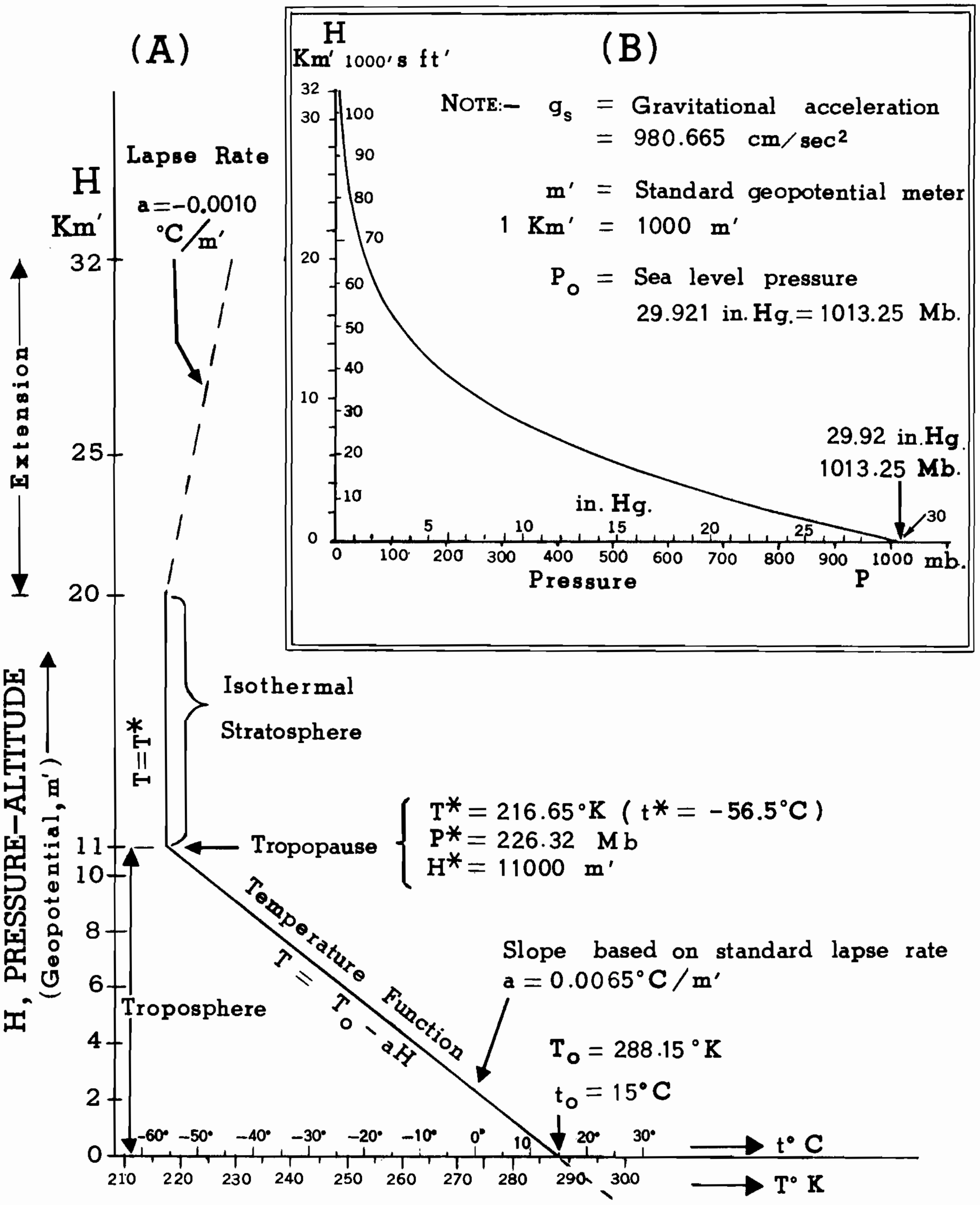

FIGURE 8.0.6. Diagrams showing the standard atmosphere. (A) U.S. Standard Atmosphere basic specifications especially in regard to temperature. (B) Pressure-Altitude (*H*) plotted against Pressure (*P*) in Standard Atmosphere.

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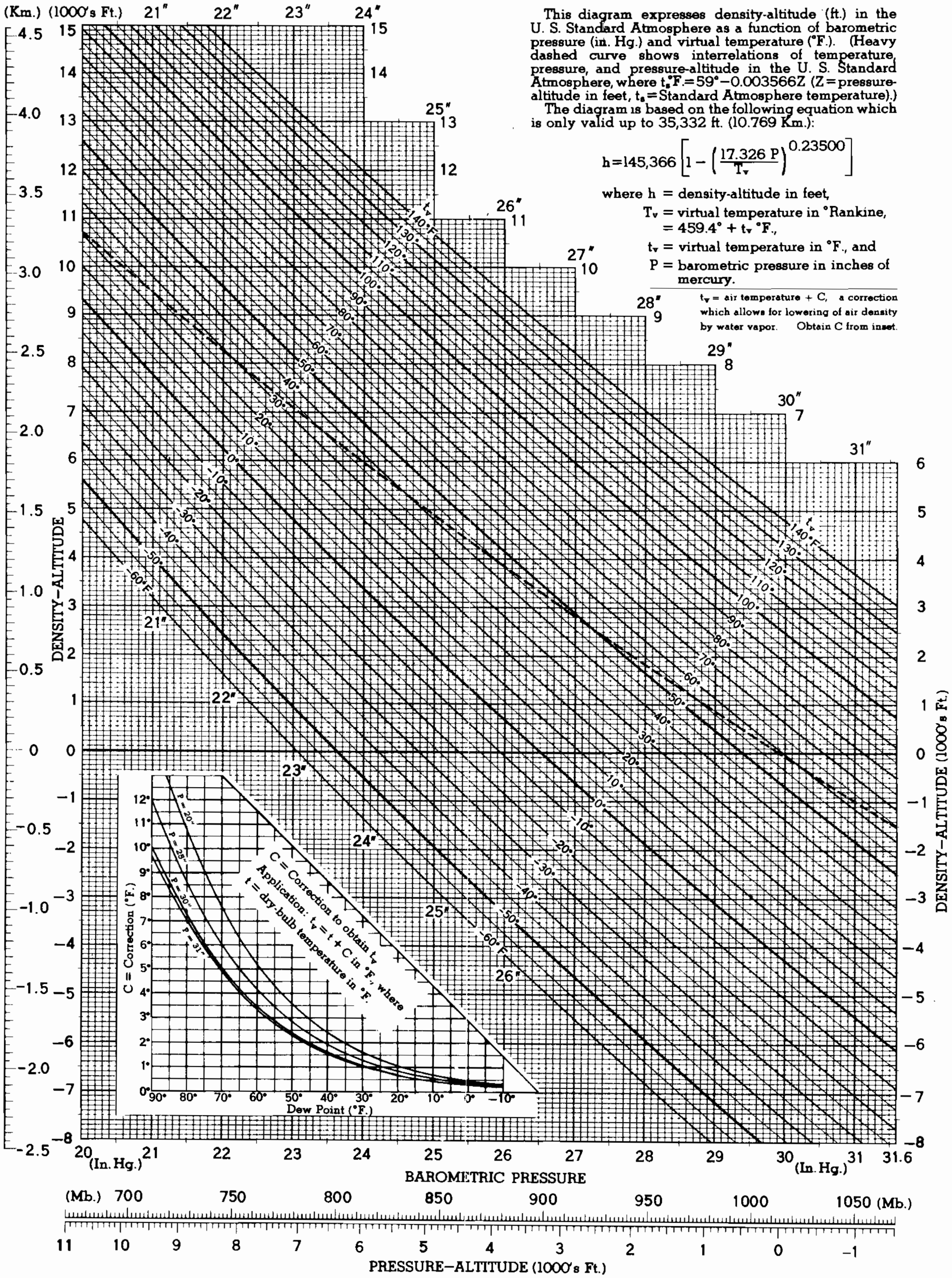
W. B. Form 1159

DENSITY–ALTITUDE DIAGRAM



This diagram expresses density-altitude (ft.) in the U. S. Standard Atmosphere as a function of barometric pressure (in. Hg.) and virtual temperature (°F.). (Heavy dashed curve shows interrelations of temperature, pressure, and pressure-altitude in the U. S. Standard Atmosphere, where t_s°F.=59°−0.003566Z (Z=pressure-altitude in feet, t_s=Standard Atmosphere temperature).)

The diagram is based on the following equation which is only valid up to 35,332 ft. (10.769 Km.):

$$h = 145{,}366\left[1-\left(\frac{17.326\,P}{T_v}\right)^{0.23500}\right]$$

where h = density-altitude in feet,

T_v = virtual temperature in °Rankine,

= 459.4° + t_v °F.,

t_v = virtual temperature in °F., and

P = barometric pressure in inches of mercury.

t_v = air temperature + C, a correction which allows for lowering of air density by water vapor. Obtain C from inset.

FIGURE 8.0.6(C). Density-Altitude diagram based upon the original (1925) U.S. Standard Atmosphere.

Geometric Altitude Z FEET	Latitude 0° ft'	Latitude 45° ft'	Latitude 90° ft'
0	0	0	0
10,000	9,968	9,995	10,021
20,000	19,927	19,980	20,033
30,000	29,876	29,955	30,035
40,000	39,816	39,921	40,027
50,000	49,746	49,878	50,010
60,000	59,667	59,825	59,984

FIGURE 8.0.7. Illustration of relationship between geopotential and geometric altitude at various latitudes. [Tabular values represent H = geopotential in standard geopotential feet (symbol ft') at the indicated latitudes and geometric altitudes (Z) in feet.]

of the non-linear, "built-in pressure scale" (S_3) as passing in review from the standpoint of the observer looking through the "window" (w).

The term "altimeter setting" as applied to any altimeter refers to the numerical value of pressure shown by the index in the window, which "looks" on the "built-in pressure scale". With regard to figs. 8.0.8 and 8.0.9, serving as illustrations, the "altimeter setting" is indicated within the framework of the "window" (w), opposite the arrow index pointing down from the 0 (zero) altitude graduation on the outer scale S_1. Some altimeters are equipped with a counter device for the purpose of showing the "altimeter setting" by means of actual numbers as illustrated by the boxed-in data thus labeled on figs. 8.0.8 and 8.0.9. Fig. 8.0.8 presents an "altimeter setting" of 29.92 inches of mercury; and fig. 8.0.9 one of 29.38 inches of mercury.

Obviously, the altimeter setting being used on the particular altimeter is subject to the control of the pilot in the aircraft or other operator, simply by turning the knob. This setting, together with the ambient pressure, determines the reading indicated by the pointer on the outside, fixed scale of altitude.

8.0.3.2 Definition of "Indicated Altitude."—*Indicated altitude* represents the altitude indicated by the altimeter. The symbol H_i is used herein for this quantity.

As illustrated in fig. 8.0.9, the pointer gives an indicated altitude of about 1900 ft., with reference to the fixed altitude scale (S_1) on the outside.

Since the "built-in altitude scale" is uniformly graduated and matches the fixed altitude scale on the outside of the altimeter, the relation of one of these scales to the other for any given setting represents a graphical addition or subtraction of pressure altitudes. This fact provides the basis on which altimeter settings apply in the operation of the sensitive pressure altimeter. It is embodied in figs. 8.0.8 and 8.0.9 (see also figs. 8.0.10 and 8.0.11).

8.0.3.3 Fundamental Principle of Operation of Altimeter.—The altimeter operates in accord with the following equation involving the three quantities described below in parentheses:

(The pressure altitude corresponding to the ambient pressure) *minus* (the pressure-altitude corresponding to the pressure value

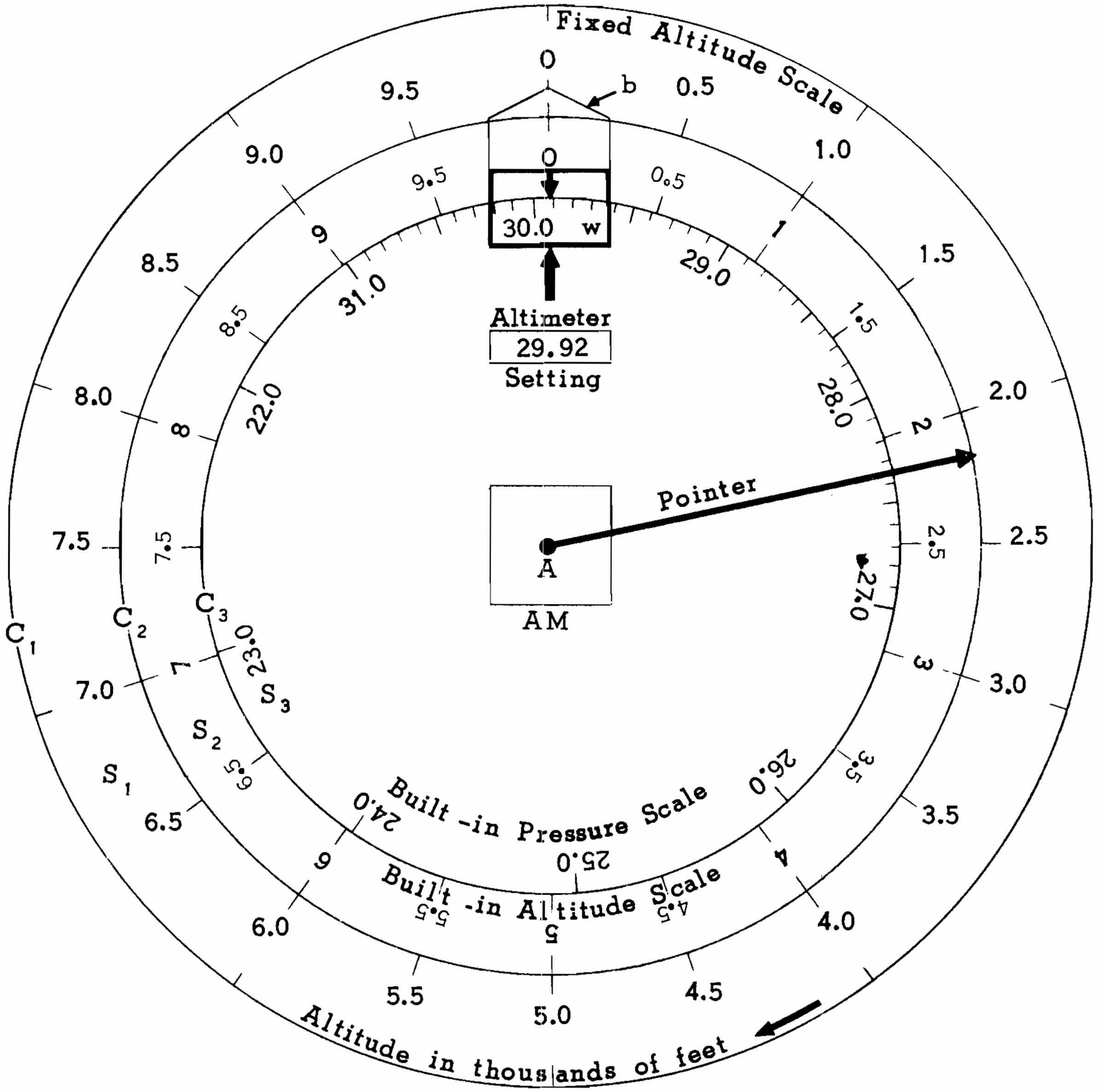


FIGURE 8.0.8. Model of a sensitive pressure altimeter to show principle of operation. Inner and outer scale relationship set for the particular altimeter setting of 29.92 inches of mercury, which is the sea-level pressure in the standard atmosphere. Disk of radius AC_2 is rotatable about axis A. Outside, visible altimeter scale S_1 on which pointer readings are made is constructed to match with the uniformly-graduated, built-in altitude scale S_2 on disk. S_3, a built-in pressure scale also on disk, is correlated with scale S_2 in accordance with the "pressure-altitude relationship" of the standard atmosphere. AM is an aneroid mechanism calibrated so that pointer is controlled by pressure variations in accord with scale S_3. b = bridge, w = window.

of the altimeter setting being used in the particular altimeter) *is equal to* (the altitude indicated by the particular altimeter).

It should be noted that "the pressure-altitude corresponding to the altimeter setting" may be either positive or negative (see Examples in sec. 8.0.2), and this implies that the subtraction in the equation must be algebraic.

Figs. 8.0.10 and 8.0.11 depict the fundamental principle of operation of the altimeter, for two different settings.

The fundamental principle may be expressed in terms of a mathematical equa-

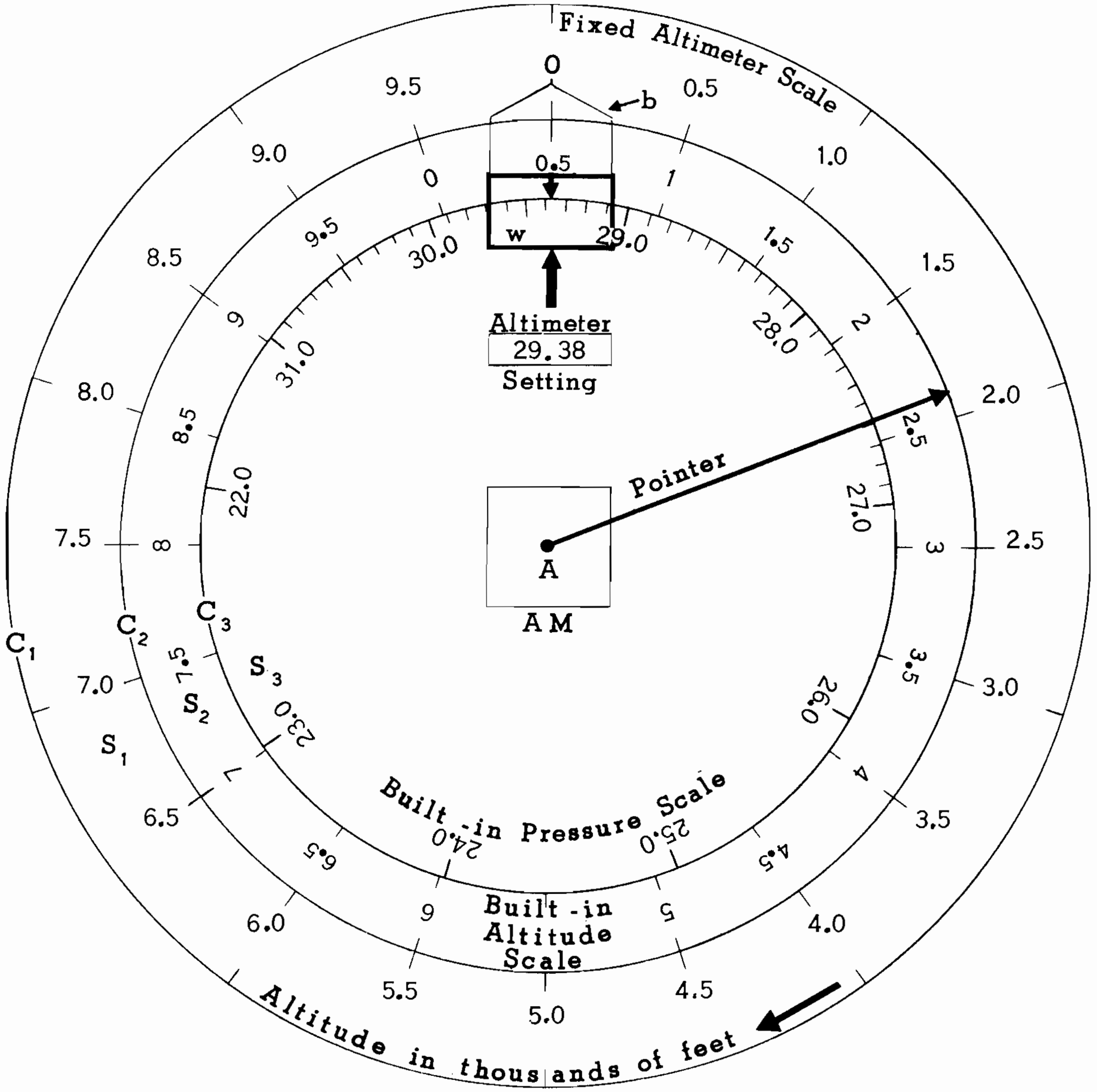


FIGURE 8.0.9. Model of a sensitive pressure altimeter to show principle of operation. Inner and outer scale relationship set for the particular altimeter setting of 29.38 inches of mercury. Disk of radius AC_2 is rotatable about axis A. Outside, visible altitude scale S_1 on which pointer readings are made is constructed to match with the uniformly-graduated, built-in altitude scale S_2 on disk. S_3, a built-in pressure scale also on disk, is correlated with scale S_2 in accordance with the "pressure-altitude relationship" of the standard atmosphere. *AM* is an aneroid mechanism calibrated so that pointer is controlled by pressure variations in accord with scale S_3. b = bridge, w = window.

tion (1) as shown below, in terms of the symbols now defined.

Let

P = ambient pressure (that is, the barometric pressure to which the aneroid element in the altimeter is subjected);

A.S. = altimeter setting (in pressure units);

P_s = station pressure (that is, the existing barometric pressure at the level designated as the station elevation, H_p);

H = pressure altitude corresponding to the ambient pressure, P;

H_A = pressure altitude corresponding to the altimeter setting, *A.S.*;

H_s = pressure altitude corresponding to the pressure, (P_s — 0.01 in. Hg);

H_p = station elevation (that is, the elevation above sea level at the surface weather reporting station; this being the level to which the station pressure, P_s, refers);

H_i = indicated altitude shown by the altimeter when subjected to ambient pressure, P, and when set to altimeter setting, $A.S.$

The foregoing statement of the fundamental principle of operation of the sensitive, pressure altimeter is written in symbolical form by the following important equation:

$$H - H_A = H_i. \qquad (1)$$

This equation is illustrated graphically by figs. 8.0.10 and 8.0.11, as well as figs. 8.0.8 and 8.0.9.

Important deductions may be made from eq. (1) with regard to the way in which an ideal pressure altimeter would perform in operations carried out under various assumed conditions. Deductions of this nature are presented in sec. 8.0.4.

8.0.4 Performance of Altimeters for Various Conditions and Operations

8.0.4.0 Introduction: Deductions from Equation (1).—Certain deductions will be drawn from eq. (1) as shown below, listed as (a), (b), (c), (d), under Sec. 8.0.4.1, 8.0.4.2, 8.0.4.3, and 8.0.4.4. To this end, account must be taken of the fact revealed by the curves in figs. 8.0.6 (B), 8.0.10, and 8.0.11; viz, that the pressure altitude increases with decreasing pressure in accord with Table 8.1 and Appendix 8.0.1.

8.0.4.1 Deduction (a) from Equation (1).—

Condition: *Altimeter Setting (A.S.) Held Constant.*

If the altimeter setting ($A.S.$) is kept constant, and the ambient pressure (P) decreases, both the pressure altitude (H) and the indicated altitude (H_i) will increase accordingly; while, if the altimeter setting ($A.S.$) is kept constant but the ambient pressure (P) increases, both the pressure altitude (H) and the indicated altitude (H_i) will decrease accordingly.

This may be interpreted simply by the conclusion that with a constant altimeter setting, flight to a lower pressure causes an increase in indicated altitude, whereas flight to a higher pressure causes a decrease in indicated altitude.

8.0.4.2 Deduction (b) from Equation (1).—

Condition: *Pressure (P) and Pressure Altitude (H) Held Constant.*

If the pressure (P) and hence pressure altitude (H) are kept constant, while the altimeter setting ($A.S.$) is made to decrease, the indicated altitude (H_i) will also decrease; if the pressure (P) and the pressure altitude (H) are kept constant, but the altimeter setting ($A.S.$) is made to increase, the indicated altitude (H_i) will also increase. This may be interpreted simply as follows: if the aircraft flight is conducted at constant pressure (or constant pressure altitude) and the pilot re-sets the altimeter, a decrease of the altimeter setting will cause the indicated altitude to appear to decrease; whereas increase of the altimeter setting by the pilot will cause the indicated altitude to appear to increase.

8.0.4.3 Deduction (c) from Equation (1).—

Condition: *Indicated Altitude (H_i) Held Constant but Altimeter Setting (A.S.) Varied.*

If the indicated altitude (H_i) is held constant but the altimeter setting ($A.S.$) is continuously being changed to higher and higher values, then the flight is being conducted at progressively lower pressure altitudes, hence at progressively higher pressures. On the other hand, if the indicated altitude (H_i) is held constant but the altimeter setting ($A.S.$) is continuously being changed to lower and lower values, then the flight is being conducted at progressively higher pressure altitudes, hence at progressively lower pressures. A special case helps to visualize the situation: if the aircraft is flown just above level ground at constant indicated altitude, and the altimeter setting progressively increases (or decreases) in the direction of flight, this signifies that the pressure in-

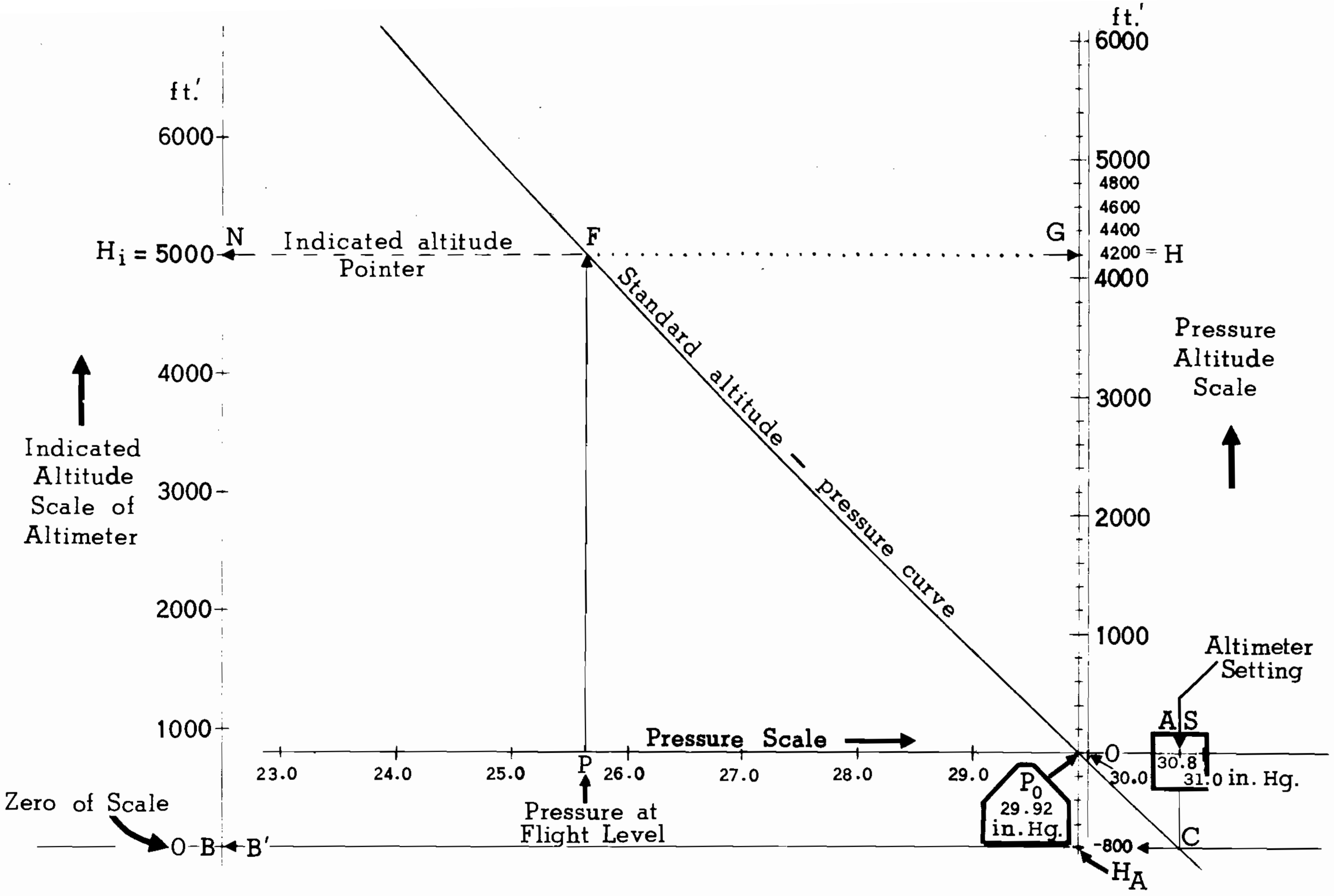


FIGURE 8.0.10. Illustration of an analog of a sensitive pressure altimeter. Point *C* on curve is determined by the value of H_A, which is the pressure altitude corresponding to the altimeter setting. Line *B′C* is aligned with *B*. Condition satisfied by the altimeter: $H - H_A = H_i$. When altimeter setting is increased (or decreased), point *C* moves down (or up) on curve; hence to align *B′C* with point *B* requires sliding curve and right-hand scale as a unit up (or down) with respect to the left-hand scale, which remains fixed.

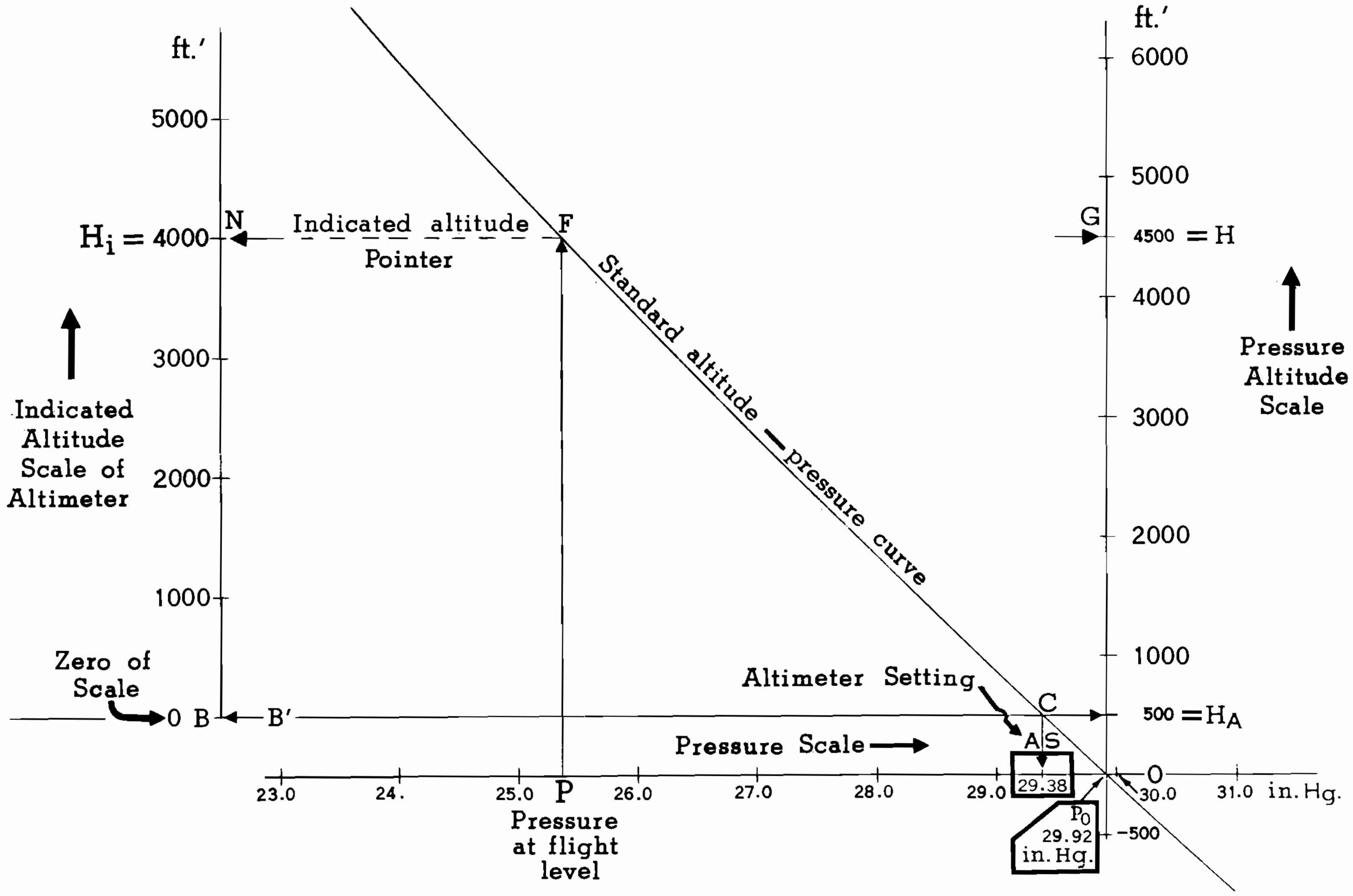


FIGURE 8.0.11. Illustration of an analog of a sensitive pressure altimeter. Point *C* on curve is determined by the value of H_A, which is the pressure altitude corresponding to the altimeter setting. Line *B′C* is aligned with *B*. Condition satisfied by the altimeter: $H - H_A = H_i$. When altimeter setting is increased (or decreased), point *C* moves down (or up) on curve; hence to align *B′C* with point *B* requires sliding curve and right-hand scale as a unit up (or down) with respect to the left-hand scale, which remains fixed.

creases (or decreases) progressively at flight level in the given direction. Thus, on such a basis useful conclusions may be drawn in regard to meteorological conditions likely to be encountered on entering into a region of higher (or lower) pressure.

8.0.4.4 Deduction (d) from Equation (1).—

Condition: *Indicated Altitude* (H_i) *and Altimeter Setting* (*A.S.*) *Both Held Constant.*

If both the indicated altitude (H_i) and the altimeter setting (*A.S.*) are held constant on any leg of a flight, the flight on this leg is being conducted at constant pressure altitude, hence at constant pressure.

From this deduction we can proceed to another extremely important conclusion regarding the correction which the pilot should apply to the indicated altitude (H_i) in order to overcome the error resulting from use in the aircraft of an altimeter setting different from the true local altimeter setting that prevails at the surface.

We deduce the following rules:

(A) For *each* 0.10 inch (of mercury) that the true local altimeter setting is *higher* than the aircraft altimeter setting, the indicated altitude would be corrected by *adding* 93 ft.

(B) For each 0.10 inch (of mercury) that the true local altimeter setting is *lower* than the aircraft altimeter setting, the indicated altitude would be corrected by subtracting 93 ft. (For a rule of thumb in round numbers, the correction may be considered as 100 ft. per 0.10 in., or nearly 1000 ft. per inch of mercury.)

8.0.4.4.1 *Rules (A) and (B) Derived Mathematically, and Illustrated.*—In this section, we demonstrate the foregoing rules. Certain terms are defined by symbols, where the subscript u denotes that the quantity referred to is effectively being *used* in the aircraft at a given time, and where the subscript t denotes that the quantity referred to is the one *truly* called for under the actual conditions existing at the surface, at the same time.

Let

$A.S._u$ = Altimeter setting being *used* in the aircraft;

$A.S._t$ = true altimeter setting existing at the surface beneath the aircraft;

H_{Au} = pressure altitude corresponding to pressure $A.S._u$;

H_{At} = pressure altitude corresponding to pressure $A.S._t$;

H_{iu} = indicated altitude used in the aircraft;

H_{it} = true indicated altitude which should apply if true, correct altimeter setting $A.S._t$ had been used;

H = pressure altitude corresponding to the ambient pressure at the level of the aircraft altimeter, when for this instrument the data in use are indicated altitude H_{iu} and altimeter setting $A.S._u$.

To prove rules (A) and (B) as stated above, we proceed as follows.

By virtue of eq. (1), the definition of H leads to the result

$$H - H_{Au} = H_{iu} \tag{a}$$

$$\therefore H = (H_{iu} + H_{Au}) \tag{b}$$

If the flight were conducted at the same pressure altitude but using the true altimeter setting $A.S._t$ current at the same time, and operating at the corresponding true indicated altitude H_{it}, we find from eq. (1) the relationship

$$H - H_{At} = H_{it} \tag{c}$$

Substituting eq. (b) in (c) we obtain

$$(H_{iu} + H_{Au}) - H_{At} = H_{it} \tag{d}$$

$$\therefore (H_{Au} - H_{At}) = (H_{it} - H_{iu}) \tag{e}$$

But, for the left-hand member of eq. (e) we may use the expression

$$(H_{Au} - H_{At}) = \frac{93\text{ ft.}}{0.10\text{ in. Hg}}\left[(A.S._t) - (A.S._u)\right] \tag{f}$$

This equation is empirical, being based on data contained in Table 8.1; taking account of the fact that *A.S.* is a pressure while H_A is the corresponding pressure altitude. For example, from Table 8.1 we find that when $A.S. = 29.30$ in. Hg, $H_A = 579$ ft.; but when $A.S. = 30.30$ in. Hg, $H_A = -348$ ft. Therefore, an increase of 1 in. Hg in *A.S.* corresponds to a decrease of 927 ft. in H_A. Reversing the order, this may be thought of in round numbers as a rate expressed as follows:

H_A decreases about 93 ft. per 0.10 in. Hg increase in $A.S.$ Since H_A varies inversely with $A.S.$, these facts lead to eq. (f). (Note: If we had taken a different range of $A.S.$ than that employed in the above sentences referring to Table 8.1, we should have obtained a slightly different value of the rate. Thus, for the range of $A.S.$ from 29.00 to 31.00 in. Hg, the average rate is a decrease of 923 ft. in H_A per 1 in. Hg increase in $A.S.$)

Substituting eq. (f) in eq. (e) we finally obtain

$$\frac{93\text{ ft.}}{0.10\text{ in. Hg}}\left[(A.S._t) - (A.S._u)\right] = (H_{it} - H_{iu}) \qquad \text{(g)}$$

This equation forms the basis for rules (A) and (B), and is of fundamental importance in determining how the indicated altitude should be corrected, if a change were made from the altimeter setting being used to the true altimeter setting prevailing at the surface.

Example (A)

$$\begin{aligned} \text{Suppose } A.S._t &= 30.10\text{ in. Hg} \\ A.S._u &= 29.80\text{ in. Hg} \\ \hline (A.S._t) - (A.S._u) &= 0.30\text{ in. Hg} \end{aligned}$$

Therefore according to eq. (g),

$$(H_{it} - H_{iu}) = \frac{93\text{ ft.}}{0.10\text{ in. Hg}}\left[(A.S._t) - (A.S._u)\right]$$

$$= \frac{93\text{ ft.}}{0.10\text{ in. Hg}}\left[0.30\text{ in. Hg}\right] = +279\text{ ft.}(\textit{Answer})$$

If we use the rate in round numbers, 100 ft./0.10 in. Hg, the answer comes out 300 ft. This means that the indicated altitude should be corrected by *adding* about 300 ft. because the true altimeter setting is 0.30 in. Hg. *higher* than the altimeter setting being used in the aircraft.

Example (B)

$$\begin{aligned} \text{Suppose } A.S._t &= 29.40\text{ in. Hg} \\ A.S._u &= 30.00\text{ in. Hg} \\ \hline (A.S._t) - (A.S._u) &= -0.60\text{ in. Hg} \end{aligned}$$

According to eq. (g) we compute on this basis

$$(H_{it} - H_{iu}) = \frac{93\text{ ft.}}{0.10\text{ in. Hg}}\left[-0.60\text{ in. Hg}\right] = -558\text{ ft.}(\textit{Answer})$$

(In round numbers, the answer is —600 ft.)

Because of the minus sign this means that the indicated altitude should be corrected by subtracting about 600 ft. because the true altimeter setting at the surface is 0.60 in. Hg lower than the altimeter setting being used in the aircraft.

8.0.5 Deduction of Method for Computing Altimeter Setting

Consider any particular time at an airport station, for which we have given the station pressure (P_s) referring to a known station elevation (H_p). In order to simplify the deduction, we shall assume that the station elevation (H_p) is the same value in feet above sea level as the published elevation of the runway at the airport.[5]

Now, consider an aircraft whose pilot wishes to land on this runway and assume, for the sake of simplicity, that the altimeter is installed at a height of 9 or 10 feet above the touchdown point of the landing gear. Since P_s represents the current station pressure, which, under the assumption, now refers to the elevation of the runway, it is clear that the ambient pressure at the level of the altimeter in the aircraft at touchdown will be (P_s — 0.01 in. Hg). This follows because the pressure 10 feet above the runway at the altimeter location is about 0.01 inch of mercury less than at the surface of the runway. Now, at the instant of touchdown, the pilot would like his altimeter to yield an indicated altitude reading (H_i) equal to the published elevation of the runway, H_p under the present assumptions. Therefore, in this case $H_i = H_p$.

It follows from eq. (1) that for these circumstances we may write the relationship: (the pressure altitude at the altimeter level, corresponding to the ambient pressure, P_s — 0.01 in. Hg) *minus* (the pressure altitude corresponding to the altimeter setting) *is equal to* (the indicated altitude, which we want to be the elevation H_p in this case, as the level that P_s refers to). Thus, the indicated altitude pertains to a height about 10 ft. lower than the actual level of the altimeter, in order to make this normal allowance for the landing gear. By rearrangement of terms in the foregoing word equation, we

---

[5] In actual practice the station elevation may be somewhat different than the field elevation. However, the existence of such a difference even up to 50 feet would not significantly affect the present argument. This conclusion stems from the ability of the altimeter to reflect changes of ambient pressure inversely as corresponding changes of indicated altitude. For further information, see sec. 8.0.7.

obtain the simple expression: (the pressure altitude corresponding to ambient pressure, $P_s - 0.01$ in. Hg) *minus* (the elevation, H_p, to which the pressure P_s refers) *is equal to* (the pressure altitude, H_A, corresponding to the altimeter setting, *A.S.*).

Now let H_s denote the pressure altitude corresponding to the ambient pressure, $P_s - 0.01$ in. Hg. Then the equation last given in words may be written in simple mathematical form

$$H_s - H_p = H_A \qquad (2)$$

Eq. (2) can be considered as a way of defining the current altimeter setting for any station; provided the value of H_s is based on the existing value of station pressure, P_s, pertaining to station elevation, H_p. Computation of altimeter setting (*A.S.*) on the basis of eq. (2) is illustrated for two cases, below.

EXAMPLE I

Station elevation, $H_p = 706$ feet
Station pressure, $P_s = 28.65$ in. Hg
$(P_s - 0.01$ in. Hg$) = 28.64$ in. Hg

By referring to Table 8.1, we find that the pressure altitude corresponding to the pressure $(P_s - 0.01$ in. Hg) is given by $H_s = 1206$ feet. According to eq. (2) we have $H_s - H_p = H_A$. Substituting the foregoing values of H_s and H_p, we get

1206 feet $-$ 706 ft. $= H_A$; that is
500 ft. $= H_A$ or 0.5 thousand feet $= H_A$

(*Note:* This value of H_A is illustrated in fig. 8.0.9 as the reading on "built-in altitude scale" S_2 opposite the index mark at the top, in line with the 0 graduation of the fixed altitude scale S_1.)

By inverse use of Table 8.1, we determine that the pressure corresponding to H_A (500 ft. as stated above) is 29.38 in. Hg. This represents the altimeter setting, hence *A.S.* = 29.38 in. Hg. This result is illustrated in figs. 8.0.9 and 8.0.11 (see reading on pressure scale opposite index arrow in window w).

EXAMPLE II

Station elevation, $H_p = 5000$ ft.
Station pressure, $P_s = 25.66$ in. Hg
$(P_s - 0.01$ in. Hg$) = 25.65$ in. Hg

By referring to Table 8.1 we find that the pressure altitude corresponding to the pressure $(P_s - 0.01$ in. Hg), 25.65 in. Hg, is given by $H_s = 4200$ ft. According to eq. (2) $H_s - H_p = H_A$. Substituting for H_s and H_p, we obtain

4200 ft. $-$ 5000 ft. $= -800$ ft. $= H_A$.

From Table 8.1, used inversely, we determine that the pressure corresponding to the pressure altitude $-$ 800 ft. (representing H_A) is 30.80 in. Hg. Therefore, we have as the altimeter setting, *A.S.* = 30.80 in. Hg. This is illustrated in fig. 8.0.10.

8.0.6 Definitions of Altimeter Setting

8.0.6.0 Introduction.—Altimeter setting may be defined either from a theoretical or operational point of view, as explained below.

8.0.6.1 Theoretical Definition of Altimeter Setting.—Assuming an altimeter to be perfectly calibrated, we can develop a definition of altimeter setting by means of eq. (1): $H - H_A = H_i$. From this we deduce that the condition which must be satisfied in order for the indicated altitude, H_i, to be zero (0), is $H = H_A$. Both H and H_A represent pressure altitudes, hence the equation $H = H_A$ implies that the pressures corresponding to these pressure altitudes must be equal. From this we conclude that if a perfectly calibrated altimeter is set to any altimeter setting *A.S.*, then subjecting the instrument to an ambient pressure equal to *A.S.* will cause the pointer to yield an indicated altitude of zero (0). That is, the altimeter setting as used in such an instrument is the ambient pressure required to produce a zero (0) altitude reading. In case of errors or imperfect calibration, this statement would not hold.

8.0.6.2 Operational Definition of Altimeter Setting.—We must distinguish between the theoretical definition given above in regard to the altimeter setting used in any particular altimeter, and the altimeter setting truly existing at a given station. The latter depends upon the station pressure (P_s) and elevation (H_p), in accordance with eq. (2). With the aid of eq. (2) we may define the altimeter setting truly existing at a given station on an operational basis, as follows:

If a perfectly calibrated altimeter is set to the altimeter setting existing at any given station whose elevation is H_p, the pointer of the instrument will yield an indicated altitude equal to H_p when the instrument is subjected to the pressure which exists at a height of about 10 feet above H_p. This operational definition forms the basis for altimeter settings rendered by meteorological stations.

In international aviation practice the term "QNH" is employed in referring to altimeter setting as here defined. With a view to making this matter clearer, it may be pointed out that the International Civil Aviation Organization (ICAO) has adopted a set of so-called "Q signals" which can be employed by aviators to ask certain questions by radio and to be furnished answers in brief form. On this basis the signal "QNH" may be applied as a question for the purpose of requesting the current value of the altimeter setting at some given airport where a landing may be contemplated, and it may also be applied by the control tower or radio communications personnel on the ground to preface the answer regarding the existing altimeter setting. The specific significance of the signal in both cases is illustrated below for a pilot who requests the altimeter setting as he is preparing to land at Idlewild International Airport shortly after ten o'clock on a certain day:

QNH? *Meaning of question:* What is the pressure value that I must use to set the sub-scale of my altimeter so that the altimeter would indicate the elevation at any point on the runway if I were landing?

QNH 29.86 inches (or 1011.2 millibars). *Meaning of answer:* The pressure value at Idlewild International Airport at 1000 hours that you must use to set the sub-scale of your altimeter so that the altimeter indicates the elevation at any point of the runway on landing is 29.86 inches of mercury (or 1011.2 millibars).

The operational definition of altimeter setting as given above forms the basis for altimeter setting tables (see fig. 6.8.3(a) and (b)) and the altimeter-setting side of the pressure reduction computer (see fig. 7.2.4(b)). Instructions regarding the preparation of altimeter-setting tables are presented in sec. 8.1. Instructions pertaining to the uses of these tables and of the computer for aviation weather reports are also given later.

8.0.7 Altimeter Setting as Affected by Change of Elevation

It is generally true that altimeter settings reported by weather stations are based on readings of barometers (or altimeter setting indicators) where the station elevation (or the elevation to which the data refer) is different from the airport elevation. As a rule the difference in elevation ranges between about 10 to 50 feet, but there may be several airports where it is somewhat greater.

As explained below, the altimeter setting may vary with the elevation pertaining to the pressure at which it is determined. Therefore, a question arises as to how the altimeter setting if measured at the airport elevation would differ from the altimeter setting, actually measured at the station elevation.

The answer to this question is most directly given by means of the equation shown below, expressed in terms of the following notation:

H_p = station elevation (in feet) referring to the level of the reported station pressure. This is the basis on which the altimeter setting ($A.S._p$) is determined.

$A.S._p$ = altimeter setting (in inches of mercury) reported by weather station based on pressure at elevation H_p.

H_a = airport elevation (in feet).

$A.S._a$ = altimeter setting (in inches of mercury) that would be determined on basis of the pressure existing at elevation H_a.

T_{mv} = mean virtual absolute temperature (in °Rankine) of the vertical column of atmosphere extending between the elevations H_p and H_a (see sec. 7.0.1 regarding absolute scale of temperature in °Rankine; and see sec. 7.0.4 regarding the definition of mean virtual absolute temperature).

T_{ms} = mean absolute temperature (in °Rankine) in the Standard Atmosphere of the vertical column extending between the altitudes of H_p and H_a; hence, when H_p and H_a are in units of feet, and the symbol *a* denotes the standard lapse rate, $a = 0.003566°$ F./ft., then

$$T_{ms} = [518.7 - a(H_p + H_a)/2]° \text{ R.}$$

It may be shown from basic theory that, to a very close degree of approximation,

$$(A.S._a - A.S._p) = \left[\frac{T_{ms} - T_{mv}}{T_{mv}}\right]\left[\frac{H_p - H_a}{925 \text{ ft.}}\right], \quad (3)$$

where the factor 925 feet represents the average change of pressure altitude corresponding to a change of one (1) inch of mercury in pressure or altimeter setting, provided the latter variables lie within the normal range of about 29.30 — 30.50 inches of mercury (see Table 8.1).

Eq. (3) reveals that when $T_{ms} = T_{mv}$, $A.S._a = A.S._p$. Thus, when the actual mean virtual temperature (T_{mv}) of the air column is equal to the standard value (T_{ms}), the altimeter setting determined at the two elevations, H_p and H_a, would be identical. Since such a condition in regard to temperature is nearly fulfilled in middle latitudes during spring and autumn, we conclude that during those seasons of the year the discrepancy between the two altimeter settings will be negligible.

Considering the case where H_p exceeds H_a, we deduce from eq. (3) that during the cold season when T_{mv} will usually be less than T_{ms}, $A.S._a$ will be greater than $A.S._p$; whereas during the warm season the situation will generally be reversed.

The following example shows the magnitude of the discrepancy in a rather extreme case.

8.0.7.1 Example of Discrepancy in Altimeter Settings Based on Different Elevations.—Consider a case in Alaska, during winter. Suppose that at station elevation $H_p = 1050$ ft., the observed virtual temperature is —39.8° F., while at the airport field elevation $H_a = 1000$ ft., the observed virtual temperature is —40.2° F. Therefore, the mean virtual temperature of the air column between H_p and H_a is —40.0° F., which is expressed in degrees Rankine as $T_{mv} = 419.7°$ R. (see sec. 7.0.1).

To compute T_{ms} we have $a = 0.003566°$ F./ft. and

$$T_{ms} = [518.7 - a(H_p + H_a)/2]° \text{ R.}$$

$$= [518.7° - (0.003566° \text{ F./ft.}) \times (1050' + 1000')/2] \text{ R.}$$

$$= [518.7° - 3.7°] \text{ R.} = 515.0° \text{ R.}$$

Substituting in eq. (3) we obtain

$$(A.S._a - A.S._p) = \left[\frac{T_{ms} - T_{mv}}{T_{mv}}\right]\left[\frac{H_p - H_a}{925 \text{ ft.}}\right]$$

in inches of mercury

$$= \left[\frac{515.0 \text{ °R.} - 419.7 \text{ °R.}}{419.7 \text{ °R.}}\right]\left[\frac{1050' - 1000'}{925'}\right]$$

$$= \left[\frac{95.3}{419.7}\right]\left[\frac{50}{925}\right] \text{ in. Hg}$$

$$= (0.227)\ (0.054) \text{ in. Hg} = 0.012 \text{ in. Hg}$$

It is clear from the foregoing example that if the mean virtual temperature of the actual air column had been +10.0° F., instead of —40.0° F., we would have $T_{mv} = 469.7°$ R., in which case we can obtain $\left[\frac{T_{ms} - T_{mv}}{T_{mv}}\right] = 0.0964$. This yields the result $(A.S._a - A.S._p) = 0.005$ in. Hg.

These examples disclose that where the difference in elevation $(H_p - H_a)$ is 50 feet, the difference in altimeter setting $(A.S._a - A.S._p)$ will rarely be greater than about 0.01 in. Hg. When the difference in elevation is less than 50 feet, the quantity $(A.S._a - A.S._p)$ is proportionately less than indicated above.

We conclude that generally $(A.S._a - A.S._p)$ will be small enough to be tolerated, and that the difference in elevation $(H_p - H_a)$ would have to be a hundred feet or more before the magnitude of $(A.S._a - A.S._p)$ might give rise to a serious problem.

8.1 COMPUTATION AND USE OF ALTIMETER SETTINGS

8.1.1 Computation of Altimeter-Setting Tables

8.1.1.0 Introduction.—Altimeter-setting tables, as illustrated in fig. 6.8.3, are designed to yield the altimeter setting (*A.S.*) for various station pressures (P_s) which refer to a *constant, known* station elevation (H_p). The fundamentals of the proposed method of computing the individual entries in altimeter-setting tables have already been presented in sec. 8.0.5. Use is made of Table 8.1 in conjunction with the following relationships:

(H_A, the pressure altitude corresponding to altimeter setting) = (H_s, the pressure altitude corresponding to the pressure, P_s — 0.01 in. Hg.) *minus* (H_p, the station elevation).

In symbolic form this is written:

$$H_A = H_s - H_p.$$

The following instructions show how this equation is applied to compute individual entries in altimeter setting tables, and a few examples are given. See eq. (1), sec. 8.4.3.

8.1.1.1 Instructions Regarding Individual Entries in Tables.—

(1) Refer to Table 8.1 and find in the body of the table the pressure altitude corresponding to a value of pressure which is 0.01 inch of mercury *less than* the station pressure, P_s. This pressure altitude is represented by the symbol H_s.

(2) The station elevation, H_p, should then be subtracted algebraically from H_s; the difference ($H_s - H_p$) thus obtained is H_A, termed the pressure altitude corresponding to the altimeter setting, *A.S.*

(3) Refer to Table 8.1 again, this time using it inversely, by finding the pressure argument which yields pressure altitude H_A as tabulated in the body of the table. This pressure is the altimeter setting, *A.S.*

Example (a) for Station Elevation, H_p = 734 ft.

Given: Station pressure,

P_s = 29.00 inches of mercury

P_s — 0.01 in. Hg = 28.99 inches of mercury

To find: Altimeter Setting

(1) From Table 8.1 the pressure altitude corresponding to pressure

(P_s — 0.01 in. Hg) is H_s = 872 ft.
Station elevation, H_p = 734 ft.

(2) Algebraic difference, ($H_s - H_p$) = H_A = 138 ft.

(3) From Table 8.1, used inversely, find that the pressure corresponding to pressure altitude H_A given above as 138 ft. is 29.77 in. Hg; this being the required altimeter setting, *A.S.* This value is entered in the body of the altimeter-setting table under the station pressure argument, P_s = 29.00 inches of mercury.

Example (b) for Station Elevation, H_p = 734 ft.

Given: Station pressure, P_s = 29.50 in. Hg
(P_s — 0.01 in. Hg) = 29.49 in. Hg

To find: Altimeter Setting

(1) From Table 8.1, the pressure altitude corresponding to pressure

(P_s — 0.01 in. Hg) is H_s = 401 ft.
Station Elevation, H_p = 734 ft.

(2) Algebraic difference, ($H_s - H_p$) = H_A = — 333 ft.

(3) From Table 8.1, used inversely, find that the pressure corresponding to the pressure altitude H_A given above as —333 ft. is 30.28 in. Hg; this being the altimeter setting, *A.S.* This value is entered in the body of the altimeter-setting table under the station pressure argument P_s = 29.50 in. Hg. (See fig. 6.8.3.)

8.1.1.2 Instructions for Mass Production of Altimeter-Setting Tables.—When a large number of entries must be compiled, the work of determining H_A can be accomplished with greater efficiency than outlined in the foregoing instructions. This improvement can be achieved by entering and making use of differences between successive tabular values in Table 8.1.

The method involving the use of such differences is illustrated in fig. 8.1.1, which shows an example of an extract of the computations made in preparing the data entered in fig. 6.8.3. Essentials of the instructions relating to this method are given at the head of fig. 8.1.1. After the method of fig. 8.1.1 is firmly in mind, the person performing the computations can dispense with the entries on line (2) beyond the first. He can also avoid copying data from Table 8.1 to enter on line (3) by working from that table.

In compiling the final altimeter-setting tables, it is important that *A.S.* be referred to the station pressure argument P_s, not (P_s — 0.01 in. Hg). However, it is important to note that lines (2) and (3) are correlated in accord with Table 8.1.

8.1.1.3 Instructions for Preparation of Tables Yielding Station Pressure as a Function of Altimeter Setting

8.1.1.3.0 *Introduction.*—At those stations where an altimeter-setting indicator is installed (see figs. 6.8.1 and 6.8.2), the altimeter setting can be secured from the read-

Basic Instructions for Computation of Altimeter Setting Tables

(Note: Data in line (3) are extracted from Table 8.1 using data in line (2) as arguments; and the differences on line (3) between successive values of H_s are labeled Δ. The differences should be entered in ink on Table 8.1, after being carefully checked. The first entry on line (5) should always be computed by subtracting line (4) from line (3), since $H_A = H_s - H_p$. Values on line (5) beyond the first entry are computed by successive subtraction of Δ beginning with the first entry.) Assumed station elevation, H_p, 734 ft.

Sample Computations

(1) P_s in. Hg		29.10		29.11		29.12		etc.		29.17		29.18		29.19
(2) P_s - 0.01 in. Hg		29.09		29.10		29.11		etc.		29.16		29.17		29.18
	Δ		Δ		Δ		Δ		Δ		Δ		Δ	
(3) H_s ft.	10	777	9	768	10	758	9	etc.	10	711	9	702	10	692
(4) H_p ft.		734												
(5) H_A ft.		43		34		24		etc.		-23		-32		-42
(6) A.S. in. Hg		29.87		29.88		29.90		etc.		29.95		29.96		29.97

Definitions of symbols: P_s is station pressure pertaining to station elevation H_p; H_s is the pressure altitude from Table 8.1 corresponding to pressure (P_s - 0.01 in. Hg); $H_A = (H_s - H_p)$; and A.S. is the pressure argument in Table 8.1 which corresponds to pressure altitude H_A.

FIGURE 8.1.1. Example of extract of computation of altimeter-setting tables.

ing of this device, properly corrected for instrumental error as explained in Chapter 6. When occasion arises to obtain the station pressure corresponding to the altimeter setting thus determined, the observer may do so in any of three possible ways, as outlined below:

(a) He may refer to the appropriate altimeter-setting table for the station (see fig. 6.8.3 for example), locate the given altimeter setting in the *body* of the table, and note the corresponding station pressure argument (side and top arguments combined).

(b) He may use the "Altimeter-Setting Computer" (see fig. 7.2.4 b) to compute the station pressure (P_s) corresponding to the given altimeter setting (*A.S.*). This involves a procedure for computing P_s as a function of *A.S.*, which is the inverse of the procedure for computing *A.S.* as a function of P_s. Instructions for the latter procedure are printed on the face of the "Altimeter-Setting Computer." The observer may check his operations with this device for both procedures by means of the examples previously given, dealing with the data directly and inversely.

(c) He may prepare a special table which yields station pressure in the body of the table as a function of altimeter setting which here serves as the argument. An example of such a special table is shown in fig. 6.8.4. By referring to such a table, based on the appropriate station elevation (H_p), the observer can directly ascertain P_s corresponding to *A.S.*

Instructions for preparing such a table are given below.

8.1.1.3.1 *Instructions for Preparing Table to Give P_s Corresponding to A.S.*

The equation on which the computations are based is

$$H_p + H_A = H_s$$

where

H_p = station elevation

H_A = pressure altitude corresponding to the altimeter setting (*A.S.*)

H_s = pressure altitude corresponding to pressure (P_s — 0.01 in. Hg);

and

P_s = station pressure, in inches of mercury, pertaining to station elevation, H_p.

Instructions are as follows:

(1) Refer to Table 8.1 and find the pressure altitude corresponding to the altimeter setting (*A.S.*). This represents H_A.

(2) Apply the value of H_A algebraically to the station elevation, H_p; that is, determine the algebraic sum $(H_p + H_A)$, which represents pressure altitude H_s. (Thus, when H_A is negative, H_s is less than H_p; and when H_A is positive, H_s is greater than H_p).

(3) Refer to Table 8.1, and using it inversely find the pressure corresponding to the pressure altitude H_s. This pressure represents $(P_s - 0.01$ in. Hg$)$.

(4) Add 0.01 inch of mercury to the pressure found in accordance with (3) above. The sum thus obtained represents P_s the required station pressure.

(5) Compile the special table by using *A.S.* as the argument, and enter the corresponding value of P_s in the body of the table.

	EXAMPLE (a)	**EXAMPLE (b)**
Given: station elevation,	$H_p = 734$ ft.	
Given argument:	$A.S. = 29.77$ in. Hg	$A.S. = 30.28$ in. Hg
(1) From Table 8.1, used directly	$H_A = 140$ ft.	$H_A = -330$ ft.
(2) From the equation, we obtain by adding algebraically	$(H_p + H_A) = H_s = 874$ ft.	$H_s = 404$ ft.
(3) From Table 8.1, used inversely, to find the pressure corresponding to H_s	$(P_s - 0.01$ in. Hg$) = 28.99$ in. Hg	$(P_s - 0.01$ in. Hg$) = 29.49$ in. Hg
(4) Adding 0.01 in. Hg to value found under step (3), we get	$P_s = 29.00$ in. Hg	$P_s = 29.50$ in. Hg

(5) To prepare special table, enter in the body of table values of P_s obtained by step (4) under the given argument (*A.S.*) shown in the heading. (See fig. 6.8.4, for example.)

8.1.2 Computation of Altimeter Setting by Means of "Altimeter-Setting Computer"

The "Sea-Level Pressure Reduction and Altimeter-Setting Computer," illustrated in fig. 7.2.4, may be used to compute altimeter settings required for reports at weather stations. For this purpose, the observer must have available the current station pressure (P_s) and the station elevation (H_p) to which P_s refers.

Instructions regarding the use of the calculator are printed on its face.

When the station is at a permanent location so that the value of the station elevation (H_p) may be expected to remain constant during the foreseeable future, an arrow head to indicate H_p should be carefully engraved on the disk of the computer in proper relation to the "station elevation scale." The engraved depression representing the arrow head should be filled with a permanent ink, and the excess ink carefully wiped away. After the ink dries, the arrow head is used in the calculation of altimeter settings by a procedure which obviates the need to employ the cursor. (Agency headquarters generally engrave and ink in the arrow heads before the computers are issued. Fig. 7.2.4 illustrates a computer with the curser set for a station elevation of 702 feet, but the arrow head is not shown in this figure.)

Before the arrow head is engraved, observers should test the accuracy of computations of altimeter setting made with the calculator. This test is performed with the aid of data contained in figs. 6.8.3, 8.0.8, 8.0.9, 8.0.10, and 8.0.11; also the examples given in secs. 8.0.5 and 8.1. For test purposes, results presented in these sources should be compared with results computed for given values of P_s by means of the calculator using the cursor to refer to H_p. Excellent agreement between the two methods should be obtained in every instance when everything is in order.

After the arrow head is engraved its location may be checked by use of similar comparisons, working out the numerical data in accord with the procedure illustrated by the examples in secs. 8.0.5 and 8.1.1.1.

8.1.3 Altimeter-Setting Reports

8.1.3.0 Purpose of Reports.—Altimeter settings are issued in airway and airport weather reports to give essential information to pilots and airport control tower personnel. Pilots need such reliable, current data for setting their altimeters so that indicated altitude will be reasonably accurate both for landing and terrain clearance, under existing meteorological conditions. (Note: Later sections should be consulted on the subject of errors in indicated altitude as affected by instrumental, meteorological, and other factors.) Accurate, current altimeter-setting data are also needed by airport control tower operators, airline operations and communications offices, FAA airway traffic control and communications centers, military meteorological units, transient pilots and others, for various types of operations. In many of these cases, the current altimeter setting reported by the weather station is used for checking and standardizing altimeters at the surface.

By furnishing the data, weather stations render an essential service to aviation. Objective of the service is an accurate system of altimeter settings which provides a national standard for altimeter measurements. Only by such a system can direct comparability be secured in respect to the readings of all instruments set on this basis. It will be clear that both absolute accuracy and comparability are important for purposes of maintaining safeguards on operations which involve landing, terrain clearance, and vertical separation of aircraft. Thus, a difference between the altimeter setting used in an aircraft instrument and the altimeter setting observed simultaneously at the tower produces an error in indicated altitudes at the time of landing; and also an inequality between the altimeter settings used in aircraft flying over a given point may violate the rules of safe vertical separation.

8.1.3.1 Effects of Pressure Variations.—Changes of barometric pressure at a station cause changes in altimeter setting of nearly the same amount, but larger by a slight amount in the majority of cases. Thus, a variation in barometric pressure at some rate, such as 0.10 inch of mercury per hour, would produce approximately the same rate of variation in altimeter setting.

By considering the data in the altimeter-setting table for his station, the observer can ascertain for himself just how much change of altimeter setting is produced by a given variation in station pressure.

Thus, it will be evident that a falling pressure will produce a falling altimeter setting, and vice versa. Hence, a fluctuating pressure will give rise to a fluctuating altimeter setting. Accordingly, the barometric pressure tendency as deduced from the microbarograph is reflected in a nearly similar tendency of altimeter setting. These facts provide a basis for estimating by how much an altimeter setting reported earlier may differ from the correct, current altimeter setting, depending on the net pressure change.

8.1.3.2 Accuracy Desired in Altimeter Settings.—As an objective, it is desired to try to maintain the absolute accuracy of altimeter settings reported at the standard synoptic hours to within about 0.01 or 0.02 inch of mercury. First of all, assuming that no errors of observation are made, this degree of accuracy can only be achieved by keeping the mercurial barometers in somewhat closer agreement, if possible, with the national standard barometer of the United States. Secondly, this tolerance can only be maintained if appropriate corrections are obtained and applied, as required under the provisions of Chapter 6. Finally, the interval between time of reading barometer or altimeter-setting indicator and time of issuance of altimeter-setting report must be sufficiently short. Otherwise, the effect of pressure change discussed in sec. 8.1.3.1 may lead to significant errors in reported altimeter setting.

8.1.3.3 Time Intervals Permissible Between Readings and Issuance.—In order to keep the reported altimeter setting within 0.02 in. Hg of the actual existing altimeter setting, readings are necessary within 30 minutes of the time of issuance if the rate of pressure change is 0.04 in. Hg (1.4 mb.) per hour or less; readings are necessary within 15 minutes of the time of issuance if the rate of pressure change is 0.08 in. Hg (2.7 mb.) per hour or less. When the rate of pressure change is significantly greater than 0.08 in. Hg (2.7 mb.) per hour, the readings should be undertaken as nearly as practicable to the time of issuance of the altimeter-setting report. The objective presented in sec. 8.1.3.2 should be kept in mind as a guide.

8.1.3.4 Methods of Determining Altimeter Setting.—There are several different convenient methods by which the altimeter setting may be determined. These methods are listed below:

(1) Direct reading of an Altimeter-Setting Indicator, suitably corrected. (The correction to the reading of the Indicator must be found in accordance with instructions given in Chapter 6.)

(2) Determination of station pressure by means of a suitably corrected barometer reading, followed by computation of the corresponding altimeter setting by use of the "Sea-Level Pressure Reduction and Altimeter-Setting Computer" (see fig. 7.2.4 b). In using the Computer, the computation must be based on the station elevation, H_p, to which the station pressure refers.

(3) Determination of station pressure (P_s) by means of a suitably corrected barometer reading, followed by ascertainment of the altimeter setting corresponding to P_s by referring to the proper "Altimeter-Setting Tables." These must be based on the station elevation (H_p) to which P_s refers. (An example of such tables is illustrated in fig. 6.8.3.)

In the special case of low level stations it is permissible to apply a constant reduction correction to the existing station pressure for the purpose of determining the altimeter setting. The observer at each low-level station should consult Table 7.1.4 to ascertain the correction which is pertinent on the basis of the elevation H_p specified for his given locality. In case there is adopted a value of H_p different from that stipulated for a given station in Table 7.1.4, the correction indicated for the station in the table is not valid. Table 8.1.1 gives the constant corrections which are to be applied to the station pressure, in order to determine the altimeter setting at stations whose elevation, H_p, is in the range 1 to 60 feet, by one foot increments. The data from Table 7.1.4 or Table 8.1.1 may be employed to construct derived tables by successive addition indicating altimeter settings which correspond to the observed station pressure, depending on the value of station elevation, H_p.

(4) Direct observation of the altimeter setting from the reading of the pressure scale of a sensitive altimeter, whose pointer indicates an altitude equal to the actual elevation above mean sea level *minus* 10 ft. (Note: Comparison of results determined by this procedure with those determined by method (3) based on reliable mercurial barometer readings usually will reveal that a correction should be applied to the former to make them agree with the latter. Such a correction should be determined as an average on the basis of at least five comparisons, and should be rechecked daily if practicable. After the correction has been thus found, it should be regularly applied algebraically to the results obtained from the altimeter by method (4). The *correction* is defined as: the altimeter setting obtained by method (3) *minus* the altimeter setting obtained by method (4). Use moving average correction.

8.1.3.4.1 *Preference Regarding Choice of Method.*—The observer should be guided by the following considerations and the instructions issued by his Service regarding choice of the method to be employed for obtaining altimeter setting when equipment is available to permit use of more than one method (see sec. 8.1.3.4):

(a) Method (1) is quicker than the other methods, and may be used for determinations of altimeter setting issued in routine reports, provided that the corrections to the Altimeter-Setting Indicator have been carefully ascertained and applied in accordance with instructions in Chapter 6.

(b) Methods (2) and (3), when based on the reading of a precision aneroid barometer, may be used for routine reports. In this case also, the correction to the barometer must be carefully determined and applied in accordance with instructions in Chapter 6.

(c) Methods (2) and (3), when based on the reading of a calibrated or standardized mercurial barometer, can be regarded as most accurate. Hence, in that case they should be used preferably at the times of the 6-

hourly synoptic observations. The data thus obtained can be employed as a check on the data secured by means of the other types of pressure measuring instruments which involve aneroid elements.

(d) Method (4) is theoretically capable of yielding results about as accurate as those obtained by Method (1), *provided* the necessary corrections are determined and applied as outlined in the note under (4). A sensitive altimeter of first class quality can give good results if properly calibrated and handled, in accordance with these instructions. Method (4) is employed in many control towers and by many aviation organizations. It should be emphasized that method (4) required daily or weekly checks as outlined under (c) above, to determine necessary corrections.

When the actual elevation of the altimeter to be used for method (4) is unknown, the procedure most convenient to carry out is as follows:

(i) Obtain the official altimeter setting reported by the weather station at the time of the 6-hourly synoptic observation.

(ii) At the same moment, adjust the knob of the altimeter until the pressure scale reads the altimeter setting thus reported.

(iii) Finally, observe the altitude then indicated by the pointer of the altimeter, and make a record of it.

Repeat this process (i)–(iii) on different occasions, preferably for several days, and determine the *average of the indicated altitudes* found by step (iii) for these occasions. Then, in order to ascertain the altimeter setting from the given instrument in the future, adjust the knob until the pointer is coincident with the average of the indicated altitudes referred to above. Finally, at this instant read the altimeter setting shown by the pressure scale.

Since the aneroid element of the altimeter may undergo drift (see Chapters 2 and 6), it is necessary to check the average of the indicated altitudes, say daily and weekly, making revisions from time to time if necessary (see sec. 6.8.2).

8.1.4 Correction of Altimeter-Setting Indicators

Altimeter-Setting Indicators (see fig. 6.8.1 and 6.8.2) have characteristics similar to those of aneroid barometers, hence, they are subject to similar errors, such as drift and hysteresis, which have been discussed in Chapters 2 and 6. Therefore, data observed by means of the Altimeter-Setting Indicator must be corrected to secure accurate results. Procedures for determining the corrections have been described in Chapter 6, sec. 6.8.2. Observers are cautioned to use utmost care in determining and applying the correction properly. The current correction should be maintained on a card posted near the Altimeter-Setting Indicator. The correction should be checked at least one day per week by two or more comparisons of the readings of this instrument with those based on reliable mercurial barometer observations. If the corrections should ever appear to grow rapidly larger, this may be regarded as evidence of malfunction of the instrument, and it should be taken out of service. Similar remarks apply to aneroid barometers and altimeters used for the obtainment of altimeter settings.

8.1.5 Checking of Altimeters at Surface by Means of Altimeter-Setting Reports

Altimeters are often installed in airport control towers and in various dispatching or communications offices. They are generally used as a source of altimeter settings to be supplied to pilots upon request.

A need exists to maintain these altimeters so that they yield accurate readings for such purposes. With this in mind, weather stations located at airports issue carefully obtained altimeter settings at the times of the regular 6-hourly synoptic observations. It is intended that local interests make use of these data as a check on their altimeters. When the instructions given in Chapter 6 are carefully followed, the data thus issued by the weather stations should be of such high quality that they can serve as standards for such checking purposes.

The best means for assuring that the surface altimeters at control towers and elsewhere yield results in harmony with the official data issued by the weather stations is to employ the method described under paragraph (4) of sec. 8.1.3.4.

When altimeters or other pressure-measuring instruments are connected to a static pressure head, it is important to eliminate any water in the system and to prevent any blocking of the openings in the head such as might arise from deposits of glaze, snow, sleet or other precipitation. Otherwise, these factors are sources of error.

8.1.6 Causes of Disparity between Altimeter Settings for Separate Points

Differences between altimeter settings pertinent to separate points generally arise owing to the following factors:

(1) Instrumental discrepancies for which proper corrections are not made.

(2) Existence of pressure gradients or of pressure differences in the horizontal between the points.

(3) Departure of existing atmospheric temperature from temperature in the standard atmosphere (see sec. 8.0.2), in cases where the points are at different elevations.

With regard to (1), instrumental discrepancies can be eliminated by re-calibration, or by application of appropriate corrections or adjustments. The method described under paragraph (4) of sec. 8.1.3.4 represents a case of the latter. (Observe method in note.)

With regard to (2), pressure differences over long paths in the horizontal are real, as evidenced by the fact that such variations are commonly observed between cyclones (LOWS) and anticyclones (HIGHS) at sea level. Hence, altimeter settings at various points on a long path may be expected to show differences which are characteristic of the attendant pressure conditions. But if the path is short, say confined to limits of a given airport with level terrain, the altimeter settings should be expected to be about the same in the small limited area, (see sec. 8.0.7) except under unusual circumstances, such as those attending passage of a tornado or a hurricane.

With regard to (3), this is a common cause for disparities between altimeter settings during the summer and winter, in cases where data for points at widely different elevations are compared. We may illustrate this most readily by an example based on an actual experience by a pilot. This case involved a comparison between data for the stations at Enterprise, Utah (elevation 5,210 ft.) Milford, Utah (elevation 5,097 ft.), and Bryce Canyon, Utah (elevation 7,589 ft.) Here is the case history:

"On August 3, 1946, an airplane flew over Bryce Canyon, Utah, after having passed over Milford, Utah, where the altimeter setting of 30.15 inches was obtained. The weather station at Bryce Canyon advised the pilot by radio that the local setting was 30.39 inches. The pilot considered that this value was erroneous, taking account of the Milford setting and the fact that Enterprise, Utah, had reported a setting of 30.17 inches a short time previously. He therefore called for a check of the Bryce Canyon setting and pointed out that it appeared to be out of harmony with the Milford setting. The value 30.39 inches was verified by the local weather observer, and repeated to the pilot."

We have here an instance where the difference in elevation between two stations is considerable, for between Milford and Bryce Canyon there is a rise of 2,492 ft. in station elevation. At the given time of the pilot's experience the mean virtual temperature was actually 77° F. (536.7° R.), for the 2,492 ft. deep column of air extending from the level of Milford (5,097 ft. elevation), to the level of Bryce Canyon (7,589 ft. elevation). However, the *standard* mean temperature of this air column was 36.4° F. (496.1° R.), as may be calculated by means of the equation referred to under the definition of the symbol T_{ms} in sec. 8.0.7.

Sec. 8.0.7 gives an equation (3) which permits us to calculate the difference between the altimeter settings at two points in a vertical column of air. This equation reads

$$(A.S._{a} - A.S._{p}) = \left[\frac{T_{ms} - T_{mv}}{T_{mv}}\right]\left[\frac{H_p - H_a}{925 \text{ ft.}}\right]$$

inches of mercury.

Let the subscript *a* refer to the Milford elevation and the subscript *p* refer to the Bryce Canyon elevation. Then we have

$$H_p = 7589 \text{ ft.}; H_a = 5097 \text{ ft.};$$
$$(H_p - H_a) = 2492 \text{ ft.};$$
$$T_{mv} = 536.7° \text{ R.}; T_{ms} = 496.1° \text{ R.};$$

and

$$\left[\frac{T_{ms} - T_{mv}}{T_{mv}}\right] = \left[\frac{-40.6}{536.7}\right] = -0.0756$$

Substituting the data in the equation we get

$$(A.S._a - A.S._p) = -0.204 \text{ inch of mercury.}$$

This result suggests that in this case, on the basis of difference of elevation and deviation of actual temperature from standard temperature given above, the altimeter setting at Milford should be about 0.204 in. Hg *lower* than at Bryce Canyon, apart from any effect due to horizontal gradient of pressure mentioned under item (2) above.

The upper-air weather chart for the 5,000 ft. level revealed that a slight horizontal gradient did exist, being such that the pressure *at this level* was about 0.033 inch of mercury *lower* at Milford than at Bryce Canyon. Therefore, the combined effect due to elevation difference and temperature deviation from standard together with horizontal pressure gradient should cause the altimeter setting at Milford to be about 0.237 inch of mercury *lower* than at Bryce Canyon; this calculated result being based on the algebraic sum of the two contributions,

$$(-0.204 \text{ in. Hg}) + (-0.033 \text{ in. Hg}) = -0.237 \text{ in. Hg.}$$

Since the actual altimeter setting report for Milford was 30.15 in. Hg, while that for Bryce Canyon was 30.39 in. Hg, the observed difference between the altimeter settings at the two points was

$$(30.15 \text{ in. Hg} - 30.39 \text{ in. Hg}) = -0.24 \text{ in. Hg.}$$

This is in excellent agreement with the calculated result.

We thus find a case where most of the disparity between the altimeter settings at two points arises from the difference in elevation when the actual mean virtual temperature of the air column deviates from the standard temperature of the air column. The agreement between theoretically calculated difference and the observed difference indicates that the effect is real and is not due to errors in the altimeter setting reports for either station.

Consequently, we should expect still greater possible disparities between the reported altimeter settings for two stations when the factors shown in eq. (3), sec. 8.0.7 are greater than those given for the above example. Thus if $(H_p - H_a)$ were 5,000 ft. instead of 2,500 ft., the effect is doubled on this account alone; and if the factor $(T_{ms} - T_{mv})/T_{mv}$ is doubled at the same time, the effect is quadrupled.

It should be noted that during extreme cold winter conditions in the United States, the factor $(T_{ms} - T_{mv})/T_{mv}$ may be readily doubled compared to the foregoing value. As an example of this, consider the following data, where the subscript *a* refers to the lower station and the subscript *p* to the higher station:

$$H_p = 6{,}000 \text{ ft.}$$
$$H_a = 1{,}000 \text{ ft.}$$
$$(H_p - H_a) = 5{,}000 \text{ ft.}$$
$$T_{mv} = 439.7° \text{ R. } (-20° \text{ F.})$$
$$T_{ms} = 506.2° \text{ R. } (46.5° \text{ F.})$$
$$(T_{ms} - T_{mv})/T_{mv} = 0.1512$$

These data yield the following result according to eq. (3), sec. 8.0.7:

$$(A.S._a - A.S._p) = 0.82 \text{ in. Hg.}$$

Such a difference could occur apart from any effect due to horizontal pressure gradient, and may be serious if not taken into account.

In regions having very severe cold, such as Alaska, it is possible for the quantity $(T_{ms} - T_{mv})/T_{mv}$ to be as large as about 0.20.

The reader should note that the algebraic sign of the factor changes from winter to summer, hence the sign of the difference between altimeter settings for points at different elevations varies accordingly, as may be inferred from eq. (3), sec. 8.0.7.

From the last example, the seriousness of the matter for terrain clearance in winter can be envisaged. Thus, if the station which reports the altimeter setting is at a low level (say in a valley) whereas the terrain to be cleared (such as a peak or ridge) is at a high level, without knowing the proper altimeter setting for the high level, the indicated altitude will be in error on the dangerous side (it reads too high) in the cold season.

During the warm season, the reverse would be true.

Another problem of safety relates to the occasional failure of different aircraft to use a common altimeter setting in a given locality when the pilots obtain the reports from different stations. It may be seen that under some circumstances the effect due to temperature deviation when combined with other sources of error (such as instrumental) may produce disparities equivalent to 1000 ft. in altitude.

8.2 ALTIMETRY ERRORS AND THEIR EFFECTS ON AIRCRAFT OPERATIONS

8.2.0 Introduction

The errors inherent in the altimetry system have a profound influence on aircraft operations, whether they relate to landing, vertical separation of aircraft, or terrain clearance. It is the purpose of this section to consider first of all the operational criteria which should prevail regarding the procedures of landing, vertical separation of aircraft, and terrain clearance, with a view to overcoming the effects of the errors that are involved in altimetry. This general problem is introduced in sec. 8.2.1. Following the latter is a series of discussions which go into more detail concerning the criteria pertinent to the various operations in order to secure the maximum safety; thus sec. 8.2.1.1 relates to landing, sec. 8.2.1.2 pertains to vertical separation of aircraft, while sec. 8.2.1.3 deals with the subject of terrain clearance.

It is considered necessary, in treating the problem of terrain clearance, to make use of a systematic method of handling the relevant data in flight planning; and to this end so-called *criterion (a)* is introduced. *Criterion (a)* affords a means of calculating on a rational basis the minimum altitude at which flight should be conducted in order to obtain a desired vertical clearance with respect to the point of maximum height above sea level on the highest obstacle which lies on or near the intended flight course. Appendix 8.2.2 provides information relating to the development of *criterion (a)* and contains a mathematical derivation of the correction to overcome the effects of the departure of actual air temperature from the pertinent value of temperature assumed in the standard atmosphere. In Appendix 8.2.2 definitions are also proposed for the corrections to overcome the error resulting from the use of an improper altimeter setting in the aircraft during flight and to overcome the pressure discrepancy which may occur due to the blowing of strong winds over the highest obstacle and its environs, for such winds, by virtue of the Bernoulli or Venturi effect, can cause significant deviations of pressure, and hence of indicated altitude, with respect to those that prevail in the undisturbed free air. At the end of Appendix 8.2.2 some considerations are presented relative to the effect of the location of the altimeter-setting reporting station on the magnitudes of the aforementioned corrections. Conclusions are presented in sec. 8.2.1.3.1 concerning the applications of criterion (a) for guidance in selecting the minimum safe indicated altitude with a view to having adequate vertical clearance of the aircraft relative to the highest obstacle on or near the intended flight course.

It is shown that the errors affecting the altimetry system can be sub-divided into those of a non-meteorological character and those of a meteorological nature. The former include such items as instrumental errors, static pressure system errors, and flight technical errors. Sec. 8.2.2 and its subsections are devoted to a classification and an assessment of these various errors of a non-meteorological character. Summarizing remarks and conclusions regarding the subject are given in sec. 8.2.2.6.

Special attention is also given to the problem of air temperature effects later, in sec. 8.3.

8.2.1 Operational Criteria Affected by Errors of Altimeters

As pointed out elsewhere, sensitive pressure altimeters are used primarily for purposes of landing, vertical separation of aircraft while enroute, and terrain clearance. Errors in the system of altimetry affect these applications in different degrees and by somewhat different means, depending upon the conditions. Clearly it is important to eliminate those significant errors which give rise to hazards or, alternatively, one must make due allowances for them in order to reduce the chances of a mishap.

With reference to the application of the instrument for landing of an aircraft on a runway during the existence of low clouds and low visibility, it is, of course, essential that the total cumulative error resulting from all causes be as small as possible at and near the touchdown point. With regard to the application for vertical separation of aircraft while enroute, it is vital that the indications of the altimeters operating in any limited area be consistent on a relative basis in order to minimize the likelihood of a midair collision between aircraft owing to discrepancies between them; while it is also highly important that the pilots involved in the operations maintain within reasonably close limits their assigned cruising altitudes or flight levels, as the case may be. With respect to the application of the altimeter for terrain clearance, it is necessary that pertinent allowances be made for errors which affect the absolute accuracy of the indicated altimeter readings in order to provide a safe vertical clearance relative to the highest points of the terrain over which flight is planned.

Thus, in both the cases of application to landing and terrain clearance the elevation of the surface to which reference is made must be known for operational purposes, in order to use in each case a suitable datum based on fixed points at ground level, or obstructions, with respect to which clearance is required. Therefore, the altimeter and height data which are used in connection with these two purposes should be considered from an *absolute* standpoint. This may be interpreted as signifying that when a pilot endeavors to ascertain the actual amount of vertical clearance with respect to the highest point on the runway for landing purposes or with respect to the highest point on the terrain for enroute flight purposes it is desirable for him to consider first the true altitude of the aircraft as determined from the *properly corrected* indicated altimeter readings and then to compare the true altitude of the aircraft with the actual elevations of the points on the surface to which reference must be made. If it is not possible to determine the total correction that ought to be applied to the indicated altitudes in order to compute the true altitudes, then an adequate allowance should be used instead of the correction with a view to providing a safe margin of clearance. The foregoing considerations are of especial importance when the presence of low ceilings, poor visibilities, and other adverse weather conditions require operations under instrument flight rules (IFR).

It may be concluded from the above presentation that certain criteria must be satisfied in order to secure a high degree of safety for operations involving reliance upon the indications of the altimeter. Briefly, these criteria can be formulated as follows:

8.2.1.1 Landing.—If the indicated altimeter readings are used without any corrections (as is usually the case for landing purposes), it is vital that the instrument be maintained so that the combined value of all possible effective errors that influence the readings, even when extreme in the most adverse sense, is kept at the lowest minimum which can be achieved practicably, within acceptable tolerances. The pilot should be supplied with a correction card which will enable him to ascertain the probable corrections under various conditions. He should take the pertinent correction into account when estimating his true vertical clearance relative to the runway and neighboring obstacles on the basis solely of the indicated altitude reading of his instrument.

Before any attempt is made to undertake a landing operation under IFR conditions at any runway it is essential to have established first of all an accepted missed approach procedure and secondly a pertinent *critical altitude* governing the minimum height with respect to ground at which such a procedure should be begun in cases where neither the approach light system nor the runway lights or runway is sighted by a pilot during an approach on instruments. The critical altitude is defined as that altitude below which it is considered unsafe to execute a missed approach procedure by reference to instruments. The critical altitude should depend upon the characteristics of the aircraft, the height of the existing obstacles in the general neighborhood, the downdrafts that may be encountered during an approach, and the possible errors in landing aid facilities and in airborne instruments, or in setting thereof. On this basis the selection of a safe critical altitude for each runway requires the assessment of these possible errors well in advance of any landing operation, so that all relevant factors can be taken into consideration.

8.2.1.2 Vertical Separation of Aircraft.—Consider the case of two aircraft assigned different cruising altitudes or flight levels, where normally one will pass over the other with an *indicated* vertical separation of 1,000 feet; for example one aircraft at an indicated altitude of 16,000 feet and the other perhaps opposite bound at an indicated altitude of 15,000 feet, although under some conditions an *indicated* vertical separation of only 500 feet may be used. Let I_2 denote the greater and I_1 the lesser of the two indicated altitudes. Suppose that the total error affecting the indicated altimeter readings is designated by e_2 in the former case and e_1 in the latter case. Then, the actual (true) altitudes in the two cases, denoted by A_2 and A_1, respectively, are represented by the expressions

$$A_2 = (I_2 - e_2),$$

and

$$A_1 = (I_1 - e_1);$$

hence the actual (true) vertical separation between the aircraft is

$$(A_2 - A_1) = (I_2 - I_1) + (e_1 - e_2).$$

The assigned difference $(I_2 - I_1)$ is normally equal to 1,000 feet, as mentioned above. In a situation of this character, it is clear from the last equation that if e_2 is a maximum while e_1 is a minimum in the mathematical sense, the actual vertical separation $(A_2 - A_1)$ will be a minimum. Equal subsidiary errors of like sign comprised within e_2 and e_1 will have their effects cancelled out by taking the difference; while unequal subsidiary errors of like sign will partially cancel (see sec. 8.2.2). However, those of unlike sign will compound and tend to produce relatively large resultant errors.

The criterion to be satisfied is that the actual (true) vertical separation $(A_2 - A_1)$ shall provide a safe clearance margin for flight operations of the given aircraft despite any possibility that e_2 may be maximum and e_1 a minimum.

The net values of e_2 and e_1 are governed by many subsidiary errors and factors discussed in following sections. Some of the subsidiary errors or factors of which e_2 and e_1 are composed have a positive sign and some a negative. They may have frequency distributions depending upon such considerations as the particular characteristics of the altimeter, the differences in maintenance procedures, the aircraft type, the flight history with respect to pressure and temperature, individual characteristics of the static pressure system of the given aircraft, variability in absolute accuracy of results of calibration and test procedures, the performance of the auto-pilot and/or pilot combination in regard to height keeping (i.e., adherence to assigned altitude), etc. Thus, it is generally considered that certain of the subsidiary errors or factors have a Gaussian frequency distribution (for example, errors due to diaphragm and drift effect, friction, instrument temperature, imperfect static balance, imperfect coordination of pressure and height scales, instability, zero setting, static-pressure system, non-representative pressure datum, non-standard atmospheric temperature, and flight departure from assigned cruising altitude or flight level). See sec. 8.2.2. On the other hand, backlash is regarded as a limit error; readability is considered to be a typical rounding-off error having a rectangular distribution; while the vertical size of the two aircraft combined is presupposed to be a constant (usually 75 feet for calculations relating to commercial aircraft).

It follows that e_2 and e_1 cannot be regarded as fixed quantities, since they depend upon the summation of the subsidiary errors and factors mentioned in the preceding paragraph.

By investigating all of these matters (see sec. 8.2.2), it is possible to estimate values of

e_2 and e_1 corresponding to certain assumed probabilities of their occurrence at various altitudes; for example, the International Civil Aviation Organization has made statistical assessments of the likely loss of vertical separation of aircraft based on a probability of 99.7%, that is 3 chances in 1,000 that the given loss ($e_2 - e_1$) will be equaled or exceeded. This is tantamount to taking a certain calculated risk; but it must be emphasized that if one wishes to indicate the likely loss of vertical separation corresponding to 3 chances in 10,000 or more, then it is necessary to show the amount of likely loss as *greater* by an appropriate degree than the amount of likely loss pertinent to 3 chances in 1,000.

As an illustration of data relevant to a probability of 99.7%, the International Civil Aviation Organization Panel on Vertical Separation of Aircraft found in a typical case involving altimeters used generally in 1956 that if $I_2 = 6{,}000$ feet and $I_1 = 5{,}000$ feet, a loss of vertical separation of approximately 546 feet is likely to be equaled or exceeded 3 times in 1,000 between aircraft passing on headings which require nominal vertical separation of 1,000 feet, subject to the condition that a constant, standard setting of 29.92 inches of mercury (QNE) is employed for the setting of the altimeters of both aircraft.[6]

In accordance with the result given in the last paragraph, the actual vertical separation between the two aircraft would be (1,000 − 546) feet, that is 454 feet, under the specified assumptions. However, it should be noted that very often the altimeter settings (QNH) which are used for setting the instruments are different for two aircraft passing over land from widely separated points of origin. As a consequence of such a difference, it is necessary to take into account certain errors which apply under these circumstances, but do not apply in the former case. First of all, one must allow additional instrumental errors owing to the change from the constant, standard setting of 29.92 inches of mercury to the basis of the altimeter setting system (QNH); and secondly, one must consider the possible difference of altimeter setting (QNH) values employed in the two aircraft. Although the effect of including these additional instrumental errors will only increase the likely loss by only several feet, a more serious effect occurs when the altimeter setting (QNH) values being used on the two aircraft are markedly different.

Thus, if the higher of the two aircraft employs a QNH value which is, say, 0.38 inch of mercury *greater* than that employed in the lower aircraft, the vertical separation will be reduced about 350 feet; and similarly for a difference of 0.50 inch of mercury between their QNH settings in the indicated direction, the reduction would be about 465 feet; while for a difference of 1.00 inch of mercury in the same manner, their vertical separation would be diminished by about 930 feet.

Studies of the behavior of altimeters have revealed that generally the instrumental errors increase with increase of indicated altitude. This characteristic is disclosed in the following table derived from information compiled and data calculated by the International Civil Aviation Organization.[6] (See Table 8.2.1 (a).)

By making use of altimeters of better quality than those available in 1956, by improving calibration and maintenance procedures, and by employing suitable techniques of eliminating the effects of static-pressure system errors as by means of a specially designed compensator, it is possible to secure a significant diminution in the likely loss of vertical separation relative to that shown in the following table. It is essential to note that columns 1 and 2 of the following table were calculated on the assumption that all aircraft operate with a constant, standard setting of 29.92 inches of mercury; hence, insofar as this assumption does not hold, the actual likely losses of vertical separation between aircraft will be much greater than those shown in those columns, as may be observed by comparing the data in columns 3 and 4 with those in columns 1 and 2, since columns 3 and 4 were based on the assumption that differences between altimeter set-

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[6] International Civil Aviation Organization, "Report of Panel on Vertical Separation of Aircraft, Second Meeting, Montreal, 3–14 June 1957," ICAO Doc 7835–AN/863, Montreal, Canada, 1958.

Table 8.2.1(a)

Table of likely loss of vertical separation between aircraft as calculated by ICAO Panel on Vertical Separation of Aircraft, 1957

Lower altimeter indicated altitude (feet)	Likely loss of vertical separation between aircraft based on a probability that the given loss will be equaled or exceeded 3 times in 1,000 occasions, considering typical commercially used altimeters as of 1956.			
	Under assumption that the altimeters are set on basis of a constant, standard setting of 29.92 in. Hg		Under assumption that the altimeter having the higher indicated altitude is set on a QNH setting which is 0.38 in. Hg greater than that used for the altimeter having the lower indicated altitude*	
	Column 1 Type I altimeter**	Column 2 Type II altimeter**	Column 3 Type I altimeter**	Column 4 Type II altimeter**
	Feet	*Feet*	*Feet*	*Feet*
5,000	546	559	760	769
10,000	641	663	829	845
20,000	922	1003	1058	1119
30,000	1323	1455	……	……
40,000	……	1839	……	……

* The assumed difference of 0.38 in. Hg between the QNH altimeter settings reduces vertical separation by 350 feet.
** Types I and II altimeters are calibrated to 30,000 and 50,000 feet, respectively.

tings (QNH) used on the two aircraft contribute a discrepancy, taken to be 350 feet in the specified case.

Considerable improvements can be effected regarding the performance of the altimetry system as a whole in comparison with that shown by Table 8.2.1(a), since the instrumental data embodied in this table are more or less representative of the older design of sensitive pressure altimeter depicted in fig. 8.0.1. As a result of engineering advances, there are available newer types and designs of pressure altimeters which have considerably better performance than the older design (see, for example, the newer types shown in figs. 8.0.2, 8.0.3, 8.0.4, and 8.0.5).

However, despite the more extensive use of these more modern instruments as time goes on, there still remain the effects of an important group of errors or adverse factors in the altimetry system as a whole apart from those dependent upon the mechanical characteristics of the pressure altimeters, such as: (a) the static-pressure system error resulting from the non-representativeness of the pressure yielded by the static pressure intake; (b) the possible discrepancy between the QNH altimeter settings used on aircraft which operate on the basis of such variable settings as reported by ground stations; (c) the so-called "flight technical error" stemming from the departure of aircraft from their assigned cruising altitudes or flight levels for a variety of possible reasons; and (d) the reduction of available airspace on a pressure basis whenever low non-standard atmospheric temperatures occur as explained further in sec. 8.3.

With respect to item (a), the static-pressure system error, improvements can be achieved by use of suitable compensating devices or of corrections. With regard to item (b), the discrepancy between QNH altimeter settings, a remedy has been considered based on the general employment of constant, standard setting (QNE) of 29.92 in. Hg for enroute vertical separation of aircraft at all levels, except for landing and takeoff. With reference to item (c), the "flight-technical error," it is possible to secure somewhat closer adherence to assigned cruising altitudes or flight levels if automatic pilots are used, provided that (1) the type of auto-pilot employed is well adapted to the requirements of height control for the particular aircraft flight characteristics, (2) the auto-pilot is suitably matched to the performance of the particular type of aircraft, (3) the auto-pilot, the associated flight controls, and the static-pressure system are carefully maintained to function at a high level of performance. The use of height locks may yield improvements in closeness of flight level control, particularly at the higher altitudes, depending upon the flight characteristics of the particular aircraft, and the observance of good maintenance practices with regard to the equipment and static pressure system. These conclusions are subject to experimental verification. Furthermore, the general employment of constant, standard setting (QNE) for enroute vertical separation poses certain problems in regard to terrain clearance, and landing, takeoff, and missed-approach procedures.

8.2.1.3 Terrain Clearance.—It is the objective here to establish a rational basis for a criterion by means of which one will be enabled to estimate or calculate the minimum cruising altitude or flight level that should provide normally an adequate vertical clearance with respect to the highest points on the terrain over which flight is to be conducted. The purpose is to present information for guidance of pilots, meteorologists, air-traffic controllers, and others concerned with the problem of determining minimum cruising altitudes or flight levels in connection with the preparation of flight plans. Fundamentally, the criterion is designed to yield a safe vertical clearance, by making allowances for all known sources of error, whether they result from mechanical characteristics of the altimeter, from nonrepresentativeness of the static-pressure input into the altimeter, from pressure and temperature variations of the atmosphere with respect to the assumed standard, or from other causes. Before it is possible to evaluate such a criterion, it is necessary to have all pertinent data and information to permit making the calculations.

Considerable use is made in this chapter of certain terms, such as "cruising altitude" and "flight level," which have special technical meanings in aviation. Therefore, it is essential to give definitions of these terms and to present other material pertinent to the problem, as published by the Federal Aviation Agency or its predecessor (see Appendix 8.2.1).

Civil Air Regulation 60.60 (CAR 60.60) defined *cruising altitude* as follows: "Cruising altitude is a level determined by vertical measurement from mean sea level."[7] The Civil Air Regulations also define *flight level* in the following terms: "Flight level is a level of constant atmospheric pressure related to a reference datum of 29.92" Hg. For example, flight level 250 is equivalent to an altimeter indication of 25,000 feet, and flight level 265 to 26,500 feet."[7]

From Civil Air Regulation 60.25 (CAR 60.25), which is quoted in Appendix 8.2.1 of this Manual of Barometry, it may be inferred that cruising altitudes are based on the use of current reported altimeter settings (QNH) pertinent to the area of flight, insofar as practicable, for purposes of setting the aircraft altimeter; whereas flight levels are based on the use of a constant, standard setting 29.92 inches of mercury (QNE).[7]

The Flight Information Manual, volume 12, November 1958, issued by the Civil Aeronautics Administration, the predecessor of the Federal Aviation Agency, in treating the subject under the caption of "Altimeter settings" contains the following statement: "All altitudes used in the control of air traffic are based on altitudes above sea level (MSL)."

In Appendix 8.2.1 some relevant information is given concerning altitude control under Visual Flight Rules (VFR) and Instrument Flight Rules (IFR). For present purposes it is worthwhile to introduce also the following quotation from the Flight Information Manual already cited in the preceding paragraph:

"*Altitude requirements.*—Aircraft operating in accordance with IFR must be flown at not less than the minimum altitude established by the Administrator of Civil Aeronautics for that portion of the route over which the operation is conducted. If no minimum has been established, flight must be conducted at not less than 1000 feet above the highest obstacle within a horizontal distance of five miles from the center of the course intended to be flown, except in those areas designated as mountainous areas, a

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[7] Civil Air Regulations Amendment 60-13. Effective January 15, 1959. Civil Aeronautics Board, Washington 25, D.C. See also Appendix 8.2.1.

clearance of 2000 feet must be maintained. Established minimum altitudes are shown on Coast and Geodetic Survey Radio Facility Charts."*

It may be concluded from the discussion thus far that the four principal elements which are entailed in regard to the criterion of establishing an adequate, safe vertical clearance with respect to terrain are those listed below:

A_x = the actual elevation above mean sea level of the point of maximum height on the highest obstacle within a horizontal distance of five miles from the course intended to be flown. (*Note:* For some operations it may be desirable to employ a horizontal distance greater than five miles, especially if position of aircraft may be uncertain in the case of flight over rugged mountainous terrain under adverse weather conditions, such as strong cross-winds of variable character, low ceiling and visibility, severe storms with downdrafts, etc.)

C_v = the vertical clearance desired between the aircraft and the point of maximum height on the highest obstacle enroute.

I_n = the minimum indicated altitude at which flight should be planned in order to achieve the vertical clearance desired with reference to the point of maximum height on the highest obstacle.

k_s = the sum of the corrections which should be applied to the minimum indicated altitude, I_n, in order to overcome the totality of errors affecting the altimetry system under the conditions which will be experienced during the intended flight.

On the basis of reasoning more fully discussed in Appendix 8.2.2, it can be readily seen that in order to secure adequate, safe terrain clearance one must satisfy the following *criterion (a)*:

$$(a) \qquad I_n + k_s \geqq A_x + C_v$$

This *criterion (a)* may be interpreted as signifying that the *minimum indicated altitude when corrected for all errors must be greater than or equal to* (≧) *the elevation of the point of maximum height which might be encountered during the flight added to the vertical clearance desired.*

In the case of flight operations over mountainous areas C_v must be at least 2,000 feet, according to the FAA Flight Information Manual. Values of A_x for peaks and crests of mountain ranges may be obtained from topographic charts.

Appendix 8.2.2 shows that the correction quantity, k_s, can be sub-divided into two main categories, designated by the symbols k_c and k_m. Here k_c denotes the sum of corrections for four basic types of *mechanical* or *non-meteorological* errors, these being classified as corrections concerning instrumental (k_i), static pressure (k_p), flight technical (k_f), and residual (k_r) effects. On the other hand k_m represents the sum of corrections for three basic types of errors involving largely *meteorological* factors, these being classified as corrections for altimeter setting discrepancy (k_a), wind Bernoulli or Venturi effects in mountainous terrain (k_w), and temperature effects resulting from departure of atmospheric temperature from that assumed in the standard atmosphere (k_t).

Thus, as described in equations (4), (5), and (6) of Appendix 8.2.2, here summarized for ready reference, one must consider separately k_c the combination of corrections for errors due to non-meteorological factors (i.e., k_i = instrumental, k_p = static-pressure system, k_f = flight technical, and k_r = residual) such that

$$k_c = (k_i + k_p + k_f + k_r); \qquad (4)$$

and k_m the combination of corrections for errors due to meteorological factors (i.e., k_a = altimeter setting deviation, k_w = wind, and k_t = temperature departure from standard) such that

$$k_m = (k_a + k_w + k_t); \qquad (5)$$

while the sum of the corrections for both non-meteorological and meteorological errors taken in their entirety is denoted by k_s defined by the equation

$$k_s = (k_c + k_m). \qquad (6)$$

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* The Administrator of Civil Aeronautics was succeeded by the Administrator of the Federal Aviation Agency effective December 31, 1958.

It is considered that estimates of k_c pertaining to non-meteorological factors may be made on the basis of information available relative to the errors involved in the functioning of the altimeter system and in the conduct of flight operations (see sec. 8.2.2 and tables therein).

Mathematical expressions for the meteorological terms k_m, k_a, k_w, and k_t are developed in Appendix 8.2.2. On the basis of these expressions and the data in sec. 8.3 regarding temperature effects it is possible to make some estimates of k_m.

By virtue of equation (6), the addition of the estimated values of k_c and k_m yields an estimated value of k_s, the sum of all pertinent corrections applicable to the altimetry system under the given conditions.

The application of *criterion (a)* is best illustrated by means of an example, for which the following conditions are assumed to be pertinent, in terms of the notation employed in Appendix 8.2.2:

(1) A_x = 14,000 feet = elevation of point of maximum height on highest obstacle, which is a mountain ridge lying athwart the intended flight course.

(2) C_v = 2,000 feet = desired vertical clearance.

(3) E_s = 3,500 feet = elevation of the station which reports altimeter setting, and is located in a valley near the foot of the mountain range on which the highest obstacle is situated.

(4) I_{ps} = 4,000 feet = pressure altitude observed at the station described under item (3) at the (expected) time of passage of the aircraft over the highest obstacle.

(5) T_{mvsx} = 449.688° Rankine (—10° F.) = mean virtual temperature of the actual air column extending from the elevation of the station (E_s) to the elevation of the point of maximum height on the highest obstacle (A_x) at the (expected) time of passage of the aircraft over the obstacle.

(6) $I_{pxw} - I_{px}$ = — 400 feet = correction estimated for the pressure deficiency produced on the crest of the highest obstacle owing to the Bernoulli or Venturi effect of the wind, which is forecast to have a velocity of about 75—80 knots perpendicular to the mountain ridge at the (expected) time of passage of the aircraft. See Appendix 8.2.2.

(7) T_{mvxa} = 419.688° Rankine (— 40° F.) = mean virtual temperature of the actual air column extending from the elevation of the point of maximum height on the highest obstacle (A_x) to the cruising altitude of the aircraft during its passage over the obstacle with an assumed vertical clearance denoted by C_v and at a pressure altitude denoted by I_{pa}, on the basis of the expectation that the aircraft will then be at a true elevation $A_a = (A_x + C_v)$.

(8) $(H_{Au} - H_{As})$ = —350 feet = assumed correction for possibility that an erroneous altimeter setting might be used to set the pressure scale of the aircraft altimeter during the time of its (expected) passage over the obstacle. (*Note:* The minus sign is taken owing to the fact that the aircraft will be flying toward an area of relatively low altimeter settings in the vicinity of the valley station

as compared with those which occur in the lowland area, e.g., at elevations of 1000—2000 feet, over which the aircraft passes when it approaches the ridge. See secs. 8.1.6 and 8.3.)

(9) Altimeter of Type II as defined in Table 8.2.2(a); that is, an altimeter calibrated to 50,000 feet, and characterized by the mechanical and non-meteorological errors listed in Table 8.2.2(a) averaged for an altitude of 15,000 feet between the data given for 10,000 and 20,000 feet. (Note: According to the International Civil Aviation Organization, the values attributed to those errors and factors listed in the specified table are conservative rather than extreme. See reference (12) of sec. 8.2.2. These data apply to a typical altimeter of the kind illustrated by fig. 8.0.1, as of the years 1956-57.)

In order to make use of *criterion (a)*, for the purpose of solving for the minimum altitude, I_n, which will provide clearance C_v with respect to the point of maximum elevation of the highest obstacle, A_x, it is necessary to ascertain the pertinent values of correction terms which compose k_s, the total correction. For this purpose, it is necessary to adopt some principle to provide guidance in regard to the selection of appropriate values of these correction terms. The errors which give rise to the need for corrections of a non-meteorological character, such as those involved in the terms k_i, k_p, k_f, and k_r, will lie within some range from zero (0) to an extreme maximum. The authorities who compiled the data shown in Table 8.2.2(a) regarded them as conservative, rather than extreme. A question therefore arises as to whether one should assume most probable values for present purposes, or extreme ones, or something in between. Owing to the need to provide here for the satisfactory accomplishment of individual missions de-

Table 8.2.2(a)

Table showing numerical values assigned to factors contributing to loss of vertical separation when using range "A" (0–35,000 feet) altimeters and range "B" (0–50,000 feet) altimeters, where calibration is carried out to 30,000 feet (type I) and to 50,000 feet (type II)

Source of Error, or Factor	Altimeter indication									
	5,000 feet		10,000 feet		20,000 feet		30,000 feet		40,000 feet	
	Type I	Type II	Type I	Type II	Type I	Type II	Type I	Type II	Type I	Type II
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1. Diaphragm } combined 2. Drift }	60	100	100	150	200	320	300	510	....	650
3. Friction	10	10	10	10	15	15	20	20	....	25
4. Temperature	15	15	20	20	25	25	35	35	....	45
5. Backlash***	10	10	10	10	10	10	10	10	....	10
6. Static Balance**	20	20	20	20	20	20	20	20	....	20
7. Coordination**	25	25	25	25	25	25	25	25	....	25
8. Instability	30	30	40	40	50	50	75	75	....	110
9. Zero-Setting**	15	15	15	15	15	30	15	30	....	20
10. Readability:										
(a) Height	20	20	20	20	20	20	20	20	....	20
(b) Pressure	15	15	15	15	15	15	15	15	....	15
11. Static Pressure System	250	250	270	270	330	330	330	330	....	330
12. Pressure Datum**	350	350	350	350	350	350	350	350	....	350
13. Non-Standard Atmospheric Temperature	10%	10%	10%	10%	10%	10%	10%	10%	....	10%
14. Size of Aircraft	75	75	75	75	75	75	75	75	....	75
15. Flight Technical	175	175	250	250	440	440	750	750	....	1000*

* This value is extrapolated from figures known for lower altimeter indications.

** Apply only when QNH setting other than 1013.25 mb. is used.

*** Does not apply when pressure setting is fixed.

spite any adverse problems of terrain clearance that may be encountered, and to promote safe practices in regard to air navigation, it appears best to assume a definite probability of the occurrence of extreme errors, keeping in mind that there is a possibility that the constituent errors which k_s is intended to correct will, on rare occasions, be largely of like algebraic signs and of such sense that they will be in the dangerous direction.

On these grounds it is considered prudent in treating the problem of terrain clearance that due allowance be made for the chance of occurrence of the worst contingency, based on the possible combination of errors of relatively extreme, large magnitude with like signs, having the most adverse effect on safety.*

First of all, consideration must be given to the *corrections* designed to overcome the instrumental, non-meteorological errors, denoted by k_i, k_p, k_f, and k_r, whose sum is designated by k_c.

In the case of altimeter of type II, the standard deviation of instrument errors, k_i, is considered to be about 41 feet at an altitude of 15,000 feet and 48 feet at an altitude of 20,000 feet, according to the International Civil Aviation Organization.[8] See also sec. 8.2.2.

The data cited in the previous paragraph are based on the assumption that the altimeter is operated with a constant, standard altimeter setting of 29.92 inches of mercury (QNE). However, when a variable altimeter setting (QNH) is to be used, proper allowance must also be made for the effects of errors due to static balance, coordination, and zero-setting as listed in Table 8.2.2(a). For the sake of simplicity, and merely for illustrative purposes, it will be supposed that the standard deviation of instrument errors pertinent to the example under consideration is 57 feet, assuming that variable altimeter setting (QNH) is used. In view of the requirement for a prudential allowance with respect to the problem of terrain clearance, it will be assumed for the present example that k_i should be *minus* (—) 3.5 times the standard deviation of instrument errors; that is -3.5×57 feet, whence $k_i = -200$ feet.

It should be noted that the combined error due to the effects classified under the captions diaphragm, hysteresis, and drift, can alone amount to a maximum of the order of 130 feet for type II altimeters at an altitude of 20,000 feet.[8] See sec. 8.2.2, and tables therein.

With regard to the correction k_p intended to overcome errors resulting from the static-pressure system, the ICAO Panel on Vertical Separation of Aircraft[8] considered that the static-pressure system error consists of two components, that is, a fixed error which remains after a correction is applied and a variable error. *In other words, it is assumed that a correction is applied.* The fixed remaining error *after correction* is presumed to amount to 50 feet and to have a rectangular distribution. On the other hand, the variable error is assumed by the Panel to have a Gaussian distribution with a standard deviation of 150 feet at an altitude of 15,000 feet and a standard deviation of 180 feet at an altitude of 20,000 feet, in the case of altimeters of types IA, IB, and II. See Table 8.2.2(a). It is believed that the application of a correction by the pilot for the static pressure system error will normally yield results accurate within 15 feet. By making allowance for the assumed statistical distributions, the Panel concluded that at an altitude of 20,000 feet the total static pressure system error should be within a tolerance of about 200 feet in the case of the specified types of altimeter, while the standard deviation will be about 67 feet. It was also concluded that for aircraft which fly at relatively high

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* The crew and passengers have in mind a direct concern for their individual safety; and this is likewise true of the aircraft operators; since the primary objective is the safe and successful accomplishment of the given mission. A careful distinction must be made between (1) mean tolerances pertaining to errors as derived from statistical probabilities based on the behavior of large numbers of altimeters, aircraft, autopilots, static-pressure systems, etc., and (2) the *actual* largest possible errors or factors that could affect adversely the operation of the particular aircraft during the given flight. Since the crew and passengers are more immediately concerned with the latter than the former, they will naturally consider it essential to give forethought to the contingencies and deem it discreet to allow for the chance that the errors may combine sometimes with the most adverse sign, to a maximum degree.

[8] International Civil Aviation Organization, Report of the Third Meeting of the Panel on Vertical Separation of Aircraft," Doc. AN-WP/1997, 15/12/58, Montreal, Canada, 1958. See also Doc. AN-WP/1997, 15/12/58, Corrigendum.

Mach numbers the use of a compensator to overcome static-pressure system errors is desirable, in order to remain within the tolerance. For the present example it will be assumed that a single correction card is used to apply a correction for the static-pressure system error which normally corrects within 15 percent of the fixed static-pressure system error specified in the aircraft manual, and that there remains a variable error whose standard deviation is 67 feet. By analogy to the method employed to estimate k_i, it will be assumed for this example that k_p is evaluated by subtracting 50 feet[8] from *minus* 3.5 × (standard deviation); hence on this basis $k_p = -3.5 \times (67 \text{ feet}) - 50$ feet $= -285$ feet.

With regard to the subject of flight technical error k_f the ICAO Panel on Vertical Separation of Aircraft[8] accepted a value of 500 feet for altitudes up to 25,000 feet. If one accepts this also for the present example with a minus sign as pertinent to flight over mountainous terrain, one has $k_f = -500$ feet.[9] [10]

Finally, with respect to the correction k_r for residual errors of a non-meteorological character not already taken into account, it is considered desirable to allow 50 feet for the size of the aircraft and 250 feet additional for contingencies. On this basis, it is assumed for the present example that $k_r = -300$ feet.

The results obtained in regard to the corrections for non-meteorological sources of error pertaining to the altimetry system can be summarized as follows: $k_i = -200$ feet, $k_p = -285$ feet, $k_f = -500$ feet, and $k_r = -300$ feet. The total of these is given by $k_c = -1285$ feet. (See equation (4).)

At this point it is necessary to turn to a consideration of the errors which result from meteorological causes. By making use of the data specified above under conditions (1)—(8), and substituting them in the relevant equations contained in Appendix 8.2.2, one finds the following results:

$k_a = -350$ feet (from condition (8) and equation (19));

$k_w = -400$ feet (from condition (6) and equation (24));

$k_t = -990$ feet (from the conditions (1)—(8) and equation (40); also verified by means of the table in sec. 8.3.)

The sum of these corrections dependent upon meteorological factors is $k_m = -1{,}740$ feet. (See equation (5).)

Finally, the total correction is given by $k_s = (k_c + k_m) = -3{,}025$ feet. (See equation (6).)

According to *criterion (a)*, the *minimum* indicated altitude (I_n) which satisfies the specified conditions is governed by the following equation:

$$I_n + k_s = A_x + C_r;$$

or

$$I_n = (A_x + C_r) - (k_s).$$

By substituting the relevant quantities in this relationship one obtains

$$I_n = (14{,}000 + 2{,}000) - (-3{,}025) \text{ feet} = 19{,}025 \text{ feet}.$$

These results have been based upon the assumption of the worst possible accumulation of consistent (negative) signs for the corrections involved in k_s; therefore the probability does not appear to be very great that this will occur. On the other hand there are climatic, meteorological and topographic conditions which can be even more extreme than those assumed (see Appendix 8.3). In addition, the altimetry system might in some individual cases not be as good as indicated by the data in Table 8.2.2(a); for example, owing to leaks in the static pressure system, or effects on the static pressure resulting from deformation of the skin of the fuselage in the vicinity of the static pressure intake vent (see sec. 8.2.2).

In any event the result given by the example serves to give special emphasis to the need for the taking of proper cognizance of the *criterion (a)* in regard to the problem of safe terrain clearance in connection with flights over regions having high mountains and characterized by extremely low temperatures during the winter (see Appendix 8.2.2 and sec. 8.3).

8.2.1.3.1 *Conclusions regarding criterion*

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[9] C. F. Jenkins and J. Kuettner, "Flight Aspects of the Mountain Wave," Flying Safety, vol. 10, No. 1, 1954.

[10] C. F. Jenkins, "Forecasting the Mountain Wave," Air Force Surveys in Geophysics, No. 15, September, 1952. Geophysics Research Directorate, Air Force Cambridge Research Center, Cambridge, Massachusetts.

(a) as applied to terrain clearance.—The following conclusions are reached with reference to the use of *criterion (a)* for flight planning in connection with the problem of terrain clearance:

(A) If it is desired to conserve airspace to the maximum possible degree and to promote safety, the data substituted in the correction terms listed in equations (4), (5), and (6) should be as representative as possible under the given circumstances.

(B) With respect to the terms k_i and k_p which relate to the corrections for instrumental errors and static-pressure system errors, respectively, these could be rendered most reliable and representative if based on specific calibrations pertinent to the particular altimeter-aircraft system involved in the flight. All corrections necessary to overcome known systematic errors should be embodied in k_i and k_p, when relevant and not otherwise compensated; while an adequate allowance for possible random variations about the assumed correction should also be included, if it is demonstrated that such occur. Whenever a compensator is employed on the aircraft to overcome the major part of the error stemming from the static-pressure system, this part of the correction should *not* be included in the term k_p. However, if there exists any systematic remaining part not covered by the device or if there may be random deviations from the result which it supplies at the input of the altimeter correction system, then the term k_p should include suitable allowances for the systematic remaining part and for the possible random deviations.

(C) It is deemed advisable to assume the correction for flight technical error (k_f) to be *negative,* for the sake of safety; and to ascertain as closely as practicable by observational means appropriate values of k_f for the given type of aircraft with and without autopilot and/or height lock, under normal operational and meteorological conditions. (See sec. 8.2.2.) Appropriate data regarding k_f should be introduced in the evaluation of the *criterion* (*a*), depending upon the individual type of aircraft, and upon whether the flight over the mountainous terrain is likely to be conducted by means of manual operation or by means of automatic equipment, such as autopilot and/or height lock. In either case prudence would suggest the choice from among the possible data of a value for k_f which is largest in absolute magnitude and is negative.

(D) The correction for residual errors (k_r), including the size of the aircraft, must be considered negative. For reasons of safety, it should contain a due allowance for contingencies, to cover unknown factors and possibly some systematic or random errors from sources that may be generally overlooked (e.g., leakage in the static pressure system, or effect of changes in configuration of the aircraft on the results yielded by that system, etc.).

(E) All of the errors that result from meteorological factors are systematic under any given set of conditions regarding the synoptic situation, altimeter setting distribution, temperature, wind, topography, location and elevation of reporting stations, flight path, etc. (see Appendix 8.2.2). Therefore, the corrections for the meteorological factors listed in equation (5) must be applied with their appropriate algebraic signs. (*Note:* It would be improper for any particular case of an aircraft flight to treat them statistically as random variables, since here one is concerned with the problem of terrain clearance; although this method of treating the data is employed in regard to the problem of vertical separation of aircraft considered on the basis of probabilities. (See secs. 8.2.1.2 and 8.2.2.)

(F) The correction (k_t) for the departure of air temperature from standard can become relatively large in absolute magnitude, provided that the factors $(A_a - E_s)$ and $(T_{mvsa} - T_{mp})/T_{mvsa}$ are both relatively large in absolute magnitude, since k_t depends on their product; where A_a = actual elevation of the aircraft above mean sea level when at cruising altitude, E_s = elevation of the station which reports altimeter setting nearest to the highest obstacle to be safely cleared during passage of the aircraft, T_{mvsa} = mean virtual absolute temperature of the actual atmospheric column extending vertically between the elevations E_s and A_a; and T_{mp} = very closely the mean absolute temperature in the standard atmosphere column extending from sea level to the pressure altitude $(I_a + I_s)$, where I_a = pressure altitude existing at actual elevation A_a, and I_s = pressure altitude existing at the station, at elevation E_s. See Appendix 8.2.2 and sec. 8.3.

The factor involving the temperature T_{mrsa} may vary over a range from positive in summer to negative in winter; and in cold climates its mid-winter value not uncommonly is about − 0.10 and may become as much as − 0.17 to − 0.25, more rarely under conditions of extremely low temperature. Tables in sec. 8.3 present relevant data concerning the *error* $(-k_t)$ in indicated altitude resulting from this temperature effect. When the elevation difference factor $(A_a - E_s)$ becomes relatively small, the correction due to air temperature, k_t, is correspondingly small in magnitude (see sec. 8.3 and Appendix 8.2.2 for additional details).

(G) In cases where the stations that report altimeter settings in mountainous areas are located in valleys or on the lower slopes, but not located on or near the crest of the highest significant obstacle for enroute aircraft, the corrections for the effects of wind and non-representative altimeter settings on terrain clearance will not always be known specifically in connection with the given obstacle. However, investigations to determine these effects can be conducted. On the basis of such studies it would be possible to compute corrections (k_w) for the wind effects. It is found that the effect of strong winds blowing *across* a mountain barrier is practically always to yield *negative* values of k_w, when the reporting station is located much below the crest (see Appendix 8.2.2). The value of k_w is correlated with the direction and the square of the wind velocity with respect to the mountain ridge, peak, or other topographic feature involved. In the case of terrain characterized by two or more high mountain ranges, with deep intervening valleys and great variations in contour configurations over an extensive region, many factors of great complexity affect k_w pertinent to the crest of the highest obstacle. Sometimes, extreme values of k_w will exist in connection with a cross wind through a mountain pass or valley where funneling of the air stream occurs.

(H) Flights over rugged terrain may lead to encounters with mountain waves, attended by downdrafts, turbulence, and special cloud forms, often giving rise to low ceilings with possibly poor visibility due to clouds and precipitation which may obscure the mountain ridges, peaks, etc.[9] [10] [11] Consideration of *criterion (a)* assumes a special importance for flight planning if there is a significant probability that the hazardous conditions of the mountain wave will exist over the intended flight course, especially since the corrections k_t, k_w and k_a may approach nearly extreme negative values during the occurrence of the mountain wave.

8.2.2 Classification and Assessment of Altimeter Errors

8.2.2.1 Classification of Errors.—An error from any source which affects the indication of an altimeter will have an influence upon the validity of the instrument readings for any of the purposes to which they are put, e.g., landing, vertical separation of aircraft, and terrain clearance. Owing to the cases of collisions and the reported number of near-misses of aircraft, the problem of vertical separation of aircraft has seemed most acute; and it may be inferred that altimeter errors made a significant contribution to this problem.

According to Civil Air Regulations (see Appendix 8.2.1), a "nominal" vertical separation of 1,000 feet should exist between aircraft within a certain range of cruising altitudes or flight levels, depending upon magnetic course headings and the flight rules in effect (VFR or IFR). However, only rarely does the "nominal" vertical separation yield a true vertical separation of 1,000 feet. The discrepancy is attributed to various sources of error in the altimetry system, and therefore it has been a matter of the utmost importance to assess the errors from the diverse causes which reduce vertical separation.

Results of studies to determine these errors and their origins are partially intended

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[11] M. A. Alaka, "Aviation Aspects of Mountain Waves," Technical Note No. 18, World Meteorological Organization, Geneva, Switzerland, 1958.

to permit aviation authorities to ascertain what will be safe "nominal" vertical separation for various altitude ranges, depending upon many factors, such as the quality of the instruments, the control of calibrations, the procedures employed in flight operations, etc. It has also been felt that such studies might pave the way for the discovery of means to overcome some of the errors, provide an incentive to the development of improved equipment or techniques, and at least enable the users of altimeters to apply appropriate corrections. With these goals in view, investigations of all of the errors inherent in the altimetry system have been undertaken by various organizations and authorities.[6 8 12 13 14 15 16 17]

The ICAO Panel on Vertical Separation of Aircraft agreed on the following classification of factors representing either errors or conditions which cause aircraft to operate at levels different from the intended cruising levels:

Instrument Errors

Errors in instrument indication due solely to the limitations of the instrument

Diaphragm error
Hysteresis error
Drift error
Friction error
Temperature error
Backlash error
Balance error
Coordination error
Instability error
Zero setting error
Readability error

Other factors which can result in a deviation from an intended cruising level

Error due to static pressure system—variable from aircraft to aircraft
Pressure datum error—due to use of different altimeter settings (QNH)
Non-standard atmospheric temperature
Size of aircraft
Flight technical error

The ICAO Panel on Vertical Separation of Aircraft considered that there are four basic types of factor in connection with the use of the pressure-responsive altimeter for vertical separation purposes, as follows:

(a) *Mechanical errors,* which result from the mechanical limitations of the instrument.

(b) *Operation and installation errors,* resulting from the manner in which the pressure altimeter is operated, and the accuracy with which the altimeter is set and read. (This includes discrepancies in the static pressure input.)

(c) *Errors of basic principle,* as in the case of the method used to convert pressure into height indications, i.e., the use of standard atmosphere.

(d) *Additional factors,* which involve the size of aircraft and the accuracy with which a desired cruising or flight level can be maintained.

In order to make explicit the significance of the terms applied in referring to the various factors listed in the foregoing classification the ICAO Panel on Vertical Separation of Aircraft issued a discussion [6 8 12] giving definitions relating to the terms, more or less as shown in the following, to which we have added some remarks when deemed advisable:

(a) *Mechanical errors*

1. *Diaphragm error.*—The error in the indications of an altimeter due to the physical properties and construction of the aneroid and linkage system, which result in a variable response in diaphragm deflection for equal changes in atmospheric pressure at different heights. (See sec. 2.9.0.)

2(a). *Drift error.*—The error in the indication of an altimeter due to the recovery effect which will occur with time

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[6] ICAO Panel on Vertical Separation of Aircraft, Second Meeting, Montreal, 3–14 June 1957, "Report of the Meeting," International Civil Aviation Organization, Doc 7835–AN/863, 1958.

[8] ICAO Panel on Vertical Separation of Aircraft, Third Meeting, Montreal, 17 November–1 December 1958, "Report of the Third Meeting," International Civil Aviation Organization, AN–WP/1997, 15/12/58. See also Corrigendum.

[12] ICAO Panel on Vertical Separation of Aircraft, First Meeting, Montreal, 14–22 February 1956, "First Interim Report of the Panel," International Civil Aviation Organization, Doc 7672–AN/860.

[13] ICAO Air Navigation Bureau, "Terrain Clearance and Vertical Separation of Aircraft (Altimeter Setting)," International Civil Aviation Organization, Montreal, ICAO Circular 26–AN/23, 1953.

[14] W. G. Brombacher, "Measurement of Altitude in Blind Flying," National Advisory Committee for Aeronautics, Technical Note No. 503, Washington, August 1934.

[15] Wm. Gracey, "The Measurement of Pressure Altitude on Aircraft," National Advisory Committee for Aeronautics, Technical Note No. 4127, Washington, October 1957.

[16] Russell L. Fine, "Flight Test Evaluation of Aircraft Pressure Altimeter Installations," WADC Technical Note 56–438, Wright Air Development Center, U.S. Air Force, October, 1956 (ASTIA Doc. No. AD 110554).

[17] Radio Technical Commission for Aeronautics, "Altimetery," Paper 215–58/DO–88, Prepared by RTCA SC–70, Washington 25, D.C., November 1, 1958.

when the instrument is exposed to a certain pressure. (See secs. 2.10.0–2.10.10.)

2(b). *Hysteresis error.*—The error in the indication of an altimeter introduced during an increase or decrease in height, due to the imperfectly elastic properties of the aneroid material which prevent the aneroid from assuming its normal shape for any given atmospheric pressure. (See secs. 2.10.0–2.10.10.)

3. *Friction error.*—The error in the indication given by an altimeter due to friction in the mechanism.

4. *Temperature error.*—The error in the indication of an altimeter due to the effect of temperature variation on its mechanism. (See sec. 2.8.2.)

5. *Backlash error.*—The error in the indication of an altimeter due to lost motion in the gear transmission between the height scale and the pressure scale.

6. *Static balance error.*—The error in the indication of an altimeter due to changes in the state of static balance of the mechanism when it is rotated from the test position to other positions.

Note:—This error is introduced when a pressure setting other than 29.92 inches of mercury (1013.25 mb.) is used, since it is caused by the rotation of the altimeter mechanism.

7. *Coordination error.*—The error in the indication of an altimeter due to inability to obtain the correct relationship between the graduation of the pressure scale and the height scale.

Note:—This error does not occur in the instruments having a fixed pressure datum.

8. *Instability error.*—The change apparent in the indication of an altimeter following consecutive ascents and descents.

Note:—This error, being additional to the errors numbered 1 to 7, inclusive, may occur any time after the original test of the instrument is completed and consequently is outside the limits specified in the tolerance curves for diaphragm and drift tests. It may be due to the variable behavior of the instrument mechanism during the changes in pressure on different occasions and/or inaccuracies in the method of testing.

(b) *Operation and installation errors*

9. *Zero-setting error.*—The error in the indication of an altimeter due to the displacement of the reference pressure datum from that used during test (29.92 in. Hg, 1013.25 mb.) to some other pressure.

Note:—The use of a setting other than 29.92 in. Hg (1013.25 mb.) has the effect of altering the diaphragm-plus-drift tolerance.

10. *Readability error.*—The error due to parallax effects when reading the graduations on the height scale and the pressure scale. (See fig. 2.10.2.)

11. *Static pressure system error.*—The error in the indication of an altimeter due to a static pressure source which applies to the instrument a pressure other than ambient atmospheric pressure. (See reference 16 previously given, on "Flight Test Evaluation of Aircraft Pressure Altimeter Installations," WADC Tech. Note 56–438, Wright Air Development Center, 1956, by Russell L. Fine.)

(c) *Errors of basic principle*

12. *Pressure datum error.*—The error in the indication of altitude provided by an altimeter due to variation in atmospheric pressure, in time and space. (See sec. 8.1.6.)

13. *Non-standard atmospheric temperature error.*—The error in the apparent vertical separation between two aircraft operating at different flight levels (or cruising altitudes) based on the same altimeter setting in any given area, resulting from the deviation of the average (mean) atmospheric temperature in the layer between the aircraft from the average temperature assumed in the standard atmosphere for the layer delimited by

the pressure altitudes at the two levels.

Note: — Separate consideration must be given, especially for purposes of terrain clearance, to the error in the *absolute* altitude indications of pressure-responsive altimeters that stems from a similar deviation of temperature for the entire layer or air column extending down from the aircraft level to the station level. For such purposes this error could also be classified as resulting from non-standard atmospheric temperature. In this case the error may be defined as the departure of the indicated altitude from the true actual altitude assuming that the altimeter is free from all other sources of error, where both the indicated and the true actual altitudes are measured with respect to the elevation of the station from which the current altimeter setting was obtained for setting the instrument, and where the cause of the specified departure of altitude is the deviation of the mean atmospheric temperature of the pertinent air column from the mean standard atmosphere temperature for the column delimited by the pressures which exist at the station and aircraft levels. See sec. 8.3 for additional details. In Table 8.2.2(a) which shows the numerical values assigned to the factors contributing to the loss of vertical separation, under certain conditions, the amount 10% is specified for the factor relating to "non-standard atmospheric temperature." This is intended to imply that actual vertical separation can be 10% less than the indicated separation, owing to the specified cause (for example, the indicated vertical separation may be 1000 feet but the actual vertical separation will be only 900 feet); but it should be noted that when very low temperatures are encountered the percentage reduction can be more than 10%, (for example, such as 17 to 25% in extreme cases).

(d) *Additional Factors*

14. *Size of aircraft.*—This is an allowance to take into account the reduction in usable airspace between two pressure levels due to the physical dimensions of an aircraft.

15. *Flight technical error.*—This refers to the random deviations of flight path in a vertical plane about the intended cruising altitude or flight level during normal operational and meteorological conditions. It is based on those conditions which a pilot normally encounters during cruise conditions or in holding patterns. At the Third Meeting of the Panel on Vertical Separation of Aircraft of the International Civil Aviation Organization, Montreal, Canada (Report dated 15 December 1958), the following discussion was considered pertinent to the subject: "The meteorological conditions taken into account in the assessment of flight technical error include light and moderate turbulence insofar as the statistics available cover such effects, and these are regarded as 'normal' in the sense used in the definition of flight technical error. It is difficult to see how vertical separation standards can in themselves guard against the risk of loss of separation in severe turbulence, as for example whilst flying on instruments in developing cumulus or cumulonimbus clouds in which several thousands of feet may be gained or lost in a very short period of time. Other measures than an increase in planned vertical separation are indicated to deal with this problem, such as the use of air-borne weather radar." The magnitude and sign of the flight technical error depend upon such factors as the following: the velocity, direction, size, spacing, and frequency of gusts and up- and downdrafts which are encountered by the aircraft; the size, speed, Mach number, weight, configuration, angle of attack, and aerodynamic characteristics of the aircraft; the operational char-

acteristics of the autopilot and/or height lock in relation to the flight characteristics of the given aircraft if these devices are used for automatic height keeping; the static-pressure system error to the input to the automatic equipment; the closeness with which the pilot maintains the intended cruising altitude or flight level if the aircraft is flown manually; etc.

8.2.2.2 General Assessment of Altimeter Errors.—Table 8.2.2(a) presents a list of what may be regarded as the nearly maximum errors pertaining to various factors which may yield a loss of vertical separation in connection with the system of aircraft altimetry, under typical commercial operating conditions, as estimated in 1956-57 by the "Panel on Vertical Separation of Aircraft" of the International Civil Aviation Organization (ICAO).[6, 12] Data are given for two classes of pressure-responsive altimeters; namely, those designed to function over range "A" (0—35,000 feet) and over range "B" (0—50,000 feet) respectively; with the understanding that any of these which are calibrated to 30,000 feet are categorized as "Type I," while those of range "B" which are calibrated to 50,000 feet are categorized as "Type II." It should be noted that Table 8.2.2(a) is based on the considerations which prevailed at the First and Second Meetings of the ICAO Panel on Vertical Separation of Aircraft.[6, 12]

8.2.2.3 Assessment of Instrument Errors.—At the Third Meeting of the ICAO Panel on Vertical Separation of Aircraft some changes in the specifications of the various categories of altimeters were adopted, and new data were added. Tables 8.2.3(a), 8.2.4(a), 8.2.5(a) and 8.2.6(a) show the so-called "maximum component instrument errors" for four types of altimeters, in which Type IA as here listed is the same as Type II in the Reports of the First and Second Meetings of the ICAO Panel on Vertical Separation of Aircraft, Type IB as here listed is the same as Type I in those Reports, while Types II and III as here listed refer to improved altimeters characterized by instrumental error tolerances which are generally more restricted than the tolerances pertaining to the previous altimeters of older design. It was noted by the Panel at the Third Meeting[8] that the component instrument errors given in these tables represent specifically the performance of the particular instruments considered in 1958, and that the component errors listed in the tables may or may not be present in other designs of instruments meeting the same performance, but whose specific characteristics were not examined. The data contained in Tables 8.2.3(a)—8.2.6(a) are restricted to instruments in which it is assumed that the altimeter setting is maintained at the constant, standard value of 29.92 inches of mercury. However, if these instruments were to be employed with a variable altimeter setting (QNH) then the items listed in Table 8.2.2(a) with reference to static balance error, coordination error, and zero-setting error would also have to be taken into account.

Table 8.2.3(a)

Maximum Component Instrument Errors for Type IA Altimeters (Same as Type II in First and Second Panel Reports—See Table 8.2.2(a)), According to Report of Third Meeting of ICAO Panel on Vertical Separation of Aircraft.[8] (Data Are Considered Effective for Altimeters in Use in 1958.)

Height × 1,000 feet	5	10	15	20	25	30	35	40
1. Diaphragm+ 2. Hysteresis+ 3. Drift	100	150	225	320	415	510	600	650
4. Friction	10	10	15	15	20	20	25	25
5. Temperature	15	15	20	25	30	35	45	55
6. Instability	30	35	40	50	60	75	90	110
7. Backlash	10	10	10	10	10	10	10	10
8. Readability:								
(a) Height	20	20	20	20	20	20	20	20
(b) Pressure	15	15	15	15	15	15	15	15

Table 8.2.4(a)

Maximum Component Instrument Errors for Type IB Altimeters (Same as Type I in First and Second Panel Reports—See Table 8.2.2(a)), According to Report of Third Meeting of ICAO Panel on Vertical Separation of Aircraft.[8] (Data Are Considered Effective for Altimeters in Use in 1958.)

Height × 1,000 feet	5	10	15	20	25	30
1. Diaphragm+						
2. Hysteresis+	60	100	150	200	250	300
3 Drift						
4. Friction	10	10	15	15	20	20
5. Temperature	15	15	20	25	30	35
6. Instability	30	35	40	50	60	75
7. Backlash	10	10	10	10	10	10
8. Readability:						
(a) Height	20	20	20	20	20	20
(b) Pressure	15	15	15	15	15	15

Table 8.2.5(a)

Maximum Component Instrument Errors for Type II Altimeters According to Report of Third Meeting of ICAO Panel on Vertical Separation of Aircraft.[8] (Data Are Considered Effective for Altimeters in Use in 1958.)

Height × 1,000 feet	5	10	15	20	25	30	35	40	45	50
1 Diaphragm+										
2. Hysteresis+	55	80	105	130	155	180	205	230	255	280
3 Drift										
4. Friction	10	10	15	15	20	20	25	25	30	30
5. Temperature	15	15	20	25	30	35	45	55	70	85
6. Instability	15	15	20	25	30	35	45	55	70	85
7. Backlash	10	10	10	10	10	10	10	10	10	10
8. Readability:										
(a) Height	20	20	20	20	20	20	20	20	20	20
(b) Pressure	15	15	15	15	15	15	15	15	15	15

Table 8.2.6(a)

Maximum Component Instrument Errors for Type III Altimeters According to Report of Third Meeting of ICAO Panel on Vertical Separation of Aircraft.[8] (Data Are Considered Effective for Altimeters in Use in 1958.)

Height × 1,000 feet	5	10	15	20	25	30	35	40	45	50
1. Diaphragm+										
2. Hysteresis+	20	30	40	50	60	70	80	90	100	110
3. Drift										
4. Friction	10	10	15	15	20	20	25	25	30	30
5. Temperature	15	15	20	25	30	35	45	55	70	85
6. Instability	15	15	20	25	30	35	45	55	70	85
7 Backlash	10	10	10	10	10	10	10	10	10	10
8. Readability:										
(a) Height	20	20	20	20	20	20	20	20	20	20
(b) Pressure	15	15	15	15	15	15	15	15	15	15

Table 8.2.7(a) presents the resultant standard deviations of instrument errors for the various types of altimeters whose maximum component instrument errors are shown in Tables 8.2.3(a)—8.2.6(a), respectively. The pertinent resultant standard deviations for the instrument errors in one aircraft contained in Table 8.2.7(a) were computed by the ICAO Panel on Vertical Separation of Aircraft at its Third Meeting,[8] under the proviso that in treating statistically the errors listed in the left-hand column those

which are embraced in items 1—6 are assumed to have a Gaussian frequency distribution, item 7 is assumed to have a limit distribution, while those in item 8 are assumed to have a rectangular distribution. On these grounds the Panel calculated the effective standard deviations pertaining to items 1–3, 4, 5, and 6 respectively, by dividing the given relevant maximum component instrument errors by 3, under the assumption that the data in Tables 8.2.3(a)—8.2.6(a) were pertinent to a probability of 99.7 percent as explained in sec. 8.2.1.2. The effective standard deviation pertaining to item 7 was taken to be the same as the value of maximum component error due to item 7 itself, since backlash is considered to have a limit distribution. Finally, the effective standard deviations relating to the data listed under item 8 were obtained by dividing the pertinent maximum component errors by the square root of three (3), since a rectangular distribution was assumed for the readability errors of the height and pressure scales. The resultant standard deviations shown in Table 8.2.7(a) were then calculated by taking the square root of the sum of the squares of the effective standard deviations of the respective components as outlined above.

8.2.2.4 Assessment of Static Pressure System Error.—Special Committee 70 on "Altimetry" of the Radio Technical Commission for Aeronautics [17] has discussed the definition of and the factors affecting static-pressure system error in the following words:

"Static pressure error (also called installation error) is defined as that error which is occasioned by a difference between ambient atmospheric pressure and that pressure sensed by the static orifice of the altimeter system.

"The source of static pressure for an aircraft may comprise either the static openings of a pitot-static tube or a flush-mounted static port. Pitot-static tubes are installed on booms or masts which are affixed to the aircraft. The primary objective of such installations is to so locate the pitot-static tube that it will correctly sense the ambient static pressure. However, the location may also be affected by structural considerations, interference with other equipment and accessibility. Flush-mounted static ports are installed on the aircraft fuselage. Great care must be taken in locating flush-mounted static ports to minimize the effects of positive or negative pressure during various phases of flight. Wind-tunnel and flight tests normally are employed to determine the best location.

"In spite of the care that may be used in selecting the location of the static pressure source, errors persist. These are primarily related to the angle of attack and/or the Mach Number. The resulting altimeter error is a function of gross weight, altitude, and indicated air speed or Mach Number. As the speed of the aircraft increases, the air flow about it varies and thereby increases the difficulty of sensing the ambient pressure. This is particularly true at transonic speeds. At Mach Numbers near unity, the pressure effect of the shock-waves can become predominant. Changes in the gross weight of an aircraft, since they affect its angle of attack, can cause a change in the air flow over the static orifice with the result that it may be subjected to pressures which are either above or below the ambient pressure. In those aircraft in which the air flow over the static orifice may be influenced by a change

Table 8.2.7(a)

Standard deviations (σ_i) of the instrument errors for different types of altimeters referred to in Tables 8.2.3(a)–8.2.6(a)

Height × 1,000 feet	5	10	15	20	25	30	35	40	45	50
Type IA	40	55	79	110	141	173	204	221	....	....
Type IB	29	40	55	72	88	106	....	....	....	....
Type II	27	33	41	48	57	64	74	83	93	104
Type III	20	22	24	27	31	34	39	44	51	58

in the aircraft configuration (such as by extending the gear and flaps or carrying external loads) an additional error may result. The significance of a given error in the measurement of pressure also increases with altitude. The ambient pressure at 50,000 feet is approximately ten per cent of that at sea level. However, this lower pressure must be measured to the same percentage of accuracy as the sea level pressure if the same altimeter accuracy is to be maintained."

One may summarize the problem in terms of the basic parameters as follows:

Static pressure system errors develop owing to three principal causes: (1) the incorrect sensing of pressure by the pressure sensing device, such as the static openings of a pitot-static tube or a flush-mounted static port in the fuselage; (2) the existence of a value of pressure at the orifices of the device different from the true static pressure of the ambient free air owing to the field of air flow about the aircraft; and (3) the lag in the tubing which connects the pressure sensing device to the altimeter (see Appendix 2.11.1).

The pressure sensing device does not generally yield the exact value of the effective static pressure at the orifice, and the ratio of its pressure error to the static pressure depends upon the Mach number, the angle of attack and yaw, the Reynolds number, and the dimensions and design of the static pressure source.

Variations in the air flow about an aircraft give rise to corresponding variations in the departure from the true static pressure existing at the opening of the pressure sensing device. The *ratio* of this departure to the actual static pressure in the ambient free air is dependent upon the Mach number, the aircraft angle of attack and yaw, the variations in aircraft configuration (such as flaps, landing gear, air brakes, wing twist, bomb bay doors, etc.), the presence of shock waves, and ground effect (if the aircraft is near the surface).

Investigation has revealed that if the aircraft does not behave as a rigid body in flight its skin contour changes significantly under air load conditions, depending upon airspeed, turbulence, weight, acceleration, etc. Also, the skin contour may vary from one aircraft to another, owing to dimensional variations in the aircraft structures which are associated with production procedures. Consequently the changes in the skin contour which are caused by these factors produce corresponding variations in the air flow over a static pressure intake orifice mounted flush with the aircraft skin surface, and these variations are reflected in correlated changes in the ratio of the pressure departure at the orifice to the true static pressure. On this account reproducibility and stability of the static pressure source calibration with service life are not always obtained to a satisfactory degree, especially in the case of aircraft which do not represent rigid bodies.

From the foregoing considerations it may be envisaged that the proper maintenance of the static pressure system is a matter of the utmost importance. With regard to this subject the ICAO Panel on Vertical Separation of Aircraft made the following statement:[8] "The Panel is of the opinion that all operators should be advised of the necessity of maintaining the static pressure system in first class condition. Minor damage around the area of, or to, the static vent or minor leaks in the static pressure system can result in errors equal to or greater than the figures assumed by the Panel for both fixed and variable errors. The Panel is of the opinion that it is not generally appreciated that the pressure measured by the static vent, unlike that measured by a pitot tube (used for air speed), is very critical to small changes in the vent itself or the aircraft structure in the vicinity of the vent. It is also important to note that any change in the measured static pressure due to damage to the vent, leaks in the lines or alteration of the structure, will not be readily apparent to maintenance personnel or pilots."

In order to determine the static pressure system error under various conditions the U.S. Air Force conducted a program which made use of calibrated pacer aircraft for comparison with other aircraft in respect to static pressure indications.[16] The static pressure system errors of the pacer aircraft were known by means of independent methods of calibration, such as the so-called “fly-by technique” or the theodolite method. Both the pacer and the other aircraft were flown together on neighboring parallel, level courses at various constant airspeeds at an assigned pressure altitude such as 10,000 or 15,000 feet. The indicated altitude readings yielded by the altimeters of both aircraft were obtained under these conditions. The readings derived from the pacer aircraft were corrected both for known altimeter instrument errors and static pressure system errors, thus providing information regarding the true pressure altitude. On the other hand the indicated altitude readings secured from the other aircraft were corrected only for the known altimeter instrument errors. Differences were taken between the true pressure altitude as obtained from the fully corrected pacer aircraft readings and the readings derived from the second aircraft, corrected only for the altimeter instrument errors. These altitude differences were attributable to the static pressure system error of the second aircraft, and they were readily converted to the equivalent error in terms of pressure units with the aid of the standard atmosphere tables.

Since all of the test flights mentioned above were at uniform pressure altitude, no determinations were made concerning the effects of varying the angle of attack or the configuration of the aircraft. Similarly, no special investigation was carried out to ascertain the effect of varying the weight. However, in each case of a high-speed aircraft flown at a constant flight level with uniform weight it has been found that the ratio of the static pressure system error to the impact pressure is a function of the Mach number, where the error is expressed in terms of pressure units and the impact pressure represents one-half of the product of the air density and the square of the true airspeed, while the Mach number is the ratio of the true airspeed to the local speed of sound.

The data yielded by the U.S. Air Force investigation [16] demonstrated that in the case of high speed aircraft the static pressure system error, *if not corrected or compensated,* could be quite significant, indeed very serious for some types of aircraft. Tables 8.2.8(a)—(c) illustrate the variation of static pressure system error with indicated

Table 8.2.8(a)

Static pressure system error (in feet, altitude) for an F-84G aircraft [16]

Indicated airspeed (knots)	Pressure altitude		
	0 feet	15,000 feet	40,000 feet
	Feet	*Feet*	*Feet*
150	10	20	70
200	60	100	240
250	155	230	500
270	205	290	735
300	285	400	
350	435	595	
400	660	895	
410	720	985	

Table 8.2.8(b)

Static pressure system error (in feet, altitude) for an F-100A aircraft [16]

Indicated airspeed (knots)	Pressure altitude		
	0 feet	20,000 feet	45,000 feet
	Feet	*Feet*	*Feet*
220			−565
230		−220	−615
240		−240	−700
250		−260	−850
255		−270	−980
260		−285	−1230
262		−290	−1365
270		−310	−1030
276		−325	−810
300		−400	
350	−295	−555	
400	−400	−730	
420	−440	−865	
430	−460	−990	
440	−480	−1230	
448	−495	−1550	
450	−500	−1525	
460	−520	−1190	
470	−545	−900	
500	−625		
550	−790		
575	−900		
600	−1090		
610	−1285		
620	−1620		
627	−1795		
640	−1450		
650	−1140		

Table 8.2.8(c)

Static pressure system error (in feet, altitude) for an F–101 aircraft [16]

Indicated airspeed (knots)	Pressure altitude		
	0 feet	20,000 feet	45,000 feet
	Feet	*Feet*	*Feet*
215			−210
220			−235
230			−290
240			−370
245			−440
250			−630
255			−960
260			−1390
262			−1570
280		−10	
300		−35	
350		−145	
400	−25	−330	
410	−35	−390	
420	−50	−505	
430	−65	−675	
440	−85	−1080	
448	−100	−1820	
450	−105		
500	−250		
550	−395		
575	−500		
600	−710		
610	−970		
620	−1500		
626	−2140		

airspeed for three different types of fighter aircraft *where no correction or compensation was used.*

Large military and commercial jet aircraft are equipped with compensators, hence in such cases the effects of the static pressure system error are largely overcome automatically. An automatic aerodynamic device for securing static pressure compensation to a close degree of approximation has been described by Korkegi.[18]

Many piston-engined aircraft which cruise at indicated airspeeds ranging from about 200–300 knots are provided with correction cards which permit pilots to apply corrections to overcome very nearly the effects of the static pressure system error for various altitudes and airspeeds. When such corrections are applied in these cases, the residual error can be kept within fairly narrow limits.

The U.S. Air Force pacer program of 1956 revealed that a majority of the piston-engined aircraft tested had static pressure system errors within plus or minus 250—300 feet over the normal operating range of airspeed, although a minority showed somewhat larger errors in certain portions of the range.[16]

Some high-speed jet aircraft are characterized by large negative static pressure system errors while others manifest large positive errors from this source, if not compensated or corrected, as may be seen from the data presented in Tables 8.2.8(a)—(c). It may be emphasized that the static pressure system error tends to be extreme at Mach numbers close to unity, while the error usually grows rapidly in absolute magnitude as the Mach number varies from about 0.65 to 1.0 (see Tables 8.2.8(a) – (c)).

The ICAO Panel on Vertical Separation of Aircraft [8] has taken the view that the static pressure system error may be expressed in terms of two errors. The first of these is a so-called "fixed error" which is recorded in the aircraft flight manual, and depends primarily upon (varies with) such factors as altitude, Mach number and angle of attack. The other is a variable error which is the probable departure from this "fixed error," where the variability is to be attributed to such factors as the spread in values between aircraft of the same type, the errors inherent in the calibration test procedure used, and the change in static pressure system error due to time in service. It may be noted that the altitude ceases to be a factor causing variations in the "fixed error" when the flight is conducted in an extent of atmosphere which is isothermal vertically (as in the stratosphere).

One of the conclusions reached by the ICAO Panel on Vertical Separation of Aircraft [8] was stated as follows: "For jet aircraft operating at the higher speeds and heights, the mach number and angle of attack factors cannot be neglected and if automatic correction is not used, the use of correction cards based on height and airspeed only will result in a residual error, after

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[18] Robert H. Korkegi, "An Aerodynamic Means of Static-Pressure Compensation for Transonic and Supersonic Aircraft," Aeronautical Engineering Rev., vol. 16, pp. 64–68, April 1957.

correction, of approximately 15 per cent of the fixed error given in a manual."

At the Third Meeting of the ICAO Panel on Vertical Separation of Aircraft[8] the following recommendation was adopted: "That every effort be made to reduce to an absolute minimum the effect of the error due to the static pressure source, and in no case should the effect of this error be permitted to exceed 200 feet. That is, that the value recorded in an aeroplane flight manual (referred to in this report as the 'fixed error') should not exceed 200 feet for the complete range of speeds and heights and for all aircraft configurations."

With respect to the "variable error," the Third Meeting in 1958 of the ICAO Panel on Vertical Separation of Aircraft reached the following conclusions:[8] "On the basis of the information available, the Panel concluded that the variable error was of the order of 3.5 mb. for heights up to 30,000 feet. Above this height a constant value of 250 feet has been used in view of the measures which have been taken to keep this error within limits for new aircraft now being introduced into service. These values, when expressed in terms of a vertical distance are as follows:

Height (1,000 ft.)	5	10	15	20	25	30	35	40	45	50
Variable Error	110	130	150	180	215	250	250	250	250	250

"The Panel concluded that, on the basis of available information, the following values for this error constituted a reasonable objective to be attained as soon as possible:

Height (1,000 ft.)	5	10	15	20	25	30	35	40	45	50
Variable Error	25	25	30	35	40	50	60	75	90	120."

Owing to the considerable magnitude of the static pressure system error pertaining to aircraft flown at airspeeds of Mach number 0.5—1.0 and beyond, if uncompensated, the Panel[8] concluded "that if such aircraft were to be operated in controlled airspace, pilots should use correction cards which would provide the 85 per cent correction referred to in [the preceding] paragraph."

In order to determine the standard deviation (σ_s) of static pressure system errors, the ICAO Panel on Vertical Separation of Aircraft[8] decided to assume a rectangular distribution for the fixed error and a Gaussian distribution for the variable error. Thus, if K = the maximum fixed static pressure system error (after correction), and V = the maximum variable static pressure system error, the standard deviation (σ_s) was computed as the square root of the sum of $K^2/3$ and $V^2/9$.

Tables 8.2.9(a) and 8.2.9(b) show the values of K, V, and σ_s pertaining to the standard deviation of static pressure system errors, for the various types of altimeters referred to in Tables 8.2.3(a)—8.2.6(a). In discussing the results presented in Tables 8.2.9(a) and 8.2.9(b) the ICAO Panel on Vertical Separation of Aircraft made the following comment:[8] "The maximum fixed static system error (K) has been given a value of ± 50 ft. for Types IA, IB, and II altimeters, even though the Panel has stated that this error could be corrected down to ± 15 ft. The reason for this is that the Panel has accepted that corrections may not be applied when the fixed error does not exceed ±50 ft. For Type III altimeter the fixed error (K) has been assumed to be ± 15 ft., as automatic corrections (compensators) have been considered to be a feature of this category of altimeter."

In Table 8.2.10(a) there are given the combined standard deviations for instrument errors and static pressure system errors per-

Table 8.2.9(a)

Standard deviation (σ_s) of static pressure system errors, based on the tolerances accepted for altimeters of types IA, IB and II

Height × 1,000 ft.		5	10	15	20	25	30	35	40	45	50
Static pressure	K	50	50	50	50	50	50	50	50	50	50
	V	110	130	150	180	215	250	250	250	250	250
System error	Total	140	156	174	200	232	265	265	265	265	265
σ_s		47	52	58	67	77	88	88	88	88	88

Table 8.2.9(b)

Standard deviation (σ_s) of static pressure system errors, based on the tolerances accepted for altimeters of type III

Height × 1,000 ft.		5	10	15	20	25	30	35	40	45	50
Static pressure System error	K	15	15	15	15	15	15	15	15	15	15
	V	110	130	150	180	215	250	250	250	250	250
	Total	113	132	153	182	216	251	251	251	251	251
σ_s		38	44	51	61	72	84	84	84	84	84

Table 8.2.10(a)

Combined standard deviations (σ_c) for instrument errors and static pressure system errors pertaining to one aircraft, according to the ICAO Panel on Vertical Separation of Aircraft [8]

Height × 1,000 ft.	5	10	15	20	25	30	35	40	45	50
Type IA	61	75	98	128	161	194	224	238	......	......
Type IB	55	66	80	98	117	137	......	......	......	......
Type II	54	62	71	82	96	110	114	121	128	136
Type III	43	49	56	66	79	90	93	95	98	102

taining to one aircraft for the four specified types of altimeters, as calculated by the ICAO Panel on Vertical Separation of Aircraft [8] on the basis of data contained in Tables 8.2.7(a), 8.2.9(a), and 8.2.9(b).

8.2.2.5 Assessment of Flight Technical Errors.—With a view to determining the maximum probable flight technical errors, the ICAO Panel on Vertical Separation of Aircraft at its Third Meeting [8] collected and analyzed various compilations of data relating to observations of deviations from an intended flight level, as recorded in normal airline operations.

The following is a quotation from the Panel Report [8] in regard to the available data considered with respect to flight technical error and the results obtained by means of a statistical analysis of the information collected: "The data were considered to be representative of a wide range of operating conditions from flight control, traffic density and meteorological viewpoints. Most of the information provided was in a form suitable for analysis, the remainder serving as valuable spot checks.

"Observations were recorded automatically by flight recorders and by check pilots or non-flying personnel occupying the supernumerary crew seat. In the case of flight recorders intentional deviations, such as those occurring with QNH setting changes, were allowed for in the tape analysis, but it was not possible to determine if and when the pilot disengaged the auto-pilot and/or height lock, nor for what reason (turbulence, etc.).

"Whilst for flight recorders the errors were sampled at small fixed time intervals of one or two minutes, the altimeter readings were logged by observers at intervals varying from every 5 minutes to once per flight level per route sector, the reading in the latter case being the maximum error experienced.

"Observations did not indicate the area or particular stage of the operation such as high or low traffic density, holding or cruise. Neither were the flight conditions, i.e. visual meteorological conditions (VMC) or instrument meteorological conditions (IMC) recorded. The data used are summarized in Table I [Table 8.2.11(a) herein] below:

"The observations for each of the above six sets were grouped in error intervals of 50 or 100 feet and height intervals of 4,000 or 5,000 feet. The standard deviation of the sample for each height band was calculated and multiplied by 3 to obtain the 99.7% probable error. The errors were then tested for correlation with height, and an upper limit for each set obtained by adding a confidence band, the size of the latter depending upon the degree of scatter of the errors. The resulting *maximum probable errors* are tabulated against flight control and height in

“TABLE I [Table 8.2.11(a)]

Obs. set	Flight control	Aircraft/engine type	Recording method	Number of observations	Height range (ft.)
1	M	All/Piston	O	1,882	0–25,000
2	A	All/Piston	O	437	0–25,000
3	AH	All/Piston	O	249	5–25,000
4	AH	Medium/Turboprop	O	1,228	10–25,000
5	AHM	Heavy Piston	R	18,148	0–19,000
6	AHM	Medium/Turboprop	R	189	10–20,000

M —Manual only
A —Auto-pilot only
AH —Auto-pilot/height lock only
AM —Auto-pilot, including observations taken when aircraft was flown manually
AHM—Auto-pilot/height lock, including observations taken when aircraft was flown manually
O —Observer
R —Flight Recorder

“TABLE II [Table 8.2.11(b)]

Obs. set	Flight control	Height (thousands of feet)				
		5	10	15	20	25
1	M	310	360	410	460	510
2	A	330	330	330	330	330
3	AH	...	320	320	320	320
4	AH	...	120	120	120	120
5	AHM	450	450	450	450	...
6	AHM	...	190	190	190	190

Table 2 [Table 8.2.11(b) herein]. It will be noted that only for the manual flight case has a definite correlation of the error with height been established. (Whilst in sets 2 and 3 the correlation appeared to be good, significance tests showed that this could not be proved and that the linearity had probably appeared by chance).”

By way of explanation it may be pointed out that the expression “99.7% probable error” in the last quoted paragraph is intended to signify that the quantity thus termed represents a value of the flight technical error which will probably be exceeded in 3 cases out of 1,000; or in other words it was considered that 99.7 per cent of the cases of flight technical errors under the specified operating conditions will have values equal to or less than the amount specified in Table 8.2.11(b).

The following conclusions were reached in regard to the subject of flight technical error by the ICAO Panel on Vertical Separation of Aircraft at its Third Meeting: [8]

“12. Since the data available reviewed above clearly show that:

1) above 20,000 ft., the amount of manual flying is insignificant,
2) the incidence of turbulence is much reduced, and
3) no evidence of correlation of error with height exists for auto-pilot equipped aircraft,

a figure for flight technical error of 500 feet at all heights was accepted for civil operations at the present time and in the near future. However, where both military and civil aircraft were liable to operate, the Panel agreed that this figure should only apply up to 25,000 feet, above that height the higher figures for flight technical error, indicated in paragraph 13, should apply.

“13. Although no detailed statistics were available to the Panel, it was indicated by one Panel Member that in respect of military aircraft flown manually, figures greater than 500 feet were required for flight technical error above 25,000 feet. The figures quoted were as follows:

Height (1,000 ft.)	25	30	35	40	45	50
Flight technical error	500	575	650	725	800	875

These were accepted by the Panel in the absence of any other data as applicable in those areas in which both civil and military aircraft are liable to operate.

“14. The following additional values were also suggested as a long term objective, having in mind that at some time in the future all aircraft using certain designated air space may be required to be fitted with autopilots equipped with height locks:

Height (1,000 ft.)	5	10	15	20	25	30	35	40	45	50
Flight technical error	200	210	230	240	260	270	280	300	310	325

“On the necessity of maintaining an intended flight level

“15. It cannot be too strongly emphasized that the choice of an upper limit for flight technical error presupposes that the pilot will aim to control the aircraft to the required datum (intended flight level) to the best of his ability and that the tolerance provided caters principally for the random variations which inevitably occur. It is considered that the attention of pilots should be drawn to the necessity of maintaining an intended flight level and a recommendation has been made to this effect:

> “*Recommendation No. 5:* That the attention of pilots be drawn to the importance of maintaining an intended flight level as accurately as possible since on the present assessment the deviations from an intended level are a major factor in the loss of vertical separation.

“16. At top of climb it appears to be a common practice to overshoot the intended cruising level by some hundreds of feet in order to accelerate to cruising speed during the subsequent shallow dive to this level. It would seem that, for many aircraft, this practice is unnecessary in that the time to achieve the desired cruising speed does not vary significantly for either the ‘overshoot’ method or the desirable one of levelling off at the correct height. In the case of aircraft which are proved to take longer, however, a preferable method would be to increase speed whilst still under ‘climb clearance’ and continue the last part of the climb at the higher speed but with a reduced rate of climb.”

In the light of the foregoing considerations the ICAO Panel on Vertical Separation of Aircraft at its Third Meeting [8] accepted the values of flight technical errors as given in Table 8.2.12(a) herein.

8.2.2.6 Summary and Conclusions Regarding Combined Errors in Altimetry.—The following summarizing remarks and conclusions are presented:

(1) The problem of safe landing and take-off with regard to altimetry has been briefly discussed already in sec. 8.2.1.1. It has been recommended that “Standards be established for the checking and setting of instruments utilized for providing pressure setting data to aircraft.” [17] Implementation of this requires a field inspection and checking program. Furthermore, standards, programs, and procedures for the periodic calibration, checking, testing, and maintenance of

Table 8.2.12(a)

Flight Technical Error as Accepted by the ICAO Panel on Vertical Separation of Aircraft [8]

Height × 1,000 ft.	5	10	15	20	25	30	35	40	45	50
Flight technical error based on operation of:										
Civil aircraft*	500	500	500	500	500	500	500	500	500	500
Civil plus Military aircraft**	500	500	500	500	500	575	650	725	800	875
All aircraft functioning under stricter specifications of an advanced procedure serving as a future objective***	200	210	230	240	260	270	280	300	310	325

*See paragraph 12 quoted from Panel Report.[8]
**See paragraph 13 quoted from Panel Report.[8]
***See paragraph 14 quoted from Panel Report.[8]

service altimeters and static pressure systems are considered absolutely essential in order to minimize errors that may affect the safety of landing operations.[17]

(2) Errors or factors which affect the indicated altitude in aircraft altimeters relative to the ground elevation or the altitude indicated by other aircraft altimeters may be classified under the general headings of *non-meteorological* and *meteorological combined with topographic factors.*

(3) Non-meteorological factors include
- (a) instrument errors;
- (b) static pressure system errors;
- (c) flight technical errors;
- (d) size of aircraft; and
- (e) human mistakes.

(4) Meteorological combined with topographic factors include:
- (f) altimeter setting differences;
- (g) temperature deviation from standard;
- (h) wind influences on mountains which cause a lowering of local pressure for various reasons, e.g. the Bernoulli or Venturi effect;
- (i) turbulence, mountain waves, and local storms or vortices which produce changes of aircraft altitude and may cause loss of control when severe; and
- (j) low ceilings, fog, undercast cloud conditions, and precipitation which give occasion to poor visibility and possible loss of visual contact with the ground, a matter of much concern in the case of flight over rough terrain when the errors combine in the most adverse sense.

(5) Table 8.2.2(a) shows certain combinations of these errors for typical altimeters in commercial airline operation as of the years 1956-1957, but the data in the table do not reflect the more extreme static system pressure errors and flight technical errors found to exist in some cases according to some later investigations.

(6) Tables 8.2.3(a)—8.2.6(a) present the so-called "maximum component instrument errors" for four different types of altimeters as of 1958, under the assumption that the constant, standard altimeter setting of 29.92 inches of mercury is used. If variable altimeter settings (QNH) are employed, the errors will be somewhat larger (see Table 8.2.2(a)). One may regard those errors compiled in Tables 8.2.3(a)—8.2.6(a) which are subject to a Gaussian distribution as approximately the 99.7 per cent probable maximum instrument errors. This signifies that it is estimated that only 0.3 per cent of the specified instrument errors under that condition will exceed the values given in the tables.

(7) Table 8.2.7(a) contains the standard deviations of the instrument errors, under the assumption mentioned in (6) above. If these data are multiplied by the factor 3, the product gives some idea regarding the probable loss of vertical separation which will be exceeded in 0.3 per cent of the cases for one aircraft; and if they are multiplied by the factor 4.24 (which represents $3 \times \sqrt{2}$, very nearly), the product gives some concept of the loss of vertical separation which will be exceeded in 0.3 per cent of the cases involving the instrument errors alone in *both* aircraft.

(8) Static pressure system errors result mainly from inaccurate indication of the input pressure by the pressure sensing device and the departure of the input pressure from the true ambient static pressure depending upon the variations in the air flow. Lag in the tubing can also contribute, especially when the aircraft is climbing or descending at a rapid rate. In the case of high speed aircraft, the static pressure system errors can become very large, if uncorrected or uncompensated, as illustrated in Tables 8.2.8(a)—(c) for several fighter aircraft. Such errors expressed in height units depend largely on the Mach number, the aircraft angle of attack and yaw, the configuration of the aircraft (flaps, landing gear, etc.), the normal acceleration, and the altitude.

(9) At airspeeds corresponding to Mach numbers in the range of about 0.65–1.0 or just over 1.0 especially as the latter value is approached, the static pressure system error assumes extreme values if uncorrected. It is possible to make use of correction cards for the purpose of correcting for the static pressure system error as a function of altitude

and indicated airspeed, and this procedure is capable of eliminating up to about 85 per cent of the error, in cases where compensators are not provided in the aircraft equipment. Modern heavy, high-speed jet aircraft are equipped with automatic compensators to overcome most of the static pressure system error. The use of the correction card has been strongly recommended for flights in areas of controlled air traffic, and for terrain clearance or other applications where absolute accuracy of altimeter data is essential. Tables 8.2.9(a)—(b) show the standard deviations of static pressure system errors based on the tolerances accepted by the ICAO Panel on Vertical Separation of Aircraft.[8] The so-called "fixed error," K, indicated in these tables is predicated on the assumption that a correction is applied to overcome the static pressure system error; while the so-called "variable error," V, is of such a character that it may be expected to exist despite the use of a correction, depending upon such factors as service life of the aircraft, errors in calibration procedures, etc. *Special emphasis is given to the need for careful maintenance to detect and repair leaks in the static pressure system, or damage around the area of the static vent, since serious discrepancies can result if these are overlooked.*

(10) Table 8.2.10(a) presents data regarding the combined standard deviations for instrument and static system pressure errors pertaining to one aircraft. As outlined in paragraph (7) these results can be converted to the approximate resulting loss of vertical separation between *two* aircraft which will be exceeded in 0.3 per cent of cases involving passages of such aircraft if the tabular data are multiplied by the factor 4.24, under the assumption of the tolerances specified in Tables 8.2.7(a) and 8.2.9(a)—(b). Thus, it will be clear that the combination of instrument errors and static pressure system errors even when corrected within the tolerances (K) specified in Tables 8.2.9(a)—(b) can contribute important losses of vertical separation between two aircraft in 3 cases out of 1,000.

(11) Flight technical error has been defined as the random vertical deviations from an intended cruising level during normal operational and meteorological conditions. Such conditions are considered to cover smooth, light, and moderate turbulence. However, the effects of encounters with severe turbulence such as that prevalent in well-developed thunderstorms or in certain mountain wave phenomena are not taken into account and therefore must be regarded as within the province of the broader problems of safe air navigation and air traffic control. Tables 8.2.11(a) and 8.2.11(b) give the relevant information concerning flight technical error obtained under actual operating conditions; while Table 8.2.12(a) shows the pertinent tolerances accepted by the ICAO Panel on Vertical Separation of Aircraft.[8] The amounts represent a significant fraction of the nominal separation. In assessing these data the possible effects of severe turbulence must be borne in mind, especially if the effects are experienced during instrument flight conditions. The given data refer to one aircraft considered at a time; hence the adverse influence of flight technical error may be seen in a more serious light when one envisages the probability of two aircraft being affected in such an opposite sense as to cause them to approach each other vertically under certain conditions, particularly where up- and down-drafts occur (e.g., within thunderstorms and within or in the vicinity of the rotor clouds which are often encountered in connection with the mountain wave).

(12) The problem of vertical separation of aircraft remains one of the most difficult to solve, since it entails so many sources of error, some of which can be fairly large in magnitude, such as flight technical error and static pressure system error, particularly in the case of high-speed aircraft operating in the range of Mach number 0.65—1.0 or at transonic speeds if the static pressure system error is uncorrected or uncompensated, as illustrated in Tables 8.2.8(a)—(c). In a certain percentage of the situations involving the passing of two aircraft with a nominal vertical separation of 1,000 feet the total of instrument errors, flight technical errors, and static pressure system errors for the two aircraft can so combine as to reduce the

actual vertical separation to zero or even make it negative, that is, cause the aircraft having the greater indicated altimeter reading to be at a lower level actually than the aircraft having the lesser indicated altimeter reading. Such occurrences are partly matters of probability, depending on the chances that all factors conspire with such algebraic signs and magnitudes as to nullify the apparent vertical separation. In order to render the probabilities of occurrence of such untoward accidents as small as possible it is essential to minimize each individual controllable source of error by systematic procedures.

(13) With reference to the non-meteorological sources of error affecting altimetry, one may list them as: instrumental, static pressure system, flight technical, and human. In order to minimize the errors from these sources the following recommendations have been adopted or considered:

(a) Procure the most accurate designs of altimeters under specifications which call for the smallest possible attainable instrumental errors.

(b) Calibrate and maintain the equipment as accurately as possible and as often as necessary to meet the desired standards of accuracy.

(c) Employ compensators which will automatically correct the static pressure system errors within close tolerances if it is practicable to install them in the aircraft; or otherwise in cases where compensators are not installed have the pilots make use of correction cards and apply appropriate corrections for the static pressure system errors, at least when cruising in controlled airspace. This is a matter of greatest importance for operations in areas which have high traffic density.

(d) Continue maintenance procedures to detect possible leaks in the static pressure system and possible damage to the aircraft skin contour in the vicinity of static pressure system vents, if such are involved in the particular aircraft; eliminate such leaks and repair any significant damage as soon as possible after discovery.

(e) Flight technical errors should be reduced to the smallest practicable magnitude by close adherence on the part of pilots to the assigned cruising altitudes or flight levels as accurately as possible. Conditions characterized by severe turbulence should be avoided insofar as practicable by such means as optimum flight planning, evasive tactics if critical weather phenomena are approached, and use of weather radar to detect the adverse conditions.

(f) In cases where the aircraft are provided with autopilot and/or height lock equipment, the equipment should be fitted and maintained to suit in the most appropriate manner the aerodynamic characteristics of the particular aircraft in order to secure the best overall height-keeping performance.

(g) The role of the human factor in the problem should be explored, with a view to the taking of appropriate remedial measures such as those which will tend to reduce chances of mistakes, e.g., misreading of an instrument or of a correction card. To this end improvements in design of altimeter presentations have been undertaken (compare figs. 8.0.2, 8.0.3, 8.0.4, and 8.0.5 with 8.0.1). The human factor involves such aspects as acuity of vision; alertness and attentiveness; effects of fatigue, length of time on duty and/or oxygen deficiency; psychological characteristics of the persons; degree of tension depending upon many elements, including roughness of the conditions encountered; the exercise of good or faulty judgment depending upon all of the foregoing considerations and others, such as experience, etc.; matters which fall within the realm of aviation medicine and psychology.

(14) Meteorological factors affecting vertical separation of aircraft, already listed under (4), include: altimeter setting differences between aircraft; departure of air temperature from standard; wind effects; turbulence, mountain waves, etc.; and loss of visual contact with the ground owing to poor visibility or obscuration of landmarks resulting from precipitation, low clouds, and the like. The effects of these may be summarized as follows:

(a) Consider two aircraft flying with a nominal vertical separation of 1,000 feet.

If the one with the higher *indicated* altitude has a greater altimeter setting than the one with the lower *indicated* altitude, then there is an actual *loss* of vertical separation which under standard temperature conditions amounts to 93 feet for each 0.10 inch of mercury difference between their altimeter settings. On the other hand, if the aircraft with the higher *indicated* altitude has a lesser altimeter setting than the aircraft with the lower *indicated* altitude, then the reverse would be true; that is, an average *gain* of 93 feet in their actual vertical separation for each 0.10 inch of mercury difference between their altimeter settings. For example, if the first aircraft is at a flight level of 24,500 feet with an altimeter setting of 29.92 inches of mercury, and a second aircraft were to be at a cruising altitude of 23,500 feet with an altimeter setting of 29.42 inches of mercury, there would be a loss of about 465 feet in vertical separation between them under standard temperature conditions. This may lead to a conflict in view of the other sources of error under consideration. It is the effect of altimeter setting difference between aircraft which has led to the proposal that en route flight operations be conducted on the basis of a constant, standard altimeter setting of 29.92 inches of mercury, provided that proper allowance for terrain clearance be made (see Appendix 8.2.2 and sec. 8.2.1.3).

(b) The influence of departure of air temperature from standard is purely a relative matter and generally varies between fairly narrow limits. Thus, consider two aircraft having a nominal vertical separation of 1,000 feet on a common altimeter setting basis. If the mean temperature of the air column is lower by 50° F. (28° C.) than the mean temperature of the standard atmosphere column extending up to the mid-point between the two aircraft, the actual vertical separation is reduced to about 900 feet. On the other hand, if the mean temperature of the air column were 50° F. higher than the standard, the vertical separation would be increased to about 1,100 feet. Under extreme conditions such as in polar or equatorial regions, during winter and summer, respectively, the effect of the temperature factor might decrease or increase the values, respectively, by another 10 or perhaps 15 per cent. Therefore, in polar regions under extreme conditions of low atmospheric temperature with reference to standard, it is possible for a nominal vertical separation of 1,000 feet to be actually as low as 750-800 feet neglecting other sources of error. Such extreme effects are only likely to occur near the surface. However, it is fairly common during the mid-winter in middle and high latitudes to have a nominal vertical separation of 1,000 feet equivalent to roughly 920 feet or thereabouts in actual vertical separation neglecting other errors. Appendix 8.2.2 gives formulas by means of which one can compute the error due to the temperature factor under specified conditions.

The following table shows the mean temperature of the standard atmosphere air column up to various altitudes.

Table 8.2.13(a)

Mean temperature of the standard atmosphere air column extending from sea level to the given pressure altitude

Pressure altitude (feet)	Mean temperature			
	°*F.*	°*C.*	°*R.*	°*K.*
0	59.0	15.0	518.7	288.2
5,000	50.0	10.0	509.7	283.2
10,000	40.9	+4.9	500.6	278.1
15,000	31.8	− 0.1	491.5	273.1
20,000	22.4	− 5.3	482.1	267.8
25,000	13.0	−10.6	472.7	262.6
30,000	+ 3.4	−15.9	463.1	257.3
35,000	− 6.3	−21.3	453.4	251.9
40,000	−15.2	−26.2	444.5	246.9
45,000	−22.0	−30.0	437.7	243.2
50,000	−27.3	−32.9	432.4	240.2

(c) Wind effects on vertical separation of aircraft can occur within limited regions of air space over mountainous terrain where the air flow is disturbed as a result of strong winds blowing across mountain barriers. A corresponding disturbance of the pressure field develops, owing largely to the vertical component of air motion and the horizontal acceleration or deceleration of the air induced by the topography. The vertical distributions of temperature, moisture, and wind play important roles in controlling the character of the perturbations in air flow and pressure. Two aircraft exposed to different regimes or phases of the disturbances under consideration, as in the case of flights at various levels in a mountain wave, can be subjected to differential pressure effects not covered by the assumptions underlying the hydrostatic equation on which the calibration of the altimeter is based. Such differential pressure effects are attended by differential errors in the indicated altitude readings of the altimeters in the two aircraft involved thus having an influence on their vertical separation.

(d) While such effects as those due to the pressure disturbances described in (c) above are only of a transient character during passage of the two aircraft through the regions of perturbed air flow, they are accompanied by turbulence often of such severity as to be capable of seriously altering the pitch, heading and the angle of attack of the aircraft. The hazards resulting from turbulence, mountain waves, local storms, and vortices over rough terrain are well known.[11] Not only may there be strong downdrafts and updrafts, but also vortices within which there is a reduction of pressure by virtue of the action of centrifugal force on the whirling body of air. It is scarcely necessary to elaborate further at this point regarding the combined effects of such possibly violent phenomena on the attitude, heading, pitch, and trajectory of an aircraft which encounters them.

(e) Loss of visual contact with the ground or landmarks due to low clouds, etc., cannot be construed, of course, as a factor which produces a direct effect on vertical separation of aircraft, but it is involved in the reactions of the pilot under the given circumstances when his aircraft runs into such a situation during flight over rugged terrain. Therefore, it is an indirect factor which often has a governing influence on the decision of the pilot when the attendant conditions indicate the need for a change in cruising altitude. In this sense the loss of visual contact with the ground or landmarks plays a motivating role in connection with flight technical error.

(15) The problem of terrain clearance, already treated in sec. 8.2.1.3 and Appendix 8.2.2, has been shown to involve both non-meteorological and meteorological factors. In order to deal with this problem in a systematic manner, *criterion (a)* was introduced. This reads

$$(a) \qquad I_n + k_s \geqq A_x + C_v$$

where I_n = minimum indicated altitude required to secure the desired vertical clearance with reference to the highest obstacle over the intended flight course; k_s = sum of corrections to overcome all known errors of the altimetry system as a whole due to the combination of non-meteorological and meteorological factors explained further below; A_x = elevation (above mean sea level) of the point of maximum height of the highest obstacle; and C_v = desired vertical clearance (see Appendix 8.2.1). In Appendix 8.2.2 k_s is sub-divided into two components, consisting of non-meteorological and meteorological correction factors, k_c and k_m, respectively. These are defined by the equations

$$k_s = (k_c + k_m),$$

where

$$k_c = (k_i + k_p + k_f + k_r),$$

and

$$k_m = (k_a + k_w + k_t).$$

In the foregoing equations k_c denotes the sum of corrections for non-meteorological errors; and k_m denotes the sum of corrections for meteorological errors. The terms contained in the equation expressing k_c are defined as follows: k_i = correction for all relevant instrumental errors; k_p = correction for that portion of the static pressure system error not compensated or corrected; k_f = correction (allowance) for flight technical error; and k_r = correction for residual factors, such as allowances for the size of the aircraft and for contingencies, or for other errors which may have been underestimated. With regard to the equation ex-

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[11] M. A. Alaka, "Aviation Aspects of Mountain Waves," Technical Note No. 18, World Meteorological Organization, Geneva, Switzerland, 1958.

pressing k_m, the terms included therein are defined as follows: k_a = correction for maximum possible departure of the altimeter setting that might be used in the aircraft during the flight from the value of altimeter setting that will be (probably) observed at the appropriate station near or on the highest obstacle; k_w = correction for the pressure deficiency produced on the highest obstacle and in its vicinity by the action of maximum probable winds blowing over the obstacle and its environs; and k_t = correction for departure from standard of the mean temperature of the actual atmospheric air column that extends from the station elevation to the actual level of the aircraft at time of intended flight under the condition that the desired vertical clearance with respect to the highest obstacle is assumed to be realized. The values of the corrections listed above must be estimated at the time of flight planning; and to this end it is desirable to have forecast data pertaining to the meteorological parameters. While this may introduce some uncertainty, it is deemed better to err on the safe side.

Criterion (a) is provided for guidance in preparing flight plans with a view to having a systematic, rational procedure designed to permit determination of the minimum indicated altitude, I_n, that will yield safe and adequate clearance of the point of maximum height of the highest obstacle during the intended flight.

By means of an example presented in sec. 8.2.1.3 it is indicated how one might go about determining both k_c and k_m on the basis of pertinent data relating to the given conditions. The chosen cruising altitude or flight level (I_n) must simultaneously satisfy *criterion (a)* and the relevant Civil Air Regulations.

The theory underlying the meteorological correction terms is more or less developed in Appendix 8.2.2. Further information regarding the correction for temperature, k_t, is presented in sec. 8.3.

It may be concluded from the examples and considerations presented in secs. 8.2.1.3 and 8.3 that it would be prudent to give due care to the evaluation of the various correction terms involved in the determination of I_n on the basis of *criterion (a)*. Under conditions of relatively low temperature, strong winds, and minimum atmospheric pressure over the region of the highest obstacle, the errors inherent in the meteorological factors combine generally in such a manner as to tend to cause k_m to approach a *maximum negative amount*, which signifies that the errors operate in the most dangerous sense and possibly to the worst degree, depending upon the height of the obstacle. Sec. 8.3 shows how this is true with respect to the correction term for temperature, k_t.

8.3 EFFECTS ON ALTIMETRY OF AIR TEMPERATURE DEVIATION FROM STANDARD

As illustrated in fig. 8.0.6 (A) and (B), sensitive pressure altimeters are calibrated in accordance with the standard atmosphere which involves the assumption of certain standard temperatures; specifically, beginning with 59° F. at sea level, decreasing with altitude to the tropopause at the rate of 3.566° F. per 1000 feet, until a height above sea level of 36,089 feet (11 kilometers) is reached, while a constant temperature of − 69.7° F. is assumed for the stratosphere over the range of altitude from 36,089 feet to 65,617 feet (20 kilometers).

It may be seen from equations (2)—(5) of Appendix 7.1 that air maintained at constant pressure will expand with increase in temperature and moisture content, while it will contract with decrease in temperature and moisture content. An immediate consequence of this fact is that the vertical distance between two flight levels corresponding to two pressure altitudes will be *more* than the indicated altitude difference between those two levels when the average (mean) actual temperature of the layer of air between those two levels *exceeds* the mean standard temperature pertinent to the pressure altitude interval; and similarly when the mean actual temperature is *lower* than the mean standard temperature, the vertical distance between the two flight levels will be *less* than the indicated altitude difference.

The effect of departure of actual air temperature from standard as described in the preceding paragraph applies also to any air column which can be envisaged as composed of a cumulation of layers of air. Therefore the actual altitude of an aircraft will be subject to this effect. To be more specific, one has to compare (*a*) the true altitude of an aircraft, as measured relative to the elevation of the station at the surface from which the altimeter setting was obtained for use in setting the aircraft altimeter, with (*b*) the indicated altitude shown by the aircraft altimeter, as measured relative to the elevation of the station. As will be pointed out later in more detail, the ratio of (*a*) to (*b*) varies in proportion to the ratio of two other quantities involving temperature, namely (*c*) the actual mean temperature of the air column between the levels of the aircraft and the station, and (*d*) the mean temperature of the standard atmosphere column delimited by pressure altitudes which exist at the two levels, provided that both of these temperatures are expressed on an absolute basis.

From the last two paragraphs it follows that both the problems of vertical separation between aircraft and terrain clearance are affected by the departure of air temperature from standard. In each of these cases we are concerned with the actual vertical separation or clearance as compared with the indicated (apparent) vertical separation or clearance inferred from the readings of two altimeters at the respective upper and lower levels of the layer of air (or air column) under consideration.

As mentioned above we are concerned with the relationship given in the form of a proportion

$$(a)/(b) = (c)/(d);$$

from which it follows that

$$[(a) - (b)]/(b) = [(c) - (d)]/(d)$$

which governs the error due to departure of actual mean temperature from standard.

It is to be emphasized that both the temperatures referred to above must be on the absolute basis expressed in consistent units; for example either

$$T^\circ \text{ K.} = (273.15 + t^\circ \text{ C.}), \text{ degrees Kelvin absolute,}$$

or

$$T^\circ \text{ R.} = (459.7 + t^\circ \text{ F.}), \text{ degrees Rankine absolute,}$$

where

t° C. is the Celsius (Centigrade) temperature, and

t° F. is the Fahrenheit temperature.

We may make the relationship clearer by expressing it in the form of an approximate equation in terms of absolute temperatures; thus

$$\frac{(\text{Actual vertical separation or clearance})}{(\text{Indicated vertical separation or clearance})} = \frac{(\text{Actual mean temperature, } T_{am})}{(\text{Standard mean temperature, } T_{sm})}.$$

In order to take into account the effect of humidity one should employ the *actual mean virtual temperature (T_{mv}) of the layer of air (or air column)*, defined explicitly in Appendix 7.1, instead of merely the actual mean temperature.

We may illustrate the significance of the foregoing equation by citing an imaginary example which involves an aircraft flying over the ocean at an indicated altitude of 15,000 feet with a constant, standard altimeter setting of 29.92 inches of mercury, while the actual mean temperature in the air column is 442.3° R. (245.7° K.) which corresponds to — 17.4° F. (— 27.4° C.); whereas the standard mean temperature for the standard atmosphere column from 0 to 15,000 feet altitude is 491.5° R. (273.1° K.), which corresponds to about 31.8° F. (— 0.1° C.). On the basis of the foregoing relationship we have

$$\frac{(\text{Actual vertical clearance above surface})}{(\text{Indicated vertical clearance above datum})} = \frac{T_{am}}{T_{sm}} = \text{temperature ratio factor.}$$

$$\frac{(\text{Actual vertical clearance above surface})}{(15{,}000 \text{ feet})} = \frac{(442.3^\circ \text{ R.})}{(491.5^\circ \text{ R.})} = 0.90.$$

The right-hand member of the relationship, representing the *temperature ratio factor*, is found in this example to be ten percent (10%) smaller than the unit *one* (1) which pertains to standard conditions, thus illustrating the significance of the factor 10% listed in Table 8.2(a) under the side caption "Non-standard atmospheric temperature"; although it must be noted that under some meteorological conditions the temperature ratio factor may be significantly smaller than 0.90 (e.g., under extremes of polar winter conditions), or larger than 1.10 (e.g., under extremes of equatorial summer conditions).

By solving the last equation, we find for the given example

Actual vertical clearance above surface = 15,000 feet × 0.90 = 13,500 feet.

Thus, if T_{am} is appreciably less than T_{sm}, the actual clearance is less than the indicated vertical clearance; and the same would be true in regard to vertical separation between aircraft. The reverse also holds; that is, if T_{am} is greater than T_{sm}, the actual vertical clearance (or vertical separation) is greater than the indicated vertical clearance (or separation); namely, when the temperature ratio factor exceeds the unit one (1). It is therefore important for aviators to know these facts, especially since the clearance with respect to terrain is adversely affected by the occurrence of temperatures lower than standard. The significance of this may be better appreciated when it is realized that the temperature ratio factor can occasionally fall as low as 0.8 or 0.75 under conditions of extreme cold over parts of northern continental United States, Alaska, Canada, and some other regions. At the same time it must be noted that the magnitude of the difference between actual vertical clearance and indicated vertical clearance is proportional to the indicated vertical clearance. This leads to the consequence that the magnitude of the difference can become quite large during cold, winter conditions when flight is undertaken over mountains in cases where the altimeter setting is obtained from a station whose elevation is well below that of the highest point on the mountain peak or ridge to be crossed by the aircraft.

One may envisage the application of the foregoing facts to the simple case of an aircraft flying over a sharply rising mountain ridge whose elevation above sea level is 15,000 feet under the assumptions that the base of the mountain lies at sea level and that the altimeter setting at the foot of the mountain is 29.92 inches of mercury, while the actual mean virtual temperature of the air column extending from sea level to the ridge top is − 17.4° F. (442.3° R.). As previously pointed out, the standard mean temperature for the standard atmosphere column extending from sea level to 15,000 feet pressure altitude is 31.8° F. (491.5° R.). By means of a calculation it can be shown that the altimeter setting which would be observed at the ridge top is 28.33 inches of mercury in the absence of wind effects and other anomalous influences apart from those due to temperature which we are considering. Therefore, if the altimeter setting actually being used in the aircraft instrument is 29.92 inches of mercury, while the aircraft flies at an indicated altitude of 15,000 feet near the ridge, the true elevation above sea level of the aircraft at that instant would be merely 13,500 feet. This shows that under these conditions the *error* in the indicated altitude is 1,500 feet, which signifies that the reading of the altimeter is 1,500 feet too high. However, if the aircraft had been cruising at an indicated altitude of 15,000 feet with an altimeter setting of 28.33 inches of mercury while in the vicinity of the mountain ridge under the assumed conditions, its true elevation above sea level would have been 15,000 feet, neglecting possible wind and other effects, apart from those due to temperature.

The foregoing example again shows that the occurrence of actual atmospheric temperatures below standard will tend to cause the altimeter setting reported by a station at the foot of a mountain barrier to be higher than the existing altimeter setting which would be measured by means of an altimeter setting indicator located at the top of the mountain (see figs. 6.8.1 and 6.8.2). See secs. 8.0.7 and 8.1.6 for further information. To summarize the temperature effect:—Considering aircraft which fly in the vicinity of a mountain top and have their altimeters adjusted to the altimeter settings which exist at the base of the mountain, then disregarding wind effects and other sources of error, the influence of atmospheric temperatures differing from standard will be as follows: (1) when the actual mean temperature in the atmospheric air column is *below* the standard mean temperature, the altimeter setting at the top of the mountain will be *less* than that observed by the station at the foot of the mountain and the indicated altitude shown by the aircraft instrument will be higher than the true altitude, that is, on the dangerous side; and (2) when the actual mean temperature in the atmospheric air column is in *excess* of the standard mean temperature, the altimeter setting at the top of the mountain will be *greater* than that observed by the station at the foot of the mountain and the indicated altitude shown by the aircraft instrument will be *lower* than the true altitude.

We define the *error* resulting from the effect of departure of actual mean temperature of the atmospheric air column from the pertinent standard mean temperature to be the indicated altitude shown by the aircraft altimeter *minus* (—) the true elevation of the aircraft above sea level, owing to the effect of such air temperature deviation from the standard.

In order to reveal the range of errors stemming from this cause, Tables 8.3(a) and 8.3(b) show how the errors in indicated altitude vary with actual mean temperature of the atmospheric air column, corrected for humidity, in the case of mountain barriers of various heights ranging from 2,000 to 16,000 feet relative to the elevation of a base station. Table 8.3(a) is pertinent to the case where the pressure altitude at the base station at the foot of the mountain is zero (0) feet; while Table 8.3(b) is pertinent to the case where the pressure altitude at the base station is 4,000 feet.

When considering the results of the computations given in Tables 8.3(a) and (b), it is necessary to take cognizance of possible extremes of temperature and terrain elevation in the various regions where flying operations are conducted (see Tables 7.1.2 and 7.1.3). In some parts of the United States, such as the western plateau area including states like Colorado, Idaho, Montana, Utah, and Wyoming, minimum temperatures of the order of — 30° F. and lower have been observed from time to time; while in Alaska conditions of even more extreme cold have been experienced; and the same is true with greater force in such regions as the Greenland icecap and the Antarctic plateau during winter. It is not uncommon for meteorological stations to be located in valleys at the foot or along the side of mountain peaks or ridges whose tops rise from perhaps 5,000 to 9,000 feet above the elevation of the stations; while even greater departures of the highest terrain elevations above the station levels exist in some localities.

Table 8.3(a)

Error in indicated altitude of a pressure altimeter due to departure of actual mean temperature of air column from standard

[Pressure altitude = 0 feet at base station]

True height of altimeter above base station (feet)	Mean virtual temperature of air column (degrees Fahrenheit)*						
	−60° F.	−35° F.	−10° F.	+15° F.	+40° F	+65° F.	+90° F.
	feet	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*
2,000	+570	+420	+290	+170	+60	−40	−120
4,000	+1100	+800	+540	+310	+90	−100	−270
6,000	+1580	+1150	+760	+410	+100	−190	−450
8,000	+2020	+1450	+940	+480	+70	−300	−640
10,000	+2420	+1710	+1090	+530	+20	−440	−860
12,000	+2770	+1940	+1200	+540	−60	−610	−1110
14,000	+3080	+2130	+1280	+520	−170	−800	−1370
16,000	+3350	+2290	+1330	+470	−310	−1010	−1660

* Mean virtual temperature of the air column represents the average temperature of the vertical air column extending from the base station to the level of the altimeter, corrected for the effect of moisture vapor content on the air density.

NOTE.—When the error in indicated altitude is positive (+), this signifies that the indicated altitude shown by the altimeter is higher than the true (actual) height of the altimeter with reference to the base station; and when the error is negative (—), the reverse is true.

Table 8.3(b)

Error in indicated altitude of a pressure altimeter due to departure of actual mean temperature of air column from standard

[Pressure altitude = 4000 feet at base station]

True height of altimeter above base station (feet)	Mean virtual temperature of air column (degrees Fahrenheit)*						
	−60° F.	−35° F.	−10° F.	+15° F.	+40° F	+65° F.	+90° F.
	feet	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*
2,000	+500	+360	+230	+110	+10	−90	−180
4,000	+960	+670	+420	+190	−20	−210	−380
6,000	+1370	+950	+570	+230	−70	−350	−600
8,000	+1740	+1190	+700	+250	−150	−510	−850
10,000	+2070	+1390	+780	+240	−260	−710	−1110
12,000	+2360	+1560	+840	+190	−390	−920	−1410
14,000	+2610	+1690	+860	+120	−550	−1160	−1720
16,000	+2820	+1780	+860	+20	−740	−1420	−2050

* Mean virtual temperature of the air column represents the average temperature of the vertical air column extending from the base station to the level of the altimeter, corrected for the effect of moisture vapor content on the air density.

NOTE.—When the error in indicated altitude is positive (+), this signifies that the indicated altitude shown by the altimeter is higher than the true (actual) height of the altimeter with reference to the base station; and when the error is negative (—), the reverse is true.

Fig. 8.3.1 is designed to illustrate the combined effects of errors due to horizontal pressure gradient and to air temperature departure from standard. This figure discloses a serious situation of rather extreme character with regard to actual minimum, winter temperature conditions, such as might be experienced where severe cold climates occur in regions having high, precipitous mountains and elevated plateaus (e.g., Alaska, Greenland, etc.). For simplicity, we have assumed that the foot of the mountain is at sea level, with an aircraft flying at an indicated altitude of 16,000 feet while operating with a constant, standard altimeter setting of 29.92 inches of mercury. The flight plan is based on the assumption that the aircraft will safely fly over the mountain top whose elevation is 14,000 feet; but it should be noted that the actual mean air temperature of the air column is much lower than standard over the entire region. Oftentimes the actual mean temperature of the air column in the vicinity of the mountain is lower than that in the free air at some distance, as depicted in fig. 8.3.1 (compare the temperature data shown near the center and at the right-hand side of the diagram). In addition, the altimeter setting observed at the foot of the mountain is 29.64 inches of mercury, which is 0.28 inch of mercury lower than the altimeter setting being used in the aircraft; thereby causing a discrepancy of 260 feet as a result of this difference in setting (which we term "error due to horizontal pressure gradient"). Since the actual mean temperature of the air column in the vicinity of the mountain is assumed to be — 40.2° F. (419.5° R.), while the standard mean temperature is 29.8° F. (489.5° R.), the maintenance by the pilot of an indicated cruising altitude of 16,000 feet will cause a discrepancy of 2,240 feet (which we term "error due to air-temperature effect"). The sum of the errors due to horizontal pressure gradient and air-temperature effect is about (260 + 2,240) feet, or 2,500 feet.

Even though the pilot might assume that flight at a cruising altitude of 16,000 feet in the situation shown by the figure will permit his aircraft to have a safe vertical clearance with respect to the mountain top, the compounding of the specified errors alone will cause the aircraft to be 2,500 feet lower than the indicated altitude, namely at a true elevation of 13,500 feet in the vicinity of the mountain, hence lower than the top by the amount of 500 feet, apart from other effects. The hazards of operations on a basis which neglects the cumulative error resulting from effects of all possible sources of discrepancy scarcely needs any further elaboration.

It is clear from the data presented in the

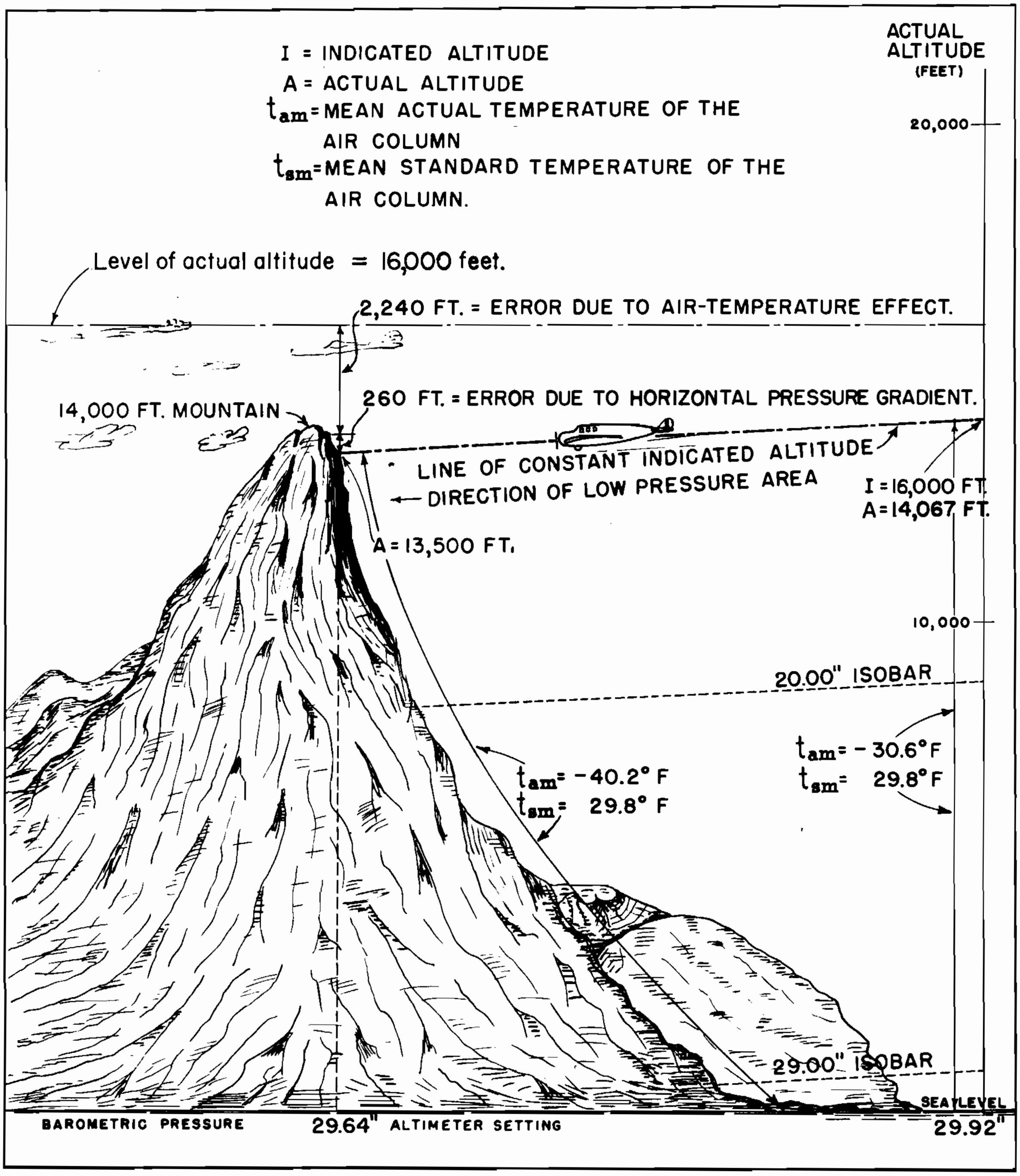

FIGURE 8.3.1. Vertical cross section along the flight path of an aircraft showing the combined effects of errors due to departure of air temperature from standard and departure of surface altimeter setting from that used for the setting of the aircraft altimeter. (Note: Hazards become serious when mountain is enshrouded in clouds or precipitation; and/or when downdrafts occur.)

tables that height difference between the meteorological stations which report altimeter settings and the crests of the mountain barriers lying athwart air routes plays an important role in the problems of terrain clearance, and of safe and economic utilization of available air space. From a knowledge of the error due to air-temperature effect for various possible conditions of temperature and height difference as just outlined, one may prepare a chart or a list of data showing which indicated cruising altitudes or flight levels should be selected in order to secure a given, safe vertical clearance (such as 2,000 feet) between the actual altitude of the aircraft and the highest points on the mountain barriers when these conditions are encountered.

Fig. 8.3.2 shows an example of a graphical method of presenting information regarding the minimum indicated altitude at which flight could be conducted in order to secure a prescribed vertical clearance with respect to the top of a mountain ridge of given elevation for any observed actual mean temperature of the air column, neglecting other possible sources of discrepancy, such as those which result from effects of wind, horizontal pressure gradient, instrumental characteristics, etc. This figure was constructed to apply to the special case of a mountain ridge whose top is at an actual elevation of 18,000 feet above sea level where it is planned to fly operationally over the mountain at an indicated altitude such that there will always be at least 2,000 feet of vertical clearance between the aircraft and the mountain crest, under the condition that the station which reports altimeter setting for use in en route flight over this mountain is at an actual elevation of 2,000 feet above sea level. We may illustrate the application of fig. 8.3.2 under these circumstances by considering an example; thus, suppose that the actual mean temperature of the air column extending from the base level at 2,000 feet to the proposed cruising altitude is 0° F., then according to the chart a cruising altitude which exceeds 20,700 feet will provide at least 2,000 feet vertical clearance with respect to the top of the mountain, neglect-

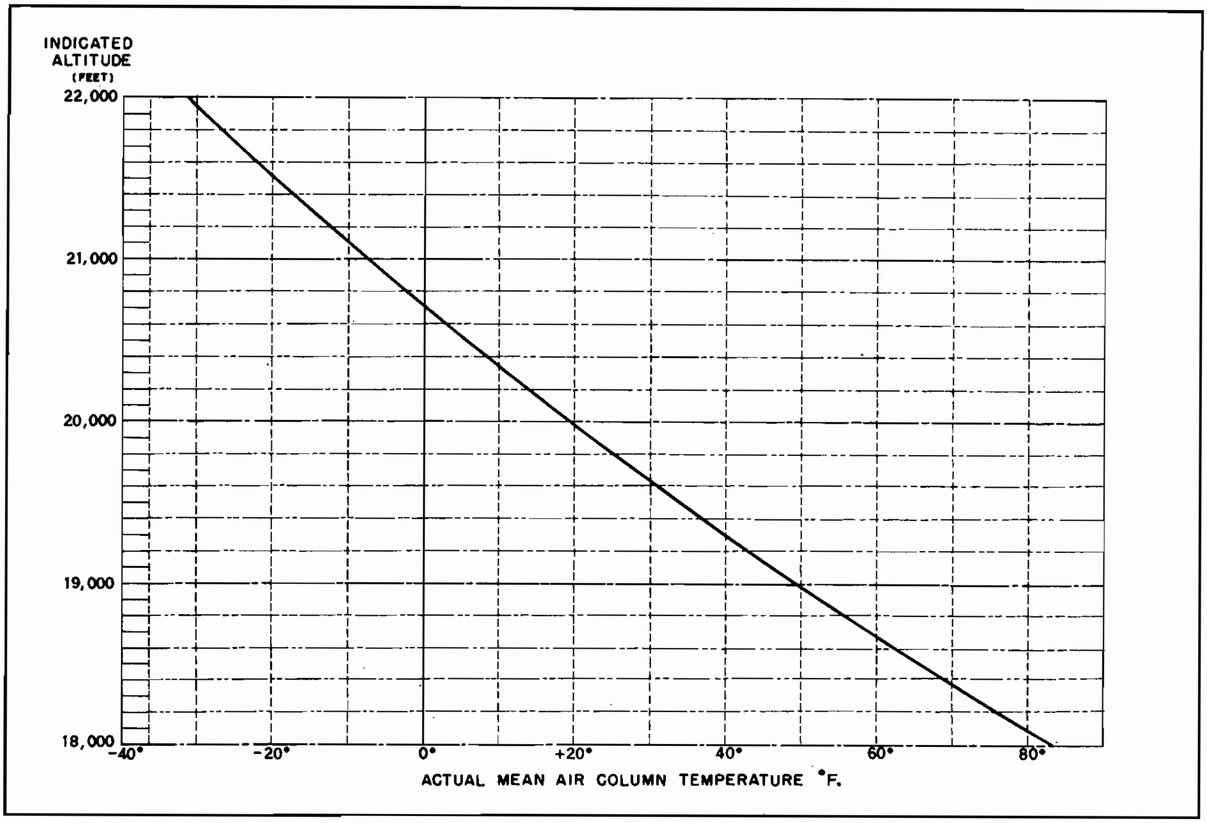

FIGURE 8.3.2. Chart specially designed for use in enroute flight planning to secure 2,000 feet vertical clearance over a mountain barrier whose crest elevation is 18,000 feet above sea level, where the elevation of the base station which reports altimeter setting for the route segment is 2,000 feet. Data on vertical scale show the indicated altitude which must be exceeded for the given actual mean temperature of the air column (horizontal scale) in order to have at least 2,000 feet of nominal vertical clearance relative to the crest, neglecting effects due to wind, altimeter mechanism errors, etc.

ing the other errors as mentioned above, apart from the air-temperature effect.

Different charts of the type exemplified in fig. 8.3.2 can be prepared to suit the special circumstances and conditions which exist with respect to any particular combination in regard to: (a) elevation of mountain top, (b) elevation of base station which reports altimeter setting for en route use over the mountain, and (c) selected amount of vertical clearance, such as 2,000 feet, between the mountain top and aircraft during passage. If desired, the chart may be modified or additional amounts of vertical clearance may be allowed to take account of sources of error other than departure of the actual mean temperature of the air column from standard.

The pertinent formula which was employed for the calculation of Tables 8.3(a) and 8.3(b) and which may also be used in connection with the preparation of charts similar to fig. 8.3.2 is as follows:

$$(A - E) = T_{mv}\left(\frac{I_p}{T_{mp}} - \frac{H_{pb}}{T_{mb}}\right),$$

valid under the assumption that the aircraft operates on the basis of a constant, standard altimeter setting of 29.92 inches of mercury, where

A = actual elevation of aircraft above sea level;

E = elevation of the base station above sea level;

T_{mv} = actual mean virtual temperature of the air column between the base station at elevation E and the aircraft at elevation A;

I_p = pressure altitude at flight level; that is, the altitude in the standard atmosphere corresponding to the barometric pressure at the flight level;

H_{pb} = pressure altitude at the base station; that is, the altitude in the standard atmosphere corresponding to the barometric pressure at the base station;

T_{mp} = mean temperature in the standard atmosphere column for the range of pressure altitude from zero (0) to I_p;

T_{mb} = mean temperature in the standard atmosphere column for the range of pressure altitude from zero (0) to H_{pb}.

In the equation given above, it is essential that consistent units be employed for the height entities A, E, I_p, and H_{pb}; while it is also essential that consistent, *absolute* scale values be used for the temperature data T_{mv}, T_{mp}, and T_{mb}. That is, the latter data should be expressed either in degrees Rankine absolute or in degrees Kelvin absolute. Appropriate values of I_p, H_{pb}, T_{mp}, and T_{mb} for various barometric pressures and pressure altitudes have been published.[2] [19]

One may transform the last equation to make it suitable for calculations pertinent to the case in which the aircraft operate with variable altimeter settings as reported by the base station. For this purpose we make use of the following symbols:

I = indicated altitude shown on the aircraft altimeter when cruising with a true altimeter setting $A.S._t$ as reported currently by the base station at elevation E;

I_p = pressure altitude at indicated cruising altitude;

H_{pb} = pressure altitude at the base station which reports the altimeter setting $A.S._t$;

H_{At} = pressure altitude corresponding to pressure $A.S._t$.

We have the relationships

$$I_p = (I + H_{At}),$$

and

$$H_{pb} = (E + H_{At}),$$

which are consistent with the method of operation of the pressure altimeter and with the definition of altimeter setting.

When these two relationships are substituted in the right-hand member of the previous equation, the latter becomes adapted for computations based on the condition that the aircraft altimeter is adjusted in accordance with the current altimeter setting reported by the base station.

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[2] National Advisory Committee for Aeronautics, "Standard Atmosphere—Tables and Data for Altitudes to 65,800 Feet," Report 1235, published by the U.S. Government Printing Office, Washington 25, D.C., 1955.

[19] U.S. Committee on Extension to the Standard Atmosphere, "U. S. Standard Atmosphere, 1962," prepared under sponsorship of National Aeronautics and Space Administration, U.S. Air Force, and U.S. Weather Bureau, published by the U.S. Government Printing Office, Washington 25, D.C., 1962 (278 pp.).

8.4 PRESSURE ALTITUDE

8.4.0 Introduction

According to the basic definition stated in sec. 8.0.2.1, the pressure altitude corresponding to any given barometric pressure P is the height above sea level (altitude H) in the standard atmosphere at which the given pressure P would exist. Therefore, the pressure altitude H is a function of the pressure P. For cases involving the troposphere pertinent to the standard atmosphere as defined in Appendix 8.0.1, this function is expressed by the following equation:

$$H = \left(\frac{T_o}{a}\right)\left[1 - \left(\frac{P}{P_o}\right)^{1/n}\right]$$

where

P = given barometric pressure;

P_o = standard barometric pressure at sea level = 1013.25 mb., that is 29.92 inches of mercury;

H = pressure altitude corresponding to the given pressure P;

T_o = standard temperature at sea level = 288.15°K. or 518.67°R.;

a = standard lapse rate in the troposphere = 0.0065°C. per m′ or 0.00356616°F. per ft′;

$n = (G/aR) = 5.25588$ (dimensionless);

$1/n = (aR/G) = 0.1902632$ (dimensionless);

$G = 98066.5$ cm.^{2}/sec.^{2} per m′;

R = gas constant for 1 gram of dry air $= 2.870531 \times 10^6$cm.^{2}/sec.^{2}°K.

In Table 8.1 there will be found values of the pressure altitude H as a function of the pressure P over a certain range. (See NACA Report 1235 for more detailed standard atmosphere tables. See also footnote 19.)

Pilots employed by some organizations make use of the pertinent data at airports for the purpose of determining what weight their aircraft can take off with safely from a runway of given length under specified conditions of pressure altitude, ambient temperature, and wind; or alternatively, the pilots may use the data to compute the length of runway necessary for safe take-off with a specified weight. In this connection the combination of pressure altitude and temperature at an airport is often applied for the purpose of ascertaining the density altitude (see fig. 8.0.6(C)) since the density altitude (or pressure altitude together with temperature) controls the engine performance.

Inasmuch as the height of a typical aircraft engine above the aircraft landing wheels is of the order of ten feet (10′), it is conventional to call for the value of the pressure altitude existing at a height of ten feet above the airport runway in order that the value may be properly used for the purpose indicated in the previous paragraph. That is, ten feet is considered to be the standard reference height with respect to runway levels for pressure altitude data pertaining to airport runways. Therefore, when the pressure altitude for a given airport is requested and no other stipulation is indicated, it may be assumed that the desired pressure altitude should relate to the height of the ten-foot plane above the airport runways.

Since pressure altitude varies with pressure P, and since pressure varies rapidly with height, the level to which the pressure altitude relates is always an important consideration in any of its applications. In practice, two situations arise most commonly: (a) the barometric pressure P at a specified station elevation or height above sea level is known, and it is desired to determine the corresponding value of the pressure altitude; (b) the field elevation H_a (height above sea level) of an airport is given while the current reported altimeter setting QNH for the airport is known, and it is desired to determine the pressure altitude corresponding to the height of the ten-foot plane above the level of the field elevation. Methods of determining the pressure altitude pertinent to situations (a) and (b) are described in secs. 8.4.1 and 8.4.2, respectively.

In cases where the altimeter setting is determined on the basis of some form of pressure observation at an elevation (height above sea level) different from the level of the ten-foot plane above the airport, the method outlined in sec. 8.4.2.2 for determining the pressure altitude may be slightly in error provided that the existing temperature at the airport departs from the standard temperature pertinent to its altitude. This matter is further discussed in sec. 8.4.3.

8.4.1 Determination of Pressure Altitude Corresponding to a Given Observed Pressure at a Specified Elevation Above Sea Level

Suppose that a barometric pressure P is given quantitatively for some specified elevation or height above sea level, and that it is desired to ascertain the pressure altitude corresponding to the given value of P. Then, the required pressure altitude may be determined most directly by referring to Table 8.1 or NACA Report 1235 and picking out from the body of the table the pressure altitude that corresponds to the given value of pressure P. This procedure is illustrated in sec. 8.0.2.1.

Another method of determining the pressure altitude corresponding to a given pressure P involves the use of face II of the circular slide rule, Pressure Reduction Computer (WBAN 54–7–8), which is illustrated in fig. 7.2.4(b). Instructions for the computation of pressure altitude pertinent to an observed station pressure P are printed on the lower portion of face II of the device.

It should be understood in connection with both of the procedures outlined above that the pressure altitude thus determined will relate strictly only to the elevation (height above sea level) to which the given barometric pressure P refers at the time of the observation of P.

Whenever possible, the value of the pressure P should be accurate at least to the nearest 0.005 inch of mercury or the equivalent.

EXAMPLE

Given: Barometric pressure, $P = 26.285$ inches of mercury, pertinent to a height above sea level of 3570 feet, which is the station elevation, H_p, at Billings, Montana, Airport.

To find the corresponding pressure altitude: Refer to Table 8.1, and find the pressure altitude in the body of the table pertaining to the pressure argument $P = 26.285$ inches of mercury, thus determining the required pressure altitude $= 3542$ feet, which relates to the specified station elevation of 3570 feet. (The same result is found by means of the Pressure Reduction Computer, face II.)

8.4.2 Determination of Pressure Altitude Corresponding to the Ten-Foot Plane Above an Airport

8.4.2.0 Introduction.—For many aeronautical applications it is necessary to employ the pressure altitude relating to the pressure existing at a height which is ten feet above the level of the airport. Such applications include the checking of engine performance and the load capability of a given aircraft prior to take-off under the existing conditions at an airport. When the pressure altitude is required for such an application, it is essential that the data be determined with relation to the ten-foot plane above the airport (or other stipulated proper level according to the needs of the user).

There are two alternative procedures which may be conveniently employed at meteorological stations for the determination of the pressure altitude at the ten-foot plane above the airport, depending upon the character of the initial argument used in the computation; i.e., whether the argument is (1) the observed station pressure P pertaining to the station elevation H_p, or (2) the altimeter setting as observed at the station. In cases where the current station pressure can be observed most readily and the altimeter setting is not directly available, the method described in sec. 8.4.2.1 may be employed for the determination of the pressure altitude at the ten-foot plane above the airport, using station pressure as the argument. On the other hand, in cases where the current altimeter setting can be observed directly, or is most conveniently obtainable, the method outlined in sec. 8.4.2.2 should be employed for the determination of the pressure altitude at the ten-foot plane above the airport, using altimeter setting as the argument. Insofar as practicable, the altimeter setting should be determined to the nearest 0.005 inch of mercury, just as the pressure should be determined to a corresponding degree of accuracy and precision, if practicable, for the purposes under consideration.

At this point we collect for future reference a group of symbols and their terminology or definitions which are used in connection with the subject under consideration:

Symbol	*Terminology*
H_p	station elevation (level to which the station pressures relate).
H_a	field elevation (reference level at the airport surface).
$(H_a + 10')$	height above sea level of the ten-foot plane above the airport.
$[H_p - (H_a + 10')] = (H_p - H_a - 10')$	height difference.
t	observed station temperature (out of doors).
P	observed station pressure (relating to station elevation H_p).
P_{10}	pressure relating to the ten-foot plane, that is, to the height $(H_a + 10')$.
C	correction to reduce the pressure from the level of H_p to the level of $(H_a + 10')$; hence $C = (P_{10} - P)$ or $P_{10} = (P + C)$.
H_{A10}	pressure altitude relating to the ten-foot plane above the airport, that is, to the height above sea level specified by $(H_a + 10')$. (Note: H_{A10} represents the pressure altitude corresponding to the pressure P_{10}.)
t_v	virtual temperature, in °F. (See Appendix 7.1.)
T_v	virtual absolute temperature, in degrees Rankine (°R.) corresponding to t_v.
A.S.	altimeter setting.
H_{AS}	pressure altitude corresponding to the pressure specified by the value of the altimeter setting, *A.S.*
T_o	standard sea-level temperature $= 518.67°$R.*
a	standard lapse rate in the troposphere $= 0.00356616°$F. per ft′.
$(T_o - aH_{A10})$	absolute temperature in the standard atmosphere pertinent to the pressure altitude H_{A10}.

8.4.2.1 Determination of Pressure Altitude for the Ten-Foot Plane Above the Airport on the Basis of Station Pressure.—The following steps are taken in the determination of the required pressure altitude:

(1) determine by means of observation the station temperature outdoors t and the station pressure P pertinent to the known station elevation H_p;

(2) if the station elevation H_p is different from $(H_a + 10')$, that is, the height above sea level of the ten-foot plane over the airport, ascertain the correction C to be applied to the station pressure P in order to determine the pressure P_{10}, which represents the pressure at the level of the ten-foot plane over the airport, making use of the observed values of t and P to find C as explained in the paragraph following step (4);

(3) under the condition specified at the beginning of step (2), apply the correction C algebraically to the observed station pressure P and thus determine the pressure P_{10} pertinent to the level of the ten-foot plane over the airport;

(4) refer to Table 8.1 and, using the pressure at the level of the ten-foot plane over the airport as the argument, find from the body of the table the corresponding required pressure altitude (which we denote here by H_{A10} since it pertains to the level of the ten-foot plane over the airport). (Note: In cases where the station elevation and the level of the ten-foot plane over the airport are equal, that is, $H_p = (H_a + 10')$, the station pressure and the pressure at the level of the ten-foot plane over the airport are

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* This is based on the standard sea-level temperature of 59°F. = 15°C., and the value of the ice-point temperature adopted in 1954, namely, 273.15° K., converted to Fahrenheit units (see Appendixes 7.1 and 8.0.1).

equal: $P = P_{10}$, in which case steps (2) and (3) are omitted.

With regard to the determination of the correction C referred to in step (2), the value of C to be applied algebraically to the station pressure P in order to reduce it from the level H_p to the level of $(H_a + 10')$ can be ascertained by means of the factors given in Table 4.1.1, which requires the use of temperature and pressure as arguments. Whenever the data are needed repeatedly under a wide range of conditions, it is desirable to prepare on this basis a compilation of corrections applicable to various convenient combinations of temperature and pressure as observed at the station. The correction C pertinent to any given temperature and pressure is readily calculated by multiplying the height difference $(H_p - H_a - 10')$ by the factor taken from Table 4.1.1 corresponding to the given temperature and pressure. It is important to take account of the proper algebraic sign of the height difference. *Note:* The algebraic sign of the correction C is always the same as that of the height difference $(H_p - H_a - 10')$.

EXAMPLE OF COMPUTATION OF CORRECTION *C* FOR HEIGHT DIFFERENCE

Billings, Montana, Airport

Station elevation $H_p = 3570$ feet above sea level
Field elevation $H_a = 3606$ feet above sea level
Height of ten-foot plane above sea level = $(H_a + 10') = 3616$ feet
Height difference = $(H_p - H_a - 10') = -46$ feet.

Suppose that the given temperature at the station is $t = 10°$ F., and that the given station pressure P is 26.00 inches of mercury. Then, from Table 4.1.1 we find that the *factor* which represents the change in pressure corresponding to a change of one (1) foot in height under these conditions is 0.0010369 inch of mercury. Thus, we determine that the correction to be applied to the station pressure P in order to determine the pressure P_{10} at the level of the ten-foot plane is C = (height difference) × (*factor*), that is,

$C = (-46 \text{ ft.}) \times (0.0010369$ inch of mercury per foot);

hence $C = -0.048$ inch of mercury.

In a similar manner, values of the correction C pertinent to various combinations of station temperature and pressure may be computed and compiled as illustrated in the following table on the basis of the specified height difference.

The following example shows how the steps (1), (2), (3) and (4), listed above, are carried out in a specific case.

EXAMPLE OF DETERMINATION OF PRESSURE ALTITUDE FOR THE TEN-FOOT PLANE ABOVE AN AIRPORT ON THE BASIS OF STATION PRESSURE READING

Billings, Montana, Airport

Station elevation $H_p = 3570$ feet above sea level
Field elevation $H_a = 3606$ feet above sea level
Height of ten-foot plane above sea level $(H_a + 10') = 3616$ feet
Height difference = $(H_p - H_a - 10') = -46$ feet

Step (1): Observed station temperature outdoors, $t = 40°$F.
Observed station pressure $P = 26.285$ inches of mercury

Step (2): Determine the correction C to reduce the station pressure from the level of the sta-

Correction C to be applied to station pressure P at Billings, Montana, Airport in order to obtain the pressure P_{10} pertaining to the level of the ten-foot plane over the airport, based on $(H_p - H_a - 10') = -46$ feet

Station temperature °F.	Station pressure, inches of mercury				
	28	27	26	25	24
	in. Hg	in. Hg	in. Hg	in. Hg	in. Hg
−40	−0.057	−0.055	−0.053	−0.051	−0.049
−30	−0.056	−0.054	−0.052	−0.050	−0.048
−20	−0.055	−0.053	−0.051	−0.049	−0.047
−10	−0.054	−0.052	−0.050	−0.048	−0.046
0	−0.052	−0.051	−0.049	−0.047	−0.045
+10	−0.051	−0.050	−0.048	−0.046	−0.044
20	−0.050	−0.048	−0.047	−0.045	−0.043
30	−0.049	−0.048	−0.046	−0.044	−0.042
40	−0.048	−0.047	−0.045	−0.043	−0.041
50	−0.047	−0.046	−0.044	−0.042	−0.041
60	−0.046	−0.045	−0.043	−0.041	−0.040
70	−0.046	−0.044	−0.042	−0.041	−0.039
80	−0.045	−0.043	−0.042	−0.040	−0.038
90	−0.044	−0.042	−0.041	−0.039	−0.038
100	−0.043	−0.042	−0.040	−0.038	−0.037

tion elevation H_p to the level of $(H_a + 10')$, on the basis of the data given in the table of corrections corresponding to the observed station temperature and pressure

$$C = -0.046 \text{ in. Hg}$$

Step (3): Apply the correction C to P, thus obtaining the pressure at the level of the ten-foot plane above the airport

$$(P + C) = P_{10} = 26.239 \text{ in. Hg}$$

Step (4): Refer to Table 8.1 and determine the pressure altitude in the body of the table corresponding to the pressure argument P_{10}

$$H_{A10} = 3589 \text{ feet}$$

8.4.2.2 Determination of Pressure Altitude for the Ten-Foot Plane Above the Airport on the Basis of Altimeter Setting.—In order to determine the pressure altitude for the ten-foot plane above the airport when the altimeter setting is most conveniently obtained, the following steps may be employed:

(1) Observe the current altimeter setting, *A.S.*

(2) Refer to Table 8.1 and find from the body of the table the pressure altitude corresponding to the altimeter setting, H_{AS}.

(3) Take the algebraic sum of the field elevation H_a and the pressure altitude H_{AS} determined in accordance with step (2), and this sum will be the value of the required pressure altitude H_{A10} which refers to the level of the ten-foot plane above the airport.

In case the value of the station elevation H_p is not the same as the value of the height of the specified ten-foot plane above sea level $(H_a + 10')$, the result yielded by the foregoing procedure would be slightly in error whenever the temperature t at the station departs significantly from the temperature in the standard atmosphere at the level where the pressure is P, the station pressure. For further explanation regarding this matter see sec. 8.4.3.

When there is a frequent demand for the pressure altitude at airports where altimeter settings are regularly observed, it is desirable to prepare a table which indicates the required pressure altitude as a function of the altimeter setting. Such a table may be readily compiled by adding algebraically the value of the field elevation H_a to the tabular data in Table 8.1 and relabeling the side arguments as altimeter setting, *A.S.*

EXAMPLE OF PREPARATION OF SPECIAL TABLE GIVING PRESSURE ALTITUDE FOR THE TEN-FOOT PLANE ABOVE THE AIRPORT AS A FUNCTION OF ALTIMETER SETTING

Notation

A.S. = altimeter setting, in inches of mercury

H_{AS} = pressure altitude (in feet) corresponding to the altimeter setting *A.S.*, that is, H_{AS} is the value taken from the body of Table 8.1 pertinent to a value of pressure argument equal to the altimeter setting *A.S.*

H_a = field elevation, in feet

H_{A10} = pressure altitude for the ten-foot plane above the airport, in feet.

Basic Formula for Preparing Table

$$H_{A10} = (H_a + H_{AS}), \text{ algebraically.}$$

The following extracts of computations show the method employed for preparing a table for Billings, Montana, Airport where H_a = 3606 feet, to indicate the pressure altitude for the ten-foot plane above the airport H_{A10}, depending upon the value of altimeter setting, *A.S.*, determined by observation at the station elevation.

The results yielded by the calculations are

Altimeter setting	*A.S.*	29.00″	29.01″	29.02″	29.03″	etc.	29.09″
Field elevation	H_a	3606′	3606′	3606′	3606′	etc.	3606′
Pressure altitude corresponding to *A.S.*	H_{AS}	+863′	+853′	+844′	+834′	etc.	+778′
Pressure altitude for the ten-foot plane above the airport	H_{A10}	4469′	4459′	4450′	4440′	etc.	4384′

Altimeter setting	*A.S.*	29.90″	29.91″	29.92″	29.93″	etc.	29.99″
Field elevation	H_a	3606′	3606′	3606′	3606′	etc.	3606′
Pressure altitude corresponding to *A.S.*	H_{AS}	+20′	+10′	+1′	−8′	etc.	−64′
Pressure altitude for the ten-foot plane above the airport	H_{A10}	3626′	3616′	3607′	3598′	etc.	3542′

Altimeter setting	*A.S.*	30.40″	30.41″	30.42″	30.43″	etc.	30.49″
Field elevation	H_a	3606′	3606′	3606′	3606′	etc.	3606′
Pressure altitude corresponding to *A.S.*	H_{AS}	−440′	−449′	−458′	−467′	etc.	−522′
Pressure altitude for the ten-foot plane above the airport	H_{A10}	3166′	3157′	3148′	3139′	etc.	3084′

Special Table
Billings, Montana, Airport

Field Elevation, H_a, 3606 feet above sea level

Values in the body of the table represent the pressure altitude for the ten-foot plane above the airport corresponding to the altimeter setting values indicated as the arguments

Altimeter setting, inches of mercury	0.00	0.01	0.02	0.03	etc.	0.09
	feet	feet	feet	feet		feet
29.00	4469	4459	4450	4440	etc.	4384
etc.						
29.90	3626	3616	3607	3598	etc.	3542
etc.						
30.40	3166	3157	3148	3139	etc.	3084
etc.						

compiled in a special table, which is illustrated in skeleton form above.

A special table of the type shown should be prepared if there are recurrent demands for pressure altitude for any given airport.

8.4.2.3 Use of Face II of the Pressure Reduction Computer in Calculating the Pressure Altitude for the Ten-Foot Plane Above an Airport, on the Basis of Altimeter Setting. —The following instructions can be employed when the altimeter setting is observed at a given airport and it is desired to determine the corresponding value of the pressure altitude for the ten-foot plane above the airport by making use of face II of the Pressure Reduction Computer (WBAN 54–7–8):

(1) Set the hairline of the cursor on the observed value of the altimeter setting on the "*P,A.S.*" scale, and set the rotor disk so that the value of the field elevation (H_a) on the "*H*" scale lies beneath the hairline maintained at the first setting described above.

(2) Read the pressure altitude pertinent to the ten-foot plane above the airport (H_{A10}) on the "*H*" scale opposite the 29.92 inch (of mercury) graduation index of the "*P,A.S.*" scale.

Note in regard to step (*2*) :—Since there is an inner and an outer "*H*" scale, a question may arise as to which of these scales the desired reading of pressure altitude should be taken from. Usually the observer can tell by experience what scale to use and, if necessary, he can try reading the answers provided by both the inner and outer parts of the "*H*" scale. When either scale has thus been used to obtain an answer, one can determine whether the proper scale has been employed by applying the following condition as a test of the result: when the altimeter setting is less than 29.92 inches of mercury, the proper value of the pressure altitude is higher than the field elevation H_a; and when the altimeter setting is greater than 29.92 inches of mercury, the proper value of the pressure altitude is lower than the field elevation H_a. This condition is a direct consequence of the basic formula indicated in the previous example, namely, $H_{A10} = H_a + H_{AS}$, together with the fact that for each inch of mercury departure of the altimeter setting (*A.S.*) from 29.92 inches of mercury, the corresponding pressure altitude H_{AS} will vary roughly 925 feet in the *opposite* direction. That is, one may consider it to be a rule of thumb that

$$H_{AS} = (29.92 \text{ in. Hg} - A.S.) \times 925 \text{ feet},$$

approximately, where *A.S.* is the altimeter setting in inches of mercury. On this basis

$$H_{A10} = H_a + (29.92 \text{ in. Hg} - A.S.) \times 925 \text{ feet},$$

approximately.

There follow two examples with given values of H_a and *A.S.*, together with proper answers, which may be used to verify the instructions stipulated above for the use of face II of the pressure-reduction computer in order to calculate the pressure altitude pertinent to the ten-foot plane above the airport, H_{A10}.

EXAMPLE I

Given: Field elevation H_a = 3606 feet, and altimeter setting *A.S.* = 29.225 inches of mercury.

Answer: Pressure altitude for the ten-foot plane above the airport $H_{A10} = 4256$ feet (read on the inner "H" scale).

EXAMPLE II

Given: Field elevation $H_a = 3606$ feet, and altimeter setting $A.S. = 30.445$ inches of mercury.

Answer: Pressure altitude for the ten-foot plane above the airport $H_{A10} = 3125$ feet (read on the outer "H" scale).

8.4.3 Effect of Temperature Variations on Pressure Altitude at an Airport

First of all, we shall show that in case the station elevation H_p is at the level of the ten-foot plane above the airport $(H_a + 10')$, then the algebraic sum of the field elevation H_a and the pressure altitude corresponding to the altimeter setting determined at the station will be equal to the pressure altitude at the level of the ten-foot plane above the airport. While this relationship is demonstrated to be true regardless of the existing temperature out of doors, it is shown subsequently that in case the station elevation H_p differs from the height above sea level represented by $(H_a + 10')$ and the existing outdoor temperature is different from the standard temperature assumed for the given level in the standard atmosphere, then the algebraic sum of the field elevation and the pressure altitude corresponding to the altimeter setting determined at the station will depart slightly from the true value of the pressure altitude for the ten-foot plane above the airport.

Let

P = station pressure;

$A.S.$ = altimeter setting;

H_{AS} = pressure altitude corresponding to the altimeter setting $A.S.$;

H_p = station elevation, that is, the height above sea level to which the station pressure P relates;

H = pressure altitude corresponding to the station pressure P;

H_a = field elevation, that is, the height of the airport above sea level;

H_{A10} = pressure altitude for the ten-foot plane above the airport, that is, the pressure altitude that exists at the height above sea level represented by $(H_a + 10 \text{ feet})$;

P_{10} = pressure which exists at the ten-foot plane above the airport, that is, the barometric pressure at the height above sea level given by $(H_a + 10')$;

$(H_p - H_a - 10')$ = height difference, that is, the difference in height between the ten-foot plane above the airport and the station elevation.

According to the definition of altimeter setting which is now used by the Weather Bureau in practice, we have

$$H_{AS} = H - (H_p - 10 \text{ ft.}). \qquad (1)$$

If we add the field elevation H_a to both the left- and right-hand sides of equation (1) we obtain

$$H_a + H_{AS} = H - (H_p - H_a - 10'). \quad (2)$$

Under the condition that the station elevation lies at the same level as $(H_a + 10')$, the level of the ten-foot plane above the airport, we have the equality

$$H_p = (H_a + 10'). \qquad (3)$$

When this relationship is substituted in equation (2), we find that

$$H_a + H_{AS} = H. \qquad (4)$$

Now let us consider the significance of the quantity H subject to the condition expressed by equation (3). First of all, it should be noted that by definition H represents the pressure altitude corresponding to the station pressure P. In view of equation (3) and the fact that the station pressure relates to the station elevation H_p it follows that the station pressure relates to the level of $(H_a + 10')$ under the specified condition. In that event the quantity H would represent the pressure altitude corresponding to the station pressure pertinent to the level $(H_a + 10')$. If we designate the pressure pertinent to the level $(H_a + 10')$ by the symbol P_{10}, it follows that under the condition expressed by equation (3) the station pressure P is equivalent to P_{10} and the quantity H represents the pressure altitude corresponding to the pressure P_{10}. Now if we denote by the symbol H_{A10} the pressure altitude corresponding to the pressure at the level of the ten-foot plane above the airport, it will be clear as a result of the foregoing considerations that when $H_p = (H_a + 10')$ the symbol H may be replaced by H_{A10}. Therefore, in cases where the station elevation H_p has a height above sea level equal to $(H_a + 10')$ we may substitute H_{A10} for H in equation (4), hence equation (4) can be rewritten

$$(H_a + H_{AS}) = H_{A10}. \qquad (5)$$

In other words, in cases where the station elevation is equivalent to the height above sea level of the ten-foot plane over the airport runway, the algebraic sum of the field elevation and the pressure altitude corresponding to the altimeter setting is equal to the pressure altitude pertinent to this ten-foot plane. It will be noted that this result is valid regardless of the outdoor air temperature so long as the station pressure P is truly equal to P_{10}, which represents the pressure existing at the level of the ten-foot plane above the airport, that is, at the height above sea level denoted by $(H_a + 10')$.

Now we shall consider the case where the station pressure P is unequal to P_{10}, under which condition it will be proved that equation (5) is not strictly accurate and that a slight correction may be required, depending upon the height difference $(H_p - H_a - 10')$ and the outdoor temperature. The magnitude of the correction will be shown to be relatively small under ordinary circumstances, and it is considered negligible when less than ten feet.

As indicated above we have let H_{A10} denote the pressure altitude at the ten-foot plane above the airport where the existing atmospheric pressure is P_{10}. In Appendix 8.0.1 and sec. 8.4.0 we have indicated the basic equation which represents pressure altitude H in general as a function of barometric pressure P in general. When we substitute P_{10} for P in the specified equation, the corresponding pressure altitude must be represented by H_{A10} instead of H; and therefore the basic equation transforms to

$$H_{A10} = \left(\frac{T_o}{a}\right)\left[1 - \left(\frac{P_{10}}{P_o}\right)^{1/n}\right]. \qquad (6)$$

By taking the derivatives of H_{A10} with respect to P_{10} in equation (6) we obtain

$$\frac{dH_{A10}}{dP_{10}} = -\left(\frac{T_o}{an}\right)\left(\frac{P_{10}}{P_o}\right)^{1/n}\left(\frac{1}{P_{10}}\right). \qquad (7)$$

If we replace the infinitesimals in the left-hand member of equation (7) by the corresponding small finite increments, we have $dP_{10} = \Delta P_{10}$, and $dH_{A10} = \Delta H_{A10}$ very nearly; and, on substituting these increments in equation (7), we secure the result

$$\Delta H_{A10} = -\left(\frac{T_o}{an}\right)\left(\frac{P_{10}}{P_o}\right)^{1/n}\left(\frac{1}{P_{10}}\right)\Delta P_{10}. \qquad (8)$$

As shown in Appendix 7.1 (see equations (12)–(16)), the application of the differential form of the hydrostatic equation together with the equation for air density and the definition of geopotential permits us to write

$$dP_{10} = -\left(\frac{G}{R}\right)\left(\frac{P_{10}}{T_v}\right)dh, \qquad (9)$$

where

T_v = virtual (absolute) temperature of the outdoor moist air;

and

dh = increment of geopotential corresponding to an increment of pressure dP_{10} in the atmosphere under the existing conditions of pressure (P_{10}) and virtual temperature (T_v).

The symbols G and R have been defined in sec. 8.4.0 (see also Appendixes 7.1 and 8.0.1).

By replacing the infinitesimals in equation (9) by the corresponding small finite increments (that is, $dP_{10} = \Delta P_{10}$, and $dh = \Delta h$), and substituting the resultant expression for ΔP_{10} in the right-hand member of equation (8) we find

$$\Delta H_{A10} = \left(\frac{T_o}{an}\right)\left(\frac{P_{10}}{P_o}\right)^{1/n}\left(\frac{G}{R}\right)\left(\frac{1}{T_v}\right)\Delta h. \qquad (10)$$

Since the quantity n was defined by the identity

$$n = (G/aR) \qquad (11)$$

as specified in sec. 8.4.0 and Appendix 8.0.1, the use of this relationship permits us to simplify equation (10) to the form

$$\Delta H_{A10} = \left(\frac{P_{10}}{P_o}\right)^{1/n}\left(\frac{T_o}{T_v}\right)\Delta h. \qquad (12)$$

On solving equation (6) for $(P_{10}/P_o)^{1/n}$, we get

$$\left(\frac{P_{10}}{P_o}\right)^{1/n} = \left(\frac{T_o - aH_{A10}}{T_o}\right). \quad (13)$$

When equation (13) is substituted in equation (12), we obtain

$$\Delta H_{A10} = \left(\frac{T_o - aH_{A10}}{T_v}\right)\Delta h. \quad (14)$$

It will be clear from the definitions previously given that H_{A10} refers to the pressure altitude corresponding to the pressure P_{10} which exists at the ten-foot plane above the airport where the height above sea level is $(H_a + 10')$, while the symbol H pertains to the pressure altitude corresponding to the station pressure P which exists at the station elevation H_p. On this basis it follows that when the height above sea level undergoes a variation from $(H_a + 10')$ to H_p, the pressure undergoes a variation from P_{10} to P, and the corresponding pressure altitude undergoes a change from H_{A10} to H. Therefore, the finite increments under consideration may be expressed as follows:

$$\Delta h = H_p - (H_a + 10') = (H_p - H_a - 10'), \quad (15)$$

$$\Delta P_{10} = (P - P_{10}), \quad (16)$$

and $$\Delta H_{A10} = (H - H_{A10}). \quad (17)$$

The substitution of equations (15) and (17) in equation (14) yields

$$(H - H_{A10}) = \left(\frac{T_o - aH_{A10}}{T_v}\right)(H_p - H_a - 10'). \quad (18)$$

If it be understood that equation (1) provides a mathematical specification of the altimeter setting in terms of the pressure altitude H corresponding to the station pressure P which relates to the station elevation H_p, it is easily shown by adding H_a to both sides of equation (1) and performing a little algebraic manipulation that equation (1) can be transformed to give the following useful expression which interrelates certain variables of interest:

$$(H_a + H_{AS}) - H = -(H_p - H_a - 10'). \quad (19)$$

When equations (18) and (19) are added, and the resultant expression is multiplied by (— 1), after a slight algebraic reduction we obtain the result

$$H_{A10} - (H_a + H_{AS}) = \left[\frac{T_v - (T_o - aH_{A10})}{T_v}\right] \times (H_p - H_a - 10'). \quad (20)$$

It will be recognized that the left-hand side of equation (20) represents the *correction* that one would have to apply algebraically to the quantity $(H_a + \mathrm{H}_{AS})$ in order to obtain the quantity H_{A10}, which is the true pressure altitude representative of the ten-foot plane over the airport based on the pressure P_{10} pertinent to the height above sea level $(H_a + 10')$. The value of the correction thus specified can be computed by means of the right-hand side of equation (20) as illustrated in the sample problem following the next paragraph.

In case all of the data are to be expressed in conventional English units, the altitude or height values will be in feet (or ft′ as indicated in Appendix 8.0.1), while the absolute temperatures T_v and T_o will be in degrees Rankine (°R.); hence in that case

$$T_v = (459.67 + t_v)\,^\circ\mathrm{R.}, \quad (21)$$

where t_v = virtual temperature, in °F. (see Appendix 7.1); and, on the basis of the data specifications in Appendix 8.0.1,

$$(T_o - aH_{A10}) = (518.67 - 0.00356616\, H_{A10})\,^\circ\mathrm{R.} \quad (22)$$

The quantity represented by equation (22) can be interpreted as the temperature in the standard atmosphere pertinent to the altitude H_{A10}. When one wishes to evaluate the right-hand side of equation (20) in a situation where it is unequal to zero, the value of the quantity H_{A10} involved in the term expressed by equation (22) will be initially unknown; but its value can be estimated closely by means of equation (5) on whose basis equation (22) transforms to the following:

$$(T_o - aH_{A10}) = [518.67 - 0.00356616\,(H_a + H_{AS})], \quad (23)$$

very nearly,

where this approximation to the standard-atmosphere temperature at the altitude H_{A10} must be expressed in degrees Rankine. If desired, successive approximations of H_{A10} can be calculated by means of equation (20), when the quantities H_a, H_{AS}, H_p, and T_v are known.

SAMPLE PROBLEM

The Problem—*Given:* H_a, H_p, *A.S.*, and t_v for a particular station; *to solve* equation (20) and to find H_{A10}.

Given:

(a) Field elevation, $H_a = 5000$ feet above sea level.

(b) Station elevation, $H_p = 5060$ feet above sea level.

(c) Altimeter setting observed at the station, *A.S.* = 29.63 inches of mercury.

(d) Virtual temperature, $t_v = -30°\text{F}$.

Solution:

(A) Refer to Table 8.1 with the altimeter setting as an argument, and thus find the value of the pressure altitude corresponding to the altimeter setting: $H_{AS} = 270$ ft′.

(B) Calculate $(H_a + H_{AS})$, that is

$$(H_a + H_{AS}) = (5000 + 270) \text{ ft.} = 5270 \text{ ft.}$$

(C) By means of equation (23) calculate the first approximate value of the temperature in the standard atmosphere for the pressure altitude H_{A10}, thus obtaining

$$\begin{aligned}[T_o - a(H_a + H_{AS})] &= (518.67 - 0.00356616 \times 5270)\,°\text{R.} \\ &= 499.88°\text{R.}\end{aligned}$$

(D) By means of equation (21) calculate the absolute value of the virtual temperature corresponding to the virtual temperature in degrees Fahrenheit; that is,

$$\begin{aligned}T_v &= (459.67 + t_v) \\ &= (459.67 - 30)\,°\text{R.} = 429.67°\text{R.}\end{aligned}$$

(E) Calculate the height difference:

$$(H_p - H_a - 10') = (5060 - 5000 - 10) \text{ ft.} = 50 \text{ ft.}$$

(F) Substitute in the right-hand member of equation (20) the results found by means of steps (C), (D), and (E) and thus determine the value of the correction specified by the left-hand side of equation (20); hence

$$\begin{aligned}\text{correction} &= H_{A10} - (H_a + H_{AS}) \\ &= \left[\frac{429.67°\text{R.} - 499.88°\text{R.}}{429.67°\text{R.}}\right] \times 50 \text{ ft.} \\ &= \left[\frac{-70.21°\text{R.}}{429.67°\text{R.}}\right] \times 50 \text{ ft.} = -8 \text{ ft.}\end{aligned}$$

(G) By virtue of the results of steps (B) and (F), one finds

$$H_{A10} = (H_a + H_{AS}) + \text{correction specified under step (F);}$$

$$H_{A10} = 5270 \text{ ft.} - 8 \text{ ft.} = 5262 \text{ ft.}$$

If this value is used in equation (22), it is found that

$$\begin{aligned}(T_o - aH_{A10}) &= (518.67 - 0.00356616 \times 5262)\,°\text{R.} \\ &= 499.905°\text{R.}\end{aligned}$$

The substitution of this value in equation (20) yields the value − 8 ft. for the correction as in the case shown under step (F); hence further approximations regarding the calculation of $(T_o - aH_{A10})$ are not justified.

Since the quantity expressed within brackets in equation (20) rarely lies outside of the range of *minus* to *plus* 0.2 (±0.2), it follows that the magnitude of the correction specified by that equation will rarely exceed 0.2 of the height difference $(H_p - H_a - 10)$ ft.

CHAPTER 9

REDUCTION TO CONSTANT PRESSURE SURFACES; HYPSOMETRY

(This chapter will be contained in volume II.)

CHAPTER 10

SPECIAL POTENTIAL OR OTHER FUNCTIONS REPRESENTING THE EARTH'S PRESSURE FIELD

(This chapter will be contained in volume II.)

CHAPTER 11

ATMOSPHERIC PRESSURE AS AFFECTED BY ACCELERATIONS, NON-STATIC CONDITIONS AND TERRAIN

(This chapter will be contained in volume II.)

CHAPTER 12

APPENDIXES (THEORY AND TECHNICAL INFORMATION)

APPENDIX 1.3.1

THEORY OF GEOPOTENTIAL

1. Introduction

It is the purpose of this appendix to explain the concept of geopotential beginning with relatively simple considerations and to present information regarding the basis of the method employed for the computation of the geopotential of a point whose latitude and geometric altitude are given.

Geopotential may be regarded as the potential energy due to the earth's gravity of a particle of unit mass relative to mean sea level.

Experiments reveal that the force of terrestrial gravity varies with geographic location and with geometric altitude, *where the latter is always understood as being measured with respect to mean sea level.* In order to visualize gravity at any point in the atmosphere we can first think of a short, weightless filament from which a plumb bob of unit mass is suspended, and then conceive of the force of terrestrial gravity as that which acts downward on the support of the filament. To extend the idea we can suppose the filament to be projected both up and down. Thus, from any fixed position on the surface of the earth let us imagine a fine thread extending toward the zenith in such a manner that every minute segment of the thread is directed vertically; i.e., along the direction assumed by a stationary plumb line. The downward direction of this line coincides with the direction of the local force of terrestrial gravity. Actually the thread would be found to have a slight curvature if extended to great altitudes.

Despite this, it is theoretically possible for a tape measure to be used as a means of determining the geometric altitude of any point located on such an imaginary vertical thread. Since terrestrial gravity varies with position along the imaginary thread, the potential energy relative to mean sea level of a unit mass at any point resulting from this gravity depends upon the geometric altitude of the point. Therefore, the geopotential at any point in the atmosphere and its corresponding geometric altitude are correlated in a manner which depends in general upon the geographic location of the point. Consequently, geopotential may be used as a vertical coordinate pertaining to a given point in the atmosphere in order to present an indication of the height of the point relative to mean sea level.

However, it should be understood that geopotential and geometric altitude are not of the same character, although they are correlated. Thus, strictly speaking one can convert from the geometric altitude of a point to its geopotential, or vice versa, for any given geographic position, assuming the distribution of gravity to be known.

The inquiring reader may ask: "If geopotential and geometric altitude are correlated, why is the former used at all?" From the standpoint of barometry the answer to this question may be seen most readily from the application of geopotential to problems that involve the interrelation of the vertical coordinate of a point with the existing air pressure, density, and temperature at the point; especially if the variation of pressure with height is entailed.

An immediate advantage of the use of geopotential instead of geometric altitude may be seen from the following consideration. Thus, let

P = atmospheric pressure
Z = geometric altitude
H = geopotential
g = acceleration of gravity
G = a *constant* which indicates the size of the unit of geopotential in terms of the unit in which the product gZ is given

and

ρ = air density.

Then, according to the hydrostatic equation (see Appendix 7.1), we have

$$dP = -\rho g dZ \tag{a}$$

whereas if the concept of geopotential is introduced we have

$$dP = -\rho G dH \tag{b}$$

An immediate advantage of (b) over (a) is that (b) contains one less variable than (a), for G is a constant whereas g varies with Z and the latitude, ignoring gravity anomalies.

This fact makes it easier to integrate equation (b) than equation (a); see appendixes 7.1 and 8.0.1. In these appendixes the geopotential is shown to be useful in regard to the calculation of height by hypsometry, the reduction of pressure, the specification of the standard atmosphere, and the application of the standard atmosphere in altimetry.

2. Basic Concept of Geopotential

Since the publication by Newton in 1687 of the results of his investigations regarding the science of mechanics, it has become known that every material body is surrounded by a gravitational field which causes it to attract every other body in the universe. Newton discovered that the periodic motion of a satellite in an elliptical orbit around its parent (as in the case of the moon revolving around the earth) could be explained on the basis of the theory that for every two particles of masses m_1 and m_2 separated by linear distance r, the force of gravitational attraction between them is proportional to $(m_1 m_2)/r^2$.

The presence of the force of gravitational attraction between the earth and neighboring material bodies within reach of direct experimental investigation was originally inferred from the free fall of such bodies towards the earth and from the existence of their weights which were determined to be proportional to their masses. However, it is essential not to conclude from these stated facts that the gravitational attraction is the only force at the bottom of the phenomena described, for some effect may be expected to result also from the rotation of the earth about its axis. This effect is experienced on a smaller scale by whirling a stone at the end of a string around an axis of rotation. It is then observed that a centrifugal force (see sec. 7) is exerted on the stone in a direction acting perpendicular to the axis along the line that connects the supporting point of the string and the stone. Similarly, a centrifugal force is exerted on every material body which rotates with reference to the earth's axis. As an example, such a force would act upon the mass of a pebble resting on the ground at the equator or upon a stationary, equal mass of air just beside the pebble. This centrifugal force, due to the spinning motions of the earth, was shown by Newton to be given by the product of three quantities as follows:

(1) the mass of the body, (2) the perpendicular distance from the earth's axis to the body, and (3) the *square* of the angular velocity of rotation of the earth about its axis (namely, 2π radians per 86,164.1 seconds which is the length of the sidereal day). The centrifugal force is directed along the outward extension of the line erected perpendicularly from the earth's axis to the body.

On the basis of the foregoing considerations there are two forces acting simultaneously on the body which determine its weight, namely (a) the gravitational attraction of the earth on the body, directed inwards towards the center of mass of the earth; and (b) the centrifugal force due to the earth's rotation, directed away from the axis on a line at right angles to it passing through the body.

The resultant of the two forces described in the previous sentence yields the weight of the body, apart from effects due to buoyancy. Since the two forces have different directions in general, the resultant weight force is not precisely directed towards the center of mass of the earth, except for a body lying on the earth's equator or on the poles.

To emphasize this aspect an extreme case of revealing character is suggested. Thus, consider a hypothetical body assumed to be maintained in space within the plane of the equator so that it is always located vertically above a fixed point on the surface. In case the radial distance of the body from the earth's center is 6.6 times the earth's equatorial radius the centrifugal force acting upon the body will be just equal and opposite to the force of terrestrial gravitational attraction acting upon it, and therefore these two forces counterbalance, yielding a zero weight and hence no up or down from the standpoint of the body.

However, in the case of any body much closer to the earth the gravitational attraction of the earth will predominate and the body will have weight recognizable as a force acting vertically downward in the direction taken by a stationary, suspended plumb line.

If one wishes to support the body at a fixed point, one must apply a force on the body equal but opposite to its weight at the point. Proceeding further, if one wishes to lift the body vertically upward against gravity at a uniform velocity, one must also apply a force equal but opposite to the weight of the body, while causing the body to undergo a displacement upward along the line of application of the force. As long as the direction of the force has a component parallel to the displacement, work is done on the body.

The concept of this process may be made more explicit by considering a body of mass m and apparent weight W at a point where a force equal but opposite to W is applied to the body and the body is given an infinitesimal, vertical, upward displacement dZ thereby doing work against gravity. By definition, work is the product of force and the magnitude of the displacement parallel to the direction of application of the force. Therefore, the amount of energy, dE, which must be expended as work against gravity in elevating the body a vertical distance dZ is expressed as

$$dE = WdZ \qquad (1)$$

Consequently, if dU denotes the amount of energy thus expended *per unit mass* for a vertical displacement dZ in lifting the body against gravity, it follows that

$$\frac{dE}{m} = dU = \frac{W}{m}dZ \qquad (2)$$

The work, dU, thus done is a measure of the increase per unit mass of potential energy due to gravity. By virtue of the law of conservation of energy, a potential energy increase of the given amount could be theoretically transformed into kinetic energy if the unit mass were released and fell freely under gravity a vertical distance dZ measured downward, neglecting the effects of air resistance.

Newton's investigations revealed that if a weight of W is manifested at a point by a body of mass m the ratio of these two quantities is given by

$$\frac{W}{m} = g \qquad (3)$$

where g = acceleration of gravity at the point.

The acceleration of gravity (g) at any point is defined as the rate of increase of velocity of a body falling freely in a vacuum under the action of terrestrial gravity at the point. As a typical value of g one might consider that observed at mean sea level at latitude 45° where the value is about 9.80616 m./sec.^{2} (that is, 9.80616 meters per second per second). See Table 3.2.1. By substituting equation (3) in equation (2) one finds

$$dU = gdZ \qquad (4)$$

For reasons which will be explained later, the potential energy, U, per unit mass due to gravity is measured with reference to the surface of mean sea level, which thus serves as the datum level for both geometric altitude, Z, and gravitational potential energy per unit mass, U.

Suppose that a unit mass is displaced in the earth's gravity field from an initial point (denoted by subscript 1) to a second point (denoted by subscript 2) over a path along which g may vary with position, then the net change in gravitational potential energy of the mass is found by summing up a sequence of terms like that given in equation (4) for a succession of infinitesimal displacements between the two points; hence integration of equation (4) yields

$$U_2 - U_1 = \int_{Z_1}^{Z_2} g dZ \qquad (5)$$

It follows that if one considers $U_1 = 0$ when $Z_1 = 0$, then

$$U = \int_{0}^{Z} g dZ \qquad (6)$$

where Z_2 is replaced by Z and U_2 by U.

Equation (6) represents the *geopotential* or gravity potential relative to mean sea level of unit mass at a point whose geometric altitude is Z. It indicates the amount of work which must be done against gravity in lifting a unit mass from the datum at mean sea level to the given point.

As was pointed out earlier, the local force of gravity at any point acts downward in the direction taken by a short plumb line, provided that there is no wind or current of air to deflect the latter. Let $\mathbf{g}$ denote the local force of gravity per unit mass, regarded as a vector; that is, a quantity specified by both a magnitude and a direction in which it acts. Now let $d\mathbf{Z}$ denote an infinitesimal vertical displacement of magnitude dZ along the upward extension of the plumb line. Thus, $d\mathbf{Z}$ is also a vector quantity. Then, according to the definition of geopotential we have

$$dU = -\mathbf{g} \cdot d\mathbf{Z} \qquad (7)$$

where the dot signifies scalar multiplication in the notation of vector analysis (that is, $\mathbf{g} \cdot d\mathbf{Z}$ represents the product gdZ multiplied by the cosine of the angle between the vector quantities $\mathbf{g}$ and $d\mathbf{Z}$).

In the present case the magnitude is represented by g, the numerical value of the local acceleration of gravity; while the direction is indicated by an arrow projected downward along the plumb line at its point of suspension.

Since the angle between the vectors $\mathbf{g}$ and $d\mathbf{Z}$ is 180°, its cosine is -1; hence equation (7) transforms to equation (4); and the equation

$$U = -\int_{0}^{Z} \mathbf{g} \cdot d\mathbf{Z} \qquad (8)$$

transforms to equation (6).

Suppose that $d\mathbf{X}$ represents an infinitesimal vector displacement of magnitude dX in a direction perpendicular to the local force of gravity vector $\mathbf{g}$. Then, the work done against gravity in producing this displacement is represented by the scalar product $\mathbf{g} \cdot d\mathbf{X}$. However, since the angle between $\mathbf{g}$ and $d\mathbf{X}$ is 90°, the cosine of this angle is zero; hence the amount of work done against gravity in this case is zero (0). Thus, a surface perpendicular to the local vector $\mathbf{g}$ at every point cannot contain any component of $\mathbf{g}$. From these facts we come to the deductions that in moving a particle along a surface which is everywhere perpendicular to $\mathbf{g}$ no force can be exerted counter to any component of the force of gravity, and that no change in the gravitational potential energy of the particle occurs as long as it remains within such a surface. In other words the geopotential is constant in the specified surface.

It is well known that a short plumb line hanging freely in the absence of wind or air currents indicates the direction of the force of gravity and that a level assumes a direction perpendicular to that of the plumb line when adjusted to establish a horizontal line.

The following conclusions may therefore be reached on the basis of the information presented above: (a) a surface which is everywhere perpendicular to the local force of gravity is a level or horizontal surface; and it is a surface of constant geopotential; i.e., $U =$ constant for the surface characterized by being everywhere tangent to a spirit level. (b) As long as a particle remains within such a surface no work need be done against gravity to keep it there, and no work is done by gravity as long as it continues to stay within the surface.

The surface of mean sea level is a special case in point illustrating the concept of a surface of constant geopotential to which the value $U = 0$ is assigned. The surface of mean sea level is determined by averaging the indications of mean tide level at many coastal points over a long period of time. Consequently, the surface of mean sea level represents the surface of equilibrium of the oceans under the influence of the resultant of gravitational attraction of the earth and the centrifugal force due to the rotation of the earth about its axis.

3. Units of Geopotential

If g and Z are given in the centimeter-gram-second system, the unit of geopotential is the cm.^{2} sec.$^{-2}$ This is a consequence of the fact that g is then specified in cm. sec.$^{-2}$ and Z is in cm., while the product yields the stated unit by virtue of equation (6).

Similarly, if g is given in meters per second per second (m. sec.$^{-2}$), and Z in meters (m.), the unit of geopotential would be m.^{2} sec.$^{-2}$, according to the basic definition expressed by equation (6).

As will be evident from the data in Table 3.2.1, the value of g near sea level is normally of the order of 9.81 m. sec.$^{-2}$ Then according to equation (5), if a unit mass were lifted 1 meter at a point where $g = 9.81$ m. sec.$^{-2}$, the geopotential would increase 9.81 m.^{2} sec.$^{-2}$

In 1910, V. Bjerknes and collaborators[1] pointed out that if one employed as the unit of geopotential a quantity whose size was exactly 10 m.^{2} sec.$^{-2}$, then the lifting of a unit mass through the vertical distance of 1 meter at a point near sea level would yield an increase of the geopotential amounting to approximately 0.98 unit, where the unit is specified as 10 m.^{2} sec.$^{-2}$

Bjerknes suggested that the unit 10 m.^{2} sec.$^{-2}$ be called the "dynamic meter," in view of the fact pointed out in the previous paragraph.

In 1947 the International Meteorological Organization (since then superseded by the World Meteorological Organization) adopted a new unit of geopotential termed the *"geopotential meter"* (abbreviated gpm.) equal to 9.8 m.^{2} sec.$^{-2}$

When one accepts this latter unit, it is necessary to modify equation (6) for the sake of consistency so that the results will be yielded in terms of the geopotential meter. Accordingly, if H denotes *geopotential in "geopotential meters,"* then equation (6) may be rewritten

$$H = \frac{1}{9.8}\int_0^Z g dZ, \text{ in gpm.,} \qquad (9)$$

where g = acceleration of gravity, in m. sec.$^{-2}$; and Z = altitude above mean sea level, in m.

We shall define the symbol G by the expression $G = 9.8$ m.^{2} sec.$^{-2}$ per gpm. Then employing G in equation (9) one may rewrite it simply as

$$H = \frac{1}{G}\int_0^Z g dZ, \text{ in gpm.,} \qquad (10)$$

where g is in m. sec.$^{-2}$ and Z in m.

Owing to the specified choice of the value adopted for G it is evident that at any point where $g = 9.8$ m. sec.$^{-2}$, an increase in geometric altitude of 1 meter corresponds to an increase in geopotential of exactly 1 geopotential meter (1 gpm.), for the latter is equal to 9.8 m.^{2} sec.$^{-2}$

By differentiation of equation (10) with respect to Z one obtains

$$GdH = gdZ \qquad (11)$$

or

$$\frac{dH}{dZ} = g/G \qquad (12)$$

From the last equation it is clear that the rate of increase of geopotential (H) with increase of geometric altitude (Z) is equal to the ratio of the acceleration of gravity (g) to the constant G.

For example, when $g = 4.9$ m. sec.$^{-2}$, an increase in Z of 1 meter produces an increase in H of 0.5 gpm. Thus, in the equations (10)—(12) the term G is merely a constant quantity which expresses the number of m.^{2} sec.$^{-2}$ units represented by 1 geopotential meter (see Appendix 7.1).

4. Variation of Gravity with Position

In this section a summary is presented regarding the normal variation of the acceleration of gravity, with geometric altitude and latitude, neglecting the effects of gravity anomalies.

All data given here in the form of equations will be based on the so-called "Meteorological Gravity System" (see Smithsonian Meteorological Tables, Sixth Revised Edition, R. J. List, Editor, published by the Smith-

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[1] V. Bjerknes et al., "Dynamical Meteorology and Hydrography," vol. 1, Carnegie Institution of Washington, Washington, D.C., 1910.

sonian Institution, Washington, D. C., 1951, pp. 488–492).

Let g_ϕ denote the acceleration of gravity at mean sea level regarded as a function of latitude (ϕ). It is assumed that g_ϕ is 0.00013 m. sec.$^{-2}$ *less* in the "Meteorological Gravity System" than in the "Potsdam Gravity System," which is generally employed in geodesy as a reference basis for gravity data.

A glance at the following brief table shows a few comparisons of g_ϕ in m. sec.$^{-2}$ based on the two systems, and given for three different latitudes.

TABLE
g_ϕ, Acceleration of Gravity at Mean Sea Level

System	Latitude		
	0°	45°	90°
	m. sec.$^{-2}$	*m. sec.*$^{-2}$	*m. sec.*$^{-2}$
Meteorological Gravity System	9.78036	9.80616	9.83208
Potsdam Gravity System	9.78049	9.80629	9.83221

The acceleration of gravity, g_ϕ in m. sec.$^{-2}$ at mean sea level at latitude ϕ is expressed in the "Meteorological Gravity System" by the equation

$$g_\phi = 9.80616\,(1 - 0.0026373\cos 2\phi + 0.0000059\cos^2 2\phi)\ \text{m. sec.}^{-2} \qquad (13)$$

Let $\left(\frac{\partial g}{\partial Z}\right)_{Z=0}$ in sec.$^{-2}$ represent the rate of variation of the acceleration of gravity, g in m. sec.$^{-2}$, with respect to geometric altitude, Z in m., evaluated for the altitude $Z = 0$; that is, for mean sea level. Then

$$\left(\frac{\partial g}{\partial Z}\right)_{Z=0} = (-3.085462\times 10^{-6} - 2.27\times 10^{-9}\cos 2\phi + 2\times 10^{-12}\cos 4\phi)\ \text{sec.}^{-2} \qquad (14)$$

If, as before (see equation (13)), g_ϕ represents the acceleration of gravity, in m. sec.$^{-2}$, at mean sea level at latitude ϕ; and if g denotes the free-air acceleration of gravity, in m. sec.$^{-2}$, at latitude ϕ and geometric altitude, Z in m.; and if $F_1(\phi)$, $F_2(\phi)$, $F_3(\phi)$, $F_4(\phi)$ and $F_5(\phi)$ are functions of latitude defined below, then

$$g = [g_\phi - F_1(\phi)Z + F_2(\phi)Z^2 - F_3(\phi)Z^3 + F_4(\phi)Z^4 - F_5(\phi)Z^5] \qquad (15.0)$$

where

$$F_1(\phi) = (3.085462\times 10^{-6} + 2.27\times 10^{-9}\cos 2\phi) \qquad (15.1)$$

$$F_2(\phi) = (7.254\times 10^{-13} + 1.0\times 10^{-15}\cos 2\phi) \qquad (15.2)$$

$$F_3(\phi) = (1.517\times 10^{-19} + 6\times 10^{-22}\cos 2\phi) \qquad (15.3)$$

$$F_4(\phi) = (2.97\times 10^{-26} + 2.0\times 10^{-28}\cos 2\phi) \qquad (15.4)$$

$$F_5(\phi) = (5.6\times 10^{-33} + 5\times 10^{-35}\cos 2\phi) \qquad (15.5)$$

The evaluation of the coefficients in the foregoing equations of this section is due to W. D. Lambert, formerly connected with the U.S. Coast and Geodetic Survey, Washington 25, D. C.[2] [3]

A little digression is necessary at this stage concerning the significance of Z, the geometrical altitude, in equation (15.0). As previously explained, the downward direction indicated by a very short plumb line suspended at any point in an atmosphere without wind or air currents represents the direction of the force of gravity at the point, and therefore it reveals the local vertical. Now consider an atmosphere, in the absence of disturbing currents, through which an

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[2] W. D. Lambert, "Formula for the Geopotential Including the Effects of Elevation and of the Flattening of the Earth," unpublished manuscript, 15 October 1948.

[3] R. A. Minzner, W. S. Ripley, and T. P. Condron, "U.S. Extension to the ICAO Standard Atmosphere—Tables and Data to 300 Standard Geopotential Kilometers," prepared under the direction of The Committee on Extension to the Standard Atmosphere, Geophysics Research Directorate and U.S. Weather Bureau, Co-sponsors, published by U.S. Government Printing Office, Washington 25, D.C., 1958. (See pp. 2–3 and 21–22.)

infinitesimal plumb line is transported continuously aloft in a vertical sense. This means that the direction of motion is determined by the instantaneous, upward vertical projection of the plumb line at each point of its trajectory. This trajectory will be orthogonal (perpendicular) to the surfaces of constant geopotential. It may be shown on the basis of equation (16) given later, that the orthogonal trajectory to those surfaces will be curved. In other words, the path taken by the plumb line during its ascent always directed against the force of gravity is a curve, which represents the *true, continuous vertical.* Therefore, one may refer to the *"curvature of the vertical."*

The true, continuous vertical may be envisaged as having its lowest terminus at the surface of mean sea level where it is tangent to a straight line erected perpendicular to that surface. The upward projection of this straight line will deviate from the true, continuous vertical.

Let us consider a point in the free atmosphere and the family of all straight lines passing through the point. Clearly, one of these lines can be projected perpendicularly to the surface of mean sea level in some locality. Now, let us consider the true, continuous vertical which passes through the point referred to in the previous sentence. It will be evident that the straight line projected perpendicularly to the surface of mean sea level at some locality is not identical with the true, continuous vertical, since the latter is curved and intersects the surface at a different locality. In general, the distance measured from the surface to the point on the straight line is not the same as that measured along the curved vertical.

On the other hand, suppose one commences with a point lying on the surface of mean sea level and erects both a straight line perpendicular to the surface at the point and a true, continuous vertical passing through the point. Then, if a given linear distance is measured off by means of a flexible tape on the straight line and along the curved vertical, the upper ends of the tape will fall at different points in the free air. Also, the direction of the force of gravity will not be indicated by the straight line.

For purposes of calculating the geopotential, Z should be measured along the true, continuous, curved vertical. However, in developing the theory underlying the coefficients given in equations (15.1)—(15.5), it was not practicable to express these coefficients in such a manner that Z in equation (15.0) represents distance measured along the true, continuous, curved vertical. Instead, the equations were derived by neglecting the effect of the curvature of the vertical. In equation (15.0) the first two terms in Z were derived in such a manner that they represent the distance measured on the straight line perpendicular to the assumed ellipsoid of reference (see sec. 6). The remaining, lower order terms were calculated on the basis of the radius vector.

At latitude 45° the angle between the radius vector and the straight line perpendicular to the surface is only 11 minutes of arc, according to Lambert. (For more details, see U.S. Extension of the ICAO Standard Atmosphere, Washington, 1958, p. 21.)

It may be concluded from the foregoing considerations that the concept of geometric altitude becomes ambiguous at great heights above sea level, and under those conditions the expressions (15.1)—(15.5) must be regarded as more or less approximate.

One means of overcoming these difficulties to some extent is to represent position in space by use of geocentric Cartesian coordinates or geocentric spherical coordinates. However, even when these systems of coordinates referred to the center of the earth are employed, there remains the problem of converting from them to the conventional system giving position in terms of geographic latitude, longitude, and geometric altitude. The conventional system entails the adoption of an ellipsoid of reference which serves as a relatively simple mathematical approximation of the actual geoid. Further information regarding the ellipsoid of reference will be given in sec. 6 of this appendix. In the meanwhile it may be pointed out that the determination of the actual geoid, or figure of the earth, with respect to the assumed ellipsoid of reference depends intimately upon the evaluation of the effects of the deviations of actual gravity from theoretical gravity (that is, gravity anomalies), according to their distribution over the surface of the earth.[4] [5] [6]

The equations previously given in this section do not take into consideration the existence of the so-called "free-air gravity anomaly" which represents the departure of actual acceleration of gravity, g, at the surface of the earth from the theoretical value that would be computed by means of equation (15.0). A compilation of data giving the free-air gravity anomalies at a considerable number of stations in the United States has been prepared at the U.S. Coast and Geodetic Survey by J. A. Duerksen.[7]

Owing to gravitational attraction due to the earth, the effects of gravity anomalies extend into space. These effects at any point in space depend upon a number of factors. These include not only the existing local gravity anomaly at the surface of the earth vertically beneath the point but also the integrated influence of the gravity anomalies distributed over the surface, the configuration of the terrain, the actual shape of the geoid or figure of the earth relative to the ellipsoid of reference, the density distribution of matter within the body of the earth, the possible deviation from hydrostatic equilibrium which may exist to a limited extent in certain regions within the earth thus causing discrepancies in the calculated shape of the geoid, etc. When fine details are considered, even the gravitational forces of attraction of the moon, the sun, and other bodies of the solar system have to be taken into account, especially at points far out into space. Observations made by means of satellites in space have revealed some small anomalous effects in the gravity field surrounding the earth due to the factors referred to above.[8] [9] [10] [11] [16] [17]

It is possible to represent the effects of the anomalies to a certain degree of approximation by assuming the existence of a fictitious surface coating on the ellipsoid of reference which has a gravity influence equivalent to that of the existing distribution of gravity anomalies on the actual earth; but in order to do this it is also necessary to know the height of the geoid relative to the surface of the assumed ellipsoid of reference, and other pertinent information.

5. Equations Expressing Geopotential (*H*)

The various data listed below are assigned units as follows: g in m. sec.$^{-2}$; Z in m.; g_ϕ in m. sec.$^{-2}$; $F_1(\phi)$ in sec.$^{-2}$; $F_2(\phi)$ in m.$^{-1}$ sec.$^{-2}$; $F_3(\phi)$ in m.$^{-2}$ sec.$^{-2}$; $F_4(\phi)$ in m.$^{-3}$ sec.$^{-2}$; $F_5(\phi)$ in m.$^{-4}$ sec.$^{-2}$; and H in geopotential meters (gpm.); while $G = 9.8$ m.^{2} sec.$^{-2}$ per gpm. It will be recalled that the function g_ϕ is defined in equation (13), while the functions $F_1(\phi)$ to $F_5(\phi)$ are defined in equations (15.1) to (15.5).

By substituting equation (15.0) in equation (9), and integrating the latter, one obtains the following expression for geopotential

$$H = \left(\frac{g_\phi}{9.8}\right) Z - \left(\frac{F_1(\phi)}{2 \times 9.8}\right) Z^2 + \left(\frac{F_2(\phi)}{3 \times 9.8}\right) Z^3 - \left(\frac{F_3(\phi)}{4 \times 9.8}\right) Z^4 + \left(\frac{F_4(\phi)}{5 \times 9.8}\right) Z^5 - \left(\frac{F_5(\phi)}{6 \times 9.8}\right) Z^6 \quad (16)$$

Equation (16) does not take account of the effects of gravity anomalies; and its validity is limited at great heights above sea level, for reasons partially discussed in sec. 4. The concept of geopotential, explained in sec. 2 as dependent on the resultant of the earth's gravitational attraction and the centrifugal force due to the earth's rotation about its axis, becomes invalid at distances

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[4] W. A. Heiskanen and F. A. Vening Meinesz, "The Earth and Its Gravity Field," McGraw-Hill Book Co., New York, 1958.

[5] H. Jeffreys, "The Earth," Cambridge University Press, Third Edition, 1952.

[6] H. Jeffreys, "The Figures of the Earth and Moon (Third Paper)," Monthly Notices of the Royal Astronomical Society, Geophysical Supplement, London, vol. 5, pp. 219–247, July, 1948.

[7] J. A. Duerksen, "Pendulum Gravity Data in the United States," U.S. Department of Commerce, Coast and Geodetic Survey, Special Publication No. 244, published by the U.S. Government Printing Office, Washington, D.C., 1949.

[8] A. H. Cook, "Determination of the Earth's Gravitational Potential from Observations on Sputnik 2 (1957β)," Geophysical Journal of the Royal Astronomical Society, London, vol. 1, pp. 341–345, Dec., 1958.

[9] S. Herrick, R. M. L. Baker, Jr. and C. G. Hilton, "Gravitational and Related Constants for Accurate Space Navigation," Proc. Eighth International Astronomical Congress, Barcelona, 1957, Springer Verlag, Vienna, 1958.

[10] R. H. Merson and D. G. King-Hele, "Use of Artificial Satellites to Explore the Earth's Gravitational Field: Results from Sputnik 2 (1957β)," Nature, vol. 182, pp. 640–641, Sept. 6, 1958.

[11] L. G. Jacchia, "The Earth's Gravitational Potential as Derived from Satellites 1957 Beta One and 1958 Beta Two," Research in Space Science, Special Report No. 19, Smithsonian Astrophysical Observatory, Cambridge, Mass., Smithsonian Institution, 1958.

from the center of the order of several times the earth's radius.

However, the concept of gravitational potential due exclusively to the earth's gravitational attraction is valid to much greater distances; and in this regard it should be noted that equation (15) is *not* designed to represent gravitational potential due to the earth's field of gravitational attraction, but rather it represents geopotential as previously defined.

It is of interest to determine the gravitational potential on the assumption that the earth is a *sphere* characterized by spherical symmetry in regard to density; that is, density in the earth is assumed to be a function of radial distance.

On the basis of this premise it was shown by Newton that the gravitational attraction outside of the assumed spherical earth may be regarded as equivalent to that due to a particle concentrated at the center of the earth and having the same mass as the earth.

Now we shall assume that the supposed spherical earth does *not* rotate about its axis, and thus the effect of the centrifugal force due to the earth's rotation will be neglected in the immediately following derivation; hence when we refer to the "assumed earth" it will be understood to represent an assumed non-rotating, spherical earth having the same mass as the actual earth, where it is further assumed that the density of matter within the spherical body is a function only of radial distance from the center.

Let

M = mass of earth;

m = mass of test particle whose gravitational potential relative to the surface of the "assumed earth" is to be determined;

R_o = radius of assumed earth;

Z = height of test particle above the surface of the "assumed earth";

g'_o = acceleration due to gravitational attraction at the surface of the "assumed earth" (that is, at radial distance R_o from the center);

g'_r = acceleration due to gravitational attraction at radial distance r from the center of the "assumed earth";

r = radial distance from center at height Z above the surface;

H'_r = geopotential at radial distance r from the center of the "assumed earth," in gpm.;

G = 9.8 m.^{2} sec.$^{-2}$ per gpm.;

W'_o = weight of test particle of mass m when at the surface of the "assumed earth," that is, at radial distance R_o from its center.

and

W'_r = weight of test particle of mass m when at radial distance r from the center of the "assumed earth".

$\dot{V}$ = acceleration, a due to force F.

The units employed for the foregoing will be the same as those used in previous sections for similar data, that is, g'_o and g'_r in m. sec.$^{-2}$; Z and R_o in m.; etc.

Newton came to the conclusion that if a uniform force F acts on a body of constant mass m it will cause the body to undergo uniform acceleration $\dot{V}$, interrelated by the equation

$$F = m\dot{V} = m\ a \qquad (17)$$

By considering weights of a body of mass m at different heights as equivalent to forces acting on the body at these heights and thereby producing accelerations due to gravitational attraction in the case of the assumed earth, it may be concluded on similar grounds that

$$W'_o = mg'_o \qquad (18)$$

and

$$W'_r = mg'_r \qquad (19)$$

By taking the ratio of the latter two equations one obtains

$$\frac{W'_r}{W'_o} = \frac{g'_r}{g'_o}. \qquad (20)$$

Newton inferred his *law of universal gravitation* from Kepler's empirically discovered laws of motions of the planets, and he was thus led to the conclusion that every particle attracts every other particle with a force directly proportional to the product of their masses and inversely proportional to the square of their distance apart. On this basis it could be shown that the "assumed earth" attracts exterior bodies or test particles as though its mass were concentrated at its center. Similarly the weight of a test particle in space outside of the "assumed earth" could be attributed to the action of the law of universal gravitation.

On these grounds (see first paragraph of sec. 2) it follows that

$$\frac{W'_r}{W'_o} = \frac{\left(\dfrac{Mm}{r^2}\right)}{\left(\dfrac{Mm}{R^2_o}\right)} = \frac{R^2_o}{r^2}. \tag{21}$$

By combining the last two equations one finds

$$\frac{g'_r}{g'_o} = \frac{R^2_o}{r^2}, \tag{22}$$

hence

$$g'_r = g'_o\,(R^2_o/r^2). \tag{23}$$

But

$$r = (R_o + Z), \tag{24}$$

so that

$$g'_r = g'_o\,\frac{R^2_o}{(R_o + Z)^2}. \tag{25}$$

We also have

$$H'_r = \frac{1}{G}\int_0^Z g'_r\,dZ \tag{26}$$

according to equation (10), applied to the case of the "assumed earth."

Substituting equation (25) in equation (26) and integrating we obtain

$$H'_r = \left(\frac{g'_o}{G}\right)\left(\frac{R_o Z}{R_o + Z}\right). \tag{27}$$

In the case of the "assumed earth" the quantity g'_o would be a constant independent of latitude; but it is known that the observed acceleration of gravity at the mean sea level surface varies systematically with latitude and is subject to gravity anomalies.[4]

Although we neglect gravity anomalies in the present considerations, we can still take account of the latitudinal variation of the acceleration of gravity for the purpose of seeking an improvement over the result yielded by equation (27) which, as previously indicated, involves the assumption of a constant value of the acceleration of gravity (g'_o) on the "assumed earth." As a first step in making such an improvement, we shall replace g'_o in equation (27) by g_ϕ, which is represented by equation (13) and denotes the acceleration of gravity at mean sea level at latitude ϕ on the ellipsoid of reference. Thus, instead of equation (27) we obtain the better approximation

$$H'_r = \left(\frac{g_\phi R_o}{G}\right)\left(\frac{Z}{R_o + Z}\right) \tag{28}$$

which is a function of latitude.

With a view to securing still a better approximation, the constant radius of the "assumed earth," R_o, could be replaced by the radial distance R_ϕ, which denotes the distance measured from the center of the ellipsoid of reference to a point on its surface at the given latitude, ϕ. Then equation (28) is modified to read

$$H'_r = \left(\frac{g_\phi R_\phi}{G}\right)\left(\frac{Z}{R_\phi + Z}\right). \tag{29}$$

After the author disclosed to W. D. Lambert in January 1949 a comparison of the results yielded by equations (16) and (29), a further improvement in the latter was suggested in 1949 by Lambert[12] along the lines shown by the following development.

We assume in harmony with equation (25) that

$$g'_r = g_\phi\,\frac{R^2_o}{(R_o + Z)^2}. \tag{30}$$

By taking the partial derivative of g'_r with respect to Z and evaluating the derivative for the condition at the surface of the "assumed earth," (that is, for $Z = 0$), we obtain from equation (30)

$$\left(\frac{\partial g'_r}{\partial Z}\right)_{Z=0} = -\frac{2g_\phi}{R_o}. \tag{31}$$

Solving equation (31) for R_o we find

$$R_o = -\frac{2g_\phi}{\left(\dfrac{\partial g'_r}{\partial Z}\right)_{Z=0}} \tag{32}$$

The denominator of the right-hand member of equation (32) is represented by equation (14) which is based on the International Ellipsoid of Reference. Suppose that

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[12] W. D. Lambert, Some notes on the calculation of geopotential; unpublished manuscript, 1949. See also: Smithsonian Meteorological Tables, Sixth Revised Edition, 1951 (pp. 217–223).

when equation (14) is substituted for the denominator term of equation (32) we denote the resultant value of R_o by the symbol R_s. In other words, R_s expresses the value of the right-hand member of equation (32) when the denominator of that member is given by equation (14).

Finally, Lambert suggested that the term R_o in equation (28) be replaced by R_s as just defined, and this procedure yielded

$$H'_r = \left(\frac{g_\phi R_s}{G}\right)\left(\frac{Z}{R_s+Z}\right). \qquad (33)$$

One should note that according to the foregoing definitions both g_ϕ and R_s are functions of latitude, ϕ.

It is remarkable that the values of H'_r yielded by equation (33) are in such close agreement with the values of H yielded by equation (16), as shown by the following table, *which refers to data for latitude 45°*:

Geopotential evaluated by two different equations for a point at latitude 45°

Z (m.)	H'_r based on eq. (33)	H based on eq. (16)	$(H'_r - H)$
	gpm.	gpm.	gpm.
100,000	98,513	98,513	0
200,000	194,021	194,020	+1
300,000	286,659	286,657	+2
400,000	376,555	376,550	+5
500,000	463,829	463,819	+10
600,000	548,594	548,576	+18

Two important factors contribute to this degree of harmony between the results obtained from those two equations; namely, (a) that the same sea-level value of the acceleration of gravity, g_ϕ, is assumed in both cases; and (b) that essentially the same vertical gradient of the acceleration of gravity at mean sea level is assumed in both cases.

Despite the specified agreement between equations (16) and (33), it should be recalled that the latter did not involve taking explicit account of the effect of the vertical component of the centrifugal force due to the earth's rotation; although some degree of allowance for this component was made implicitly by the introduction of the quantities g_ϕ and R_s which depend on latitude and therefore are inherently affected by this force component.

On these grounds we should expect equation (33) to become quickly invalid at great altitudes where the vertical component of the centrifugal force assumes a magnitude approaching that of the gravitational attraction.

6. International Ellipsoid of Reference

The shape and size of the earth are matters of great concern in many fields, such as astronomy, geodesy, mapping, meteorology, navigation, oceanography, surveying, and many others. By employing triangulation to measure the length of an arc between two points on the earth's surface, and by making astronomical observations with telescopes at the points to determine the angle which the arc subtends at the earth's center, it is possible to calculate the radius of the earth pertinent to the arc connecting the two points. When such measurements and calculations are made with regard to arcs covering various ranges of latitude and longitude in different parts of the globe, it is demonstrated that the earth in comparison with a sphere is flattened in polar regions and bulged out in equatorial regions.

This characteristic was predicted by Newton who deduced it theoretically. If one assumes the earth to consist of a fluid of uniform density throughout, theoretical considerations lead to the conclusion that the earth would be an exact ellipsoid of revolution flattened at the poles (that is, oblate). On this assumption the shape of the earth could be produced by rotating a suitable ellipse about its shorter (minor) axis.

However, it is known that the density in the earth varies systematically with depth; hence the figure of the earth is not exactly that of an oblate ellipsoid. The term "*geoid*" is used in referring to the actual figure of the earth as determined on the basis of mean sea level; the latter being extended beneath the continents by a mathematical extrapolation which could be visualized by imagining a grid of narrow sea-level canals to be cut across the land areas from ocean to ocean.

By making use of precise measurements of geodetic triangulation in regard to arc lengths, and astronomical observations in regard to latitude and longitude of numerous pairs of points on the continents, it has been shown that the geoid differs little from an oblate ellipsoid. Similar conclusions have been reached from an investigation based on the distribution of gravity anomalies over the earth's surface.

In order to provide a datum or basis of reckoning for triangulation and astronomical observation, the International Association of Geodesy at its meeting in Madrid in 1924 adopted the so-called "International Ellipsoid of Reference." At the Stockholm meeting in 1930 the International Association of Geodesy adopted the same ellipsoid of reference as a basis for the formula expressing normal gravity at mean sea level as a function of latitude.

Thus, when one attempts to describe the geoid (that is, the actual figure of the mean sea-level surface of the earth), it is extremely useful to employ the International Ellipsoid of Reference as a datum, since the ellipsoid departs from the geoid by only small amounts of the order of 0 to perhaps several hundred meters in extreme cases, either positively or negatively. The utility of the ellipsoid is enhanced by the fact that the perpendicular distance measured from any point on the geoid to the nearest portion of the ellipsoid surface can be calculated, provided that one knows the distribution of gravity anomalies over the entire geoid (that is, the departures of actual gravity from normal gravity over the mean sea-level surface of the globe).[4]

Furthermore, the International Ellipsoid of Reference is a practical necessity to provide a basis for the reckoning of geographic latitude and longitude, used as the system of coordinates for position on the earth. Such coordinates can be determined on the continents by geodetic triangulation and/or astronomical observations. To apply the latter method in general requires a knowledge of the Greenwich Meridian Time. In order to estimate the equatorial radius and the flattening of the earth, assumed to be an ellipsoid in the case of the triangulation-astronomic method, use is made of the observed latitudinal and longitudinal components of the deflections of the vertical, i.e. of the difference between the normal of the geoid, or the plumb line, and the normal of the ellipsoid of reference.

Here, too, the application of the triangulation-astronomic observations to determine geographic position or the size of the earth depends upon the assumption of an ellipsoid of reference. The combination of methods having the most value for all of the various purposes of astronomy, geodesy, geophysics, mapping, etc., involves the use of gravity anomalies as previously explained; astronomic observations to determine latitude, longitude, and azimuth; and triangulation to determine arc lengths.[4] [13]

In order to describe explicitly the International Ellipsoid of Reference and some related parameters it is necessary to define certain terms and symbols pertaining to the ellipsoid as follows (see fig. 12.1.3.1.1):

a = semi-major axis (equatorial radius)

b = semi-minor axis (polar radius)

f = flattening $= (a - b)/a$

ϵ = eccentricity $= \sqrt{a^2 - b^2}/a$

ϕ = geographic latitude

λ = geographic longitude

N = normal to the meridian ellipse at any point, measured perpendicular to the ellipse and terminating where the line intercepts the axis of the ellipsoid

ω = angular velocity of rotation of the earth about its axis
$= 7.292116 \times 10^{-5}$ radian sec.$^{-1}$

x, y, z = geocentric Cartesian coordinates of a point of the International Ellipsoid of Reference; where x is measured parallel to the equatorial plane and in the plane of the Greenwich meridian; y is measured parallel to the equatorial plane but perpendicular to the plane of the Greenwich meridian; and z is measured parallel to the polar axis.

Z = geometric altitude of a point in space above the ellipsoid of reference (measured as a perpendicular distance from the surface of the ellipsoid).

D_0 = AP = radial distance of a point P at latitude ϕ on the surface of the el-

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[13] W. M. Kaula, "Reconciliation of Stokes' Function and Astro-Geodetic Geoid Determinations," Jour. Geophysical Research, vol. 64, pp. 61–71, (1959).

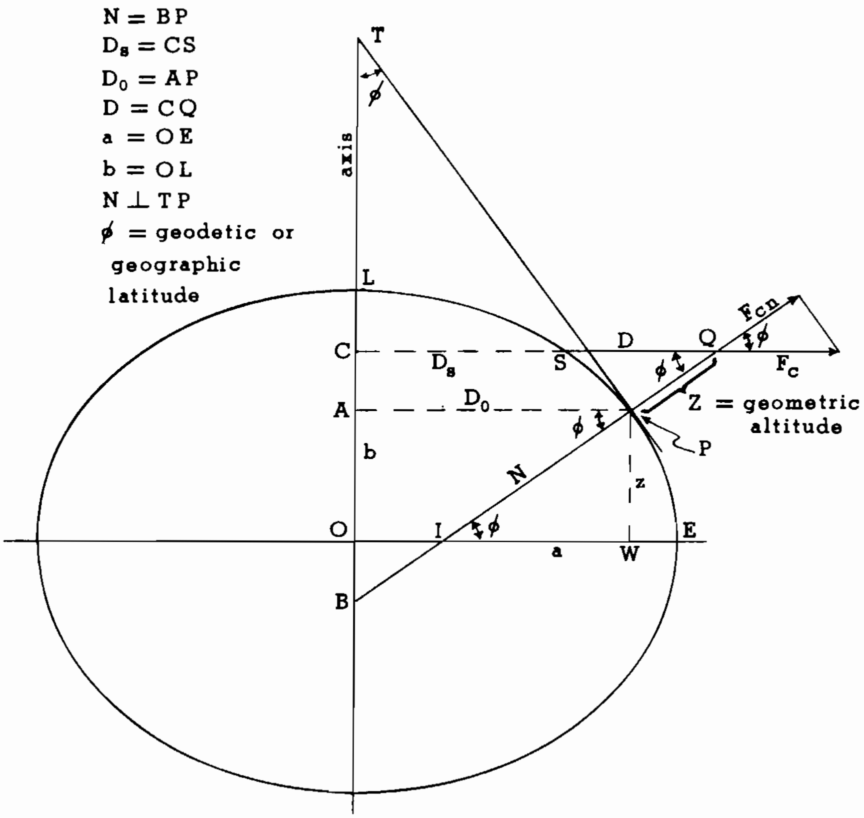

FIGURE 12.1.3.1.1. Meridian ellipse of the International Ellipsoid of Reference (shown with the polar radius compressed to an exaggerated degree in relation to the equatorial radius), illustrating the centrifugal force per unit mass, F_c, and its normal component, F_{cn}, due to the earth's rotation.

lipsoid of reference, where D_o is measured perpendicularly from the polar axis; i.e., D_o is the radius of the parallel in latitude ϕ.

D = CQ = radial distance of a point Q at latitude ϕ at a geometric altitude Z above the ellipsoid of reference, where D is measured perpendicularly from the polar axis.

D_s = CS = radial distance of the point S where the line CQ drawn from point Q perpendicular to the polar axis intersects the surface of the ellipsoid of reference, and C is the point where this perpendicular intersects the axis.

F_c = centrifugal force per unit mass due to the earth's rotation acting on a particle at point Q along the outward extension of line CQ, where Q is at latitude ϕ and geometric altitude Z.

F_{cn} = component of F_c projected on the outward extension of the line BQ passing through the point Q and normal to the ellipsoid of reference.

F_{cno} = value of F_{cn} when the point Q is coincident with the point P on the surface of the ellipsoid of reference at the same latitude; that is, when Z is reduced to zero (0); hence it is the normal outward component of the centrifugal force per unit mass at mean sea level at latitude ϕ.

g_e = acceleration of gravity at the equator on the ellipsoid of reference.

c = $\omega^2 a/g_e$ = ratio of centrifugal force to acceleration of gravity at the equator on the ellipsoid of reference.

The International Association of Geodesy at its meeting in Madrid (1924) adopted the following values of the parameters a and f to specify the *International Ellipsoid of Reference:*

Semi-major axis
(equatorial radius), $a = 6{,}378{,}388$ meters
Flattening, $f = 1/297$ exactly.

On the basis of these specified values and the definition of flattening (f), one calculates the semi-minor axis (polar radius), $b = 6{,}356{,}911.946$ meters.

Fig. 12.1.3.1.1 represents the meridian ellipse (greatly exaggerated) obtained by passing a plane through the polar axis of the ellipsoid of reference, whose center is at O. If P is a point on the ellipsoid at latitude ϕ, we denote by N the normal to the meridian ellipse at that point, where $N = BP$ in fig. 12.1.3.1.1.

By trigonometry the radial distance at P is

$$D_o = N \cos \phi. \qquad (34)$$

The equation of the meridian ellipse is

$$\frac{D_o^2}{a^2} + \frac{z^2}{b^2} = 1. \qquad (35)$$

Since the eccentricity is defined by

$$\epsilon = \sqrt{a^2 - b^2}/a, \qquad (36)$$

one may solve this for b^2 and substitute the result in equation (35), which then yields the equation of the meridian ellipse in the form

$$D_o^2(1 - \epsilon^2) + z^2 = a^2(1 - \epsilon^2). \qquad (37)$$

From equation (37) one finds the slope of the tangent (TP) to the ellipse at P

$$\frac{dz}{dD_o} = -\, D_o(1 - \epsilon^2)/z. \qquad (38)$$

The slope of BP, the normal to the ellipse at P, is the negative reciprocal of the slope of the tangent at P, namely

$$-\frac{dD_o}{dz} = z/D_o(1 - \epsilon^2). \qquad (39)$$

But, the slope of the normal BP is represented by the trigonometric tangent of its angle of inclination (ϕ) to the D_o- or x-axis, hence

$$z/D_o(1 - \epsilon^2) = \tan \phi = \sin \phi/\cos \phi\ . \qquad (40)$$

Therefore, equations (34) and (40) yield

$$z = D_o(1 - \epsilon^2) \sin \phi/\cos \phi = N(1 - \epsilon^2) \sin \phi. \qquad (41)$$

By squaring equation (41) and substituting the expression for z^2 in equation (37), one finds

$$D_o^2 + D_o^2(1 - \epsilon^2) \sin^2 \phi/\cos^2 \phi = a^2. \qquad (42)$$

The solution of equation (42) for D_o gives

$$D_o = a \cos \phi/\sqrt{1 - \epsilon^2 \sin^2\phi}. \qquad (43)$$

By equating (34) and (43) one finds

$$N = a/\sqrt{1 - \epsilon^2 \sin^2 \phi}. \qquad (44)$$

Let us suppose that fig. 12.1.3.1.1 refers to the ellipse in the Greenwich meridian. When the ellipse is rotated about its minor axis through an angle λ, which represents longitude, the point P moves to another position P', and the surface of an ellipsoid of revolution is generated (see fig. 12.1.3.1.2). This ellipsoid may be readily described in any of several geocentric systems of coordinates, including the rectangular Cartesian (x, y, z).

Thus, by virtue of the rotation of the ellipse from the Greenwich meridian through an angle λ, we have for point P'

$$x = D_o \cos \lambda, \qquad (45)$$

and

$$y = D_o \sin \lambda. \qquad (46)$$

By substituting equation (34) in (45) and (46) we obtain

$$x = N \cos \phi \cos \lambda, \qquad (47)$$

and

$$y = N \cos \phi \sin \lambda. \qquad (48)$$

The parameter N is given by equation (44); while the remaining coordinate z is expressed by equation (41). From equation (36) one finds

$$(1 - \epsilon^2) = b^2/a^2; \qquad (49)$$

which, when substituted in equation (41) yields

$$z = N(b^2/a^2) \sin \phi. \qquad (50)$$

The system of equations (47), (48), and (41) or (50) gives the parametric representation of the ellipsoid of reference in term of the geodetic latitude, ϕ, and longitude λ, making use of the parameter N.

Let equation (47) and (48) each be squared and divided by a^2; and let equation (50) be squared and divided by b^2. Then when the resulting expressions are added

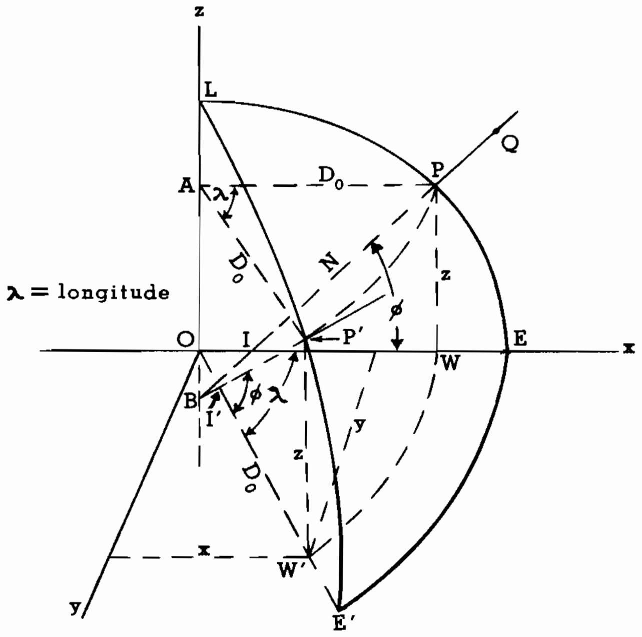

FIGURE 12.1.3.1.2. An illustration of how the ellipsoid is generated by rotating the meridian ellipse about its polar axis.

one obtains after a slight reduction involving the use of equations (44) and (49), the following equation which represents the International Ellipsoid of Reference in geocentric, rectangular Cartesian coordinates:

$$(x^2 + y^2)/a^2 + z^2/b^2 = 1. \qquad (51)$$

It should be pointed out that the values adopted for the semi-major axis, *a*, and the flattening, *f*, are not necessarily the true values, for no person can really know what the true ones are; and besides that, the "best" values in the sense of least squares depend upon the assumptions underlying the evaluation of the relevant astronomic and geodetic data, and upon the method of calculation, as well as upon the data themselves and the procedures employed in regard to their reduction.[4 5 9 13 14 15 16 17]

For example, Jeffreys[5] found

$$a = 6{,}378{,}099 \pm 116 \text{ m.}$$

and

$$1/f = 297.10 \pm 0.36;$$

whereas Chovitz and Fischer[13] when assuming

$$1/f = 297 \pm 1$$

recommend

$$a = 6{,}378{,}260 \pm 100 \text{ m.};$$

while Fischer[15] finds tentatively

$$a = 6{,}378{,}270 \text{ m.};$$

assuming

$$1/f = 297$$

exactly.

7. Effect of Centrifugal Acceleration

As previously indicated, the rotation of the earth about its axis produces a centrifugal force per unit mass (centrifugal acceleration) on any body attached to the earth. If a body of unit mass is at point *P* in fig. 12.1.3.1.1, the centrifugal acceleration is given by $\omega^2 D_o$; and if the body is at the equator, point *E*, the centrifugal acceleration is $\omega^2 a$; where ω is the angular velocity of rotation of the earth about its axis.

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[14] B. Chovitz and Irene Fischer, "A New Determination of the Figure of the Earth from Arcs," Trans. Amer. Geophysical Union, vol. 37, pp. 534–545, (1956).

[15] Irene Fischer, "A Tentative World Datum from Geoidal Heights Based on the Hough Ellipsoid and the Columbus Geoid," Jour. Geophysical Research, vol. 64, pp. 73–84, (1959).

[16] J. A. O'Keefe, Ann Eckels and R. K. Squires, "Vanguard Measurements Give Pear-Shaped Component of Earth's Figure," Science, vol. 129, pp. 565–566, 27 Feb 1959.

[17] H. Jeffreys, "The Reduction of Gravity Observations," The Geophysical Jour. of the Royal Astron. Soc., vol. 2, pp. 42–44, March, 1959.

Now let us consider the centrifugal force per unit mass, denoted by F_c, on a body at any point Q, whose geometric altitude above sea level is Z and whose geographic latitude is ϕ (see fig. 12.1.3.1.1). We assume that the body (or test particle of unit mass) is fixed with respect to geocentric axes, x, y, z, which rotate with the earth (see fig. 12.1.3.1.2).

Accordingly we have

$$F_c = \omega^2 D, \tag{52}$$

where D is the radial distance of point Q from the polar axis (see fig. 12.1.3.1.1), and F_c is directed outward along the extension of CQ, the perpendicular to the polar axis from point Q.

By taking the component of F_c projected on the outward extension of the normal to the ellipsoid, (line BPQ in fig. 12.1.3.1.1), we obtain the normal or vertical *outward* component of the centrifugal force per unit mass, denoted by F_{cn}; determined as

$$F_{cn} = F_c \cos\phi. \tag{53}$$

From fig. 12.1.3.1.1 we find by trigonometry

$$D = (N + Z) \cos\phi, \tag{54}$$

where N is the normal distance at the given latitude ϕ, pertaining to point P at the foot of the perpendicular from point Q to the surface of the ellipsoid. The value of N is expressed by equation (44).

When equations (52), (53), (54), and (44) are combined, one obtains

$$F_{cn} = \omega^2 \left(a/\sqrt{1 - \epsilon^2 \sin^2\phi} + Z\right) \cos^2\phi. \tag{55}$$

If the value of Z in equation (55) is reduced to zero (0), the corresponding value of F_{cn} refers to point P in fig. 12.1.3.1.1, at mean sea level on the ellipsoid surface. Therefore, if we denote F_{cno} as the normal outward component of the centrifugal force per unit mass at mean sea level, it is given by

$$F_{cno} = (\omega^2 a \cos^2\phi)/\sqrt{1 - \epsilon^2 \sin^2\phi}. \tag{56}$$

Substituting equation (56) in (55) we obtain

$$F_{cn} = F_{cno} + \omega^2 Z \cos^2\phi. \tag{57}$$

Let $U_{c\phi}$ denote the contribution to the geopotential at point Q due to the centrifugal acceleration referred to a constant latitude ϕ. Then, if dU_c represents the amount of work which must be *expended* in order to elevate a unit mass by vertical distance dZ under the influence of the normal, vertical outward component of the centrifugal acceleration at the given latitude,

$$dU_{c\phi} = -F_{cn}\, dZ. \tag{58}$$

The minus sign is included in equation (58) for the reason that the component F_{cn} does work on the unit mass instead of requiring work to be done on it during the lifting process, owing to the fact that the component is directed outward along the vertical.

Substituting equation (57) in equation (58), and integrating the latter between the limits from zero (0) to Z in geometric altitude, *while the latitude ϕ is kept constant,* we find

$$U_{c\phi} = - F_{cno}Z - (\omega^2/2) Z^2 \cos^2\phi. \tag{59}$$

The units of $U_{c\phi}$ here will be understood to be m.^{2} sec.$^{-2}$, when Z and a are in meters, and ω in sec.$^{-1}$ In order to convert $U_{c\phi}$ to units of geopotential meters, it should be divided by 9.8.

Let U_{cs} denote the contribution to the geopotential at point Q relative to the geopotential at point S where both geopotentials are due explicitly to the centrifugal acceleration referred to a plane parallel to the equator and passing through the line CSQ in fig. 12.1.3.1.1. Then, if dU_{cs} represents the amount of work which must be expended in order to move a unit mass a distance dD along the radial line SQ outside of the ellipsoid, under the influence of the centrifugal acceleration F_c acting outward along the line CSQ, then

$$dU_{cs} = - F_c dD. \tag{60}$$

The minus sign appears in equation (60) owing to the fact that F_c does work on the mass, rather than requiring an expenditure of energy to displace the unit mass along the line SQ outside of the ellipsoid.

By substituting equation (52) in equation (60) and integrating between the limits of D_s and D, where D_s denotes the radial distance from the polar axis to the surface of the ellipsoid measured along the line CS in fig. 12.1.3.1.1, then

$$U_{cs} = -(\omega^2/2)\ (D^2 - D_s^2). \qquad (61)$$

It should be noted that the points S and Q in fig. 12.1.3.1.1 are at different latitudes. One may evaluate D by means of equation (54); while D_s may be calculated from a somewhat similar relationship, except that $Z = 0$ and that the parameter N and the latitude should be pertinent to the latitude of point S.

The difference between $U_{c\phi}$ and U_{cs} stems from the contribution in work expended due to the centrifugal acceleration while the unit mass undergoes a displacement from the latitude of point P to that of point S along the surface of the ellipsoid. In other words, the contribution in going directly from point P to point Q is equal to the contribution in going from P to S along the ellipsoid *plus* the contribution in going from S to Q. The work expenditure must be the same along any path between two terminal points, since the law of conservation of energy must hold. This conclusion follows from the fact that the field of the potential due to centrifugal acceleration is a function of position, hence it is conservative.

Finally, let U_{cc} denote the contribution to the geopotential at point Q relative to the geopotential at point C where both geopotentials are due explicitly to the centrifugal acceleration referred to a plane parallel to the equator and passing through the line CSQ in fig. 12.1.3.1.1. In other words, U_{cc} represents the contribution to the geopotential due to the centrifugal acceleration and measured relative to the polar axis. Hence, if dU_{cc} is defined in the same manner as dU_{cs}, we have

$$dU_{cc} = -F_c dD. \qquad (62)$$

When equation (52) is substituted in equation (62) and the latter is integrated between the limits of zero (0) and D, which denotes radial distance CQ in fig. 12.1.3.1.1, one finds

$$U_{cc} = -(\omega^2/2)D^2; \qquad (63)$$

or

$$U_{cc} = -(\omega^2/2)(x^2 + y^2), \qquad (64)$$

where x, y represent the geocentric, rectangular Cartesian coordinates of the point Q, hence measured from the polar axis in the plane of the equator.

It should be noted that equations (52), (53), and (55) to (64), inclusive, have been developed under the assumption that the position of the body whose geopotential is under consideration will be determined with reference to a geocentric system of coordinates (x, y, z) as shown in fig. 12.1.3.1.2, in which the z-axis is coincident with the earth's axis, and the system of axes is *rotating* about the earth's axis as though frozen in the earth. However, in situations where one is concerned with a body whose position is determined with reference to an inertial coordinate system, the specified equations do *not* apply; which would be the case to a close degree of approximation if the gravitational potential is required for a free-falling body from outer space, where the position is measured with reference to a fixed, *non-rotating* system of coordinate axes, whose origin is located at the center of earth (for example, system (x, y, z) shown in fig. 12.1.3.1.2 when *not rotating* and rigidly anchored in position with respect to the center of mass of all of the stars of the universe). In the latter case the component of geopotential due to gravitational attraction of the earth on the body will be needed, while the component due to centrifugal force resulting from the earth's rotation will not be pertinent.

APPENDIX 1.4.1

INTERNATIONAL BAROMETER CONVENTIONS

The following recommendation was adopted in 1953 at the first session of the Commission for Instruments and Methods of Observation of the World Meteorological Organization,[1] and this recommendation was approved by the Executive Committee of the World Meteorological Organization in the same year, to take effect on 1 January 1955:[2]

Recommendation No. 9 (CIMO-I)—International Barometer Conventions

The COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATION,

NOTING,

(1) The disparity which exists between the definitions of units of pressure used by some Meteorological Services and by physical scientists as a whole;

(2) The several temperatures at which the scales of various makes of mercurial barometers have been standardized;

(3) The different methods employed for the determination of local acceleration of gravity;

(4) The various techniques used by Meteorological Services in connection with the reduction of barometric readings to a gravity datum; and

(5) The discrepancy which exists between the gravity datum used by many Meteorological Services and the standard (normal) gravity adopted by the International Committee on Weights and Measures, which is universally accepted by physical scientists;

REALIZING the need to eliminate the discrepancies and different practices through the international adoption of a single system of barometer conventions; and

CONSIDERING,

(1) That the system must be in accord with the best value of physical and geodetic functions, constants or parameters, so that it will commend itself both to meteorologists and physical scientists, thus having a better chance of receiving universal acceptance; and

(2) That the system of barometer conventions embodied in the Annex was developed as a result of co-ordinated activity and exchange of ideas by various authorities in regard to the subject;

RECOMMENDS,

(1) That the system of international barometer conventions outlined in the Annex shall form the basis for the definitions of pressure units and methods of evaluating mercurial barometer readings used by the Meteorological Services of the Members; and

(2) That the attention of the Members be invited to the provisions in the Annex which imply that new procurements of barometers shall be in accord with the international barometer conventions so far as they relate to the scales and scale units of the instruments; while at the same time realizing that old instruments not in accord with those conventions may be continued in service, provided that before being reported their readings shall be properly corrected to agree with the new conventions, taking proper account of any significant deviation of their scales from the new standards specified in the Annex.

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[1] World Meteorological Organization, Commission for Instruments and Methods of Observation, "Abridged Final Report of the First Session," Toronto, 10th August-4th September 1953, WMO—No. 19 RP. 9, Secretariat of the World Meteorological Organization—Geneva, Switzerland. (See Recommendation No. 9, (CIMO-I), pp. 73-78.)

[2] World Meteorological Organization, Fourth Session of the Executive Committee, Geneva, 6th-26th October 1953, "Abridged Report With Resolutions," WMO—No. 20 RC. 5, Secretariat of the World Meteorological Organization—Geneva, Switzerland. (See Resolution 48 (EC-IV), pp. 88-89.)

ANNEX

INTERNATIONAL BAROMETER CONVENTIONS

(I) Standard temperature and density of mercury

The value of 0° C shall be the standard temperature to which mercurial barometer readings are reduced for the purpose of relating actual density of mercury at its observed temperature to the standard density of mercury at 0° C.

The standard density of mercury at 0° C. (symbol $\rho_{Hg,o}$) shall be considered to be 13.5951 grams per cubic centimeter; and, for the purposes of calculating absolute pressures by means of the hydrostatic equation, the mercury in the column of a mercurial barometer shall be regarded conventionally as an incompressible fluid.

(II) Standard (Normal) gravity

Barometric readings shall be reduced from local acceleration of gravity to standard (normal) gravity. The value of standard (normal) gravity (symbol g_n) shall be regarded as a conventional constant,

$$g_n = 980.665 \text{ cm/sec}^2.$$

Note—This is recognized by scientists as a gravity datum to which reported barometric data in mm. or inches of mercury shall refer, but it does *not* represent the value of gravity at latitude 45°, at sea level.

(III) Pressure units

(a) The *millibar*, defined as a unit of pressure equal to 1000 dynes/cm.^{2}, shall be the unit in which pressures are reported for meteorological purposes.

(b) In accordance with the provisions of paragraphs (I) and (II), a column of mercury at a standard temperature of 0° C. when subjected to an acceleration of gravity equal to standard (normal) gravity, $g_n = 980.665$ cm./sec.^{2}, may be regarded as representing pressure due to the weight of mercury on a unit cross-section area (one square centimeter). When the mercury column under these standard conditions of temperature and gravity has a *true* scale height of one millimeter, it shall be considered to represent a unit of pressure called "one millimeter of mercury under standard conditions", a symbol "$(\text{mm Hg})_n$". When it is clear from the context that standard conditions are implied, the briefer term "millimeter of mercury" may be used in reference to this unit. In view of the provisions of paragraphs (I), (II), and (IIIa), a column of mercury having a true scale height of 760 millimeters when subjected to standard conditions of temperature and gravity yields a pressure of 1013250 dynes/cm.^{2} = 1013.250 mb.

Consistent with the foregoing the following conversion factors obtain

$$1 \text{ millibar} = 0.750062\ (\text{mm Hg})_n$$

$$1\ (\text{mm Hg})_n = 1.333224 \text{ mb.}$$

(c) Analogous to the case outlined above under (b), "one inch of mercury under standard conditions", symbol "$(\text{in.Hg})_n$", shall refer to the pressure due to the weight of mercury, per unit cross section area when the column has a true scale height of one inch, *provided* the mercury is at the standard temperature of 0° C. (32° F.) and it is subjected to an acceleration of gravity equal to the standard (normal) value, $g_n = 980.665$ cm./sec^2.

When it is clear from the context that standard conditions are implied, the briefer term "inch of mercury" may be used in reference to this unit.

In cases where the conventional engineering relationship between the inch and millimeter is assumed, namely 1 inch = 25.4 millimeters, the following conversion factors obtain:

$$1 \text{ mb} = 0.0295300\ (\text{in.Hg})_n$$

$$1\ (\text{in.Hg})_n = 33.8639 \text{ mb}$$

$$1\ (\text{mm Hg})_n = 0.03937008\ (\text{in.Hg.})_n$$

(d) When pressure data are issued, preference shall be given to expressing them in millibars; but if they are required in other units they should be given preferably in standard units as outlined under (b) and (c) above; that is, either in "$(\text{mm Hg})_n$" or in "$(\text{in.Hg})_n$", as the case may be.

(IV) Mercurial barometer scales and standard instrumental conditions

Except for mercurial barometers, still serviceable and graduated with scales on a different basis than that outlined below, scales on mercurial barometers shall be graduated so that they yield true pressure readings directly in standard units as defined under paragraph III when the entire instrument is maintained at the standard temperature of 0° C and at the standard (normal) value of gravity, $g_n = 980.665$ cm./sec^2.

It will be understood that the foregoing recommendation implies that the scales of Fortin barometers graduated in millimeters or inches shall yield true linear readings when the scale is maintained at a temperature of 0° C, except possibly for the case of barometers referred to in the first clause of the preceding paragraph.

Mercurial barometers having scales engraved so as to yield standard units of pressure as prescribed in paragraph III when the instrument is maintained at the standard conditions of temperature and gravity specified under paragraphs (I) and (II) should have inscribed on the barometer scale (s) whichever of the following legends are appropriate:

(1) "True mb at 0° C and 980.665 cm/s^2"

(2) "True (mm Hg)$_n$ at 0° C and 980.665 cm/s^2"

(3) "True (in. Hg)$_n$ at 0° C and 980.665 cm/s^2"

Barometers may have more than one scale engraved on them; for example, mb and (mm Hg)$_n$, or mb and (in.Hg)$_n$, provided the conditions specified above are fulfilled.

(V) Recommended practices for reducing mercurial barometer readings to standard gravity

The following practices are recommended for reducing such barometer readings to standard gravity:

Let:

B = observed reading of mercurial barometer;

B_1 = barometer reading reduced to standard temperature but not to standard gravity, and corrected for instrumental errors;

B_n = barometer reading reduced to standard gravity and standard temperature, and corrected for instrumental errors;

B_{ca} = climatological average of B_1 at the station;

$g_{\phi,H}$ = local acceleration of gravity (in cm./sec.^{2}) at a station at latitude ϕ and elevation H above sea level and given according to the "Meteorological Gravity System"; (see paragraph VI);

g_n = standard acceleration of gravity—980.665 cm./sec.^{2}

The following relations or the equivalent are appropriate:

$$B_n = B_1 \frac{g_{\phi,H}}{g_n}, \text{ or} \qquad (1)$$

$$B_n = B_1 + B_1 \left[\frac{g_{\phi,H}}{g_n} - 1\right] \qquad (2)$$

The approximate equation (3) given below may be used, provided that the result given by it does not differ by more than 0.1 mb. from the result that would be obtained with the aid of equation (2):

$$B_n = B_1 + B_{ca} \left[\frac{g_{\phi,H}}{g_n} - 1\right] \qquad (3)$$

approximately.

(VI) Determination of local acceleration of gravity

The value of $g_{\phi,H}$ required for reducing mercurial barometer readings to standard gravity, as explained in paragraph V above, shall be ascertained in accordance with the provisions of the Annex to the Recommendation 10 [see chapter 3]:

"Determination of local acceleration of gravity", based on the "Meteorological Gravity System".

(VII) Standard instrumental conditions for mercurial barometers bearing altitude scales

Except for mercurial barometers still serviceable and graduated with scales on a different basis than that outlined below, mercurial barometers that bear a scale representing altitudes corresponding to pressures in accordance with some specified standard atmosphere shall have the scale graduated so that it will indicate the assumed pressure-altitude relationship when the entire instrument is maintained at the standard temperature of 0° C. and at the standard (normal) value of gravity, $g_n = 980.665$ cm./sec^2.

Barometers bearing scales satisfying these standard conditions should have inscribed on the scales an inscription of the following character:

"True - - - - pressure-altitude

at 0° C, 980.665 cm/sec^2"

where there is inserted in the blank space the standard on which the pressure-altitude relationship is based, for example, ICAO.

APPENDIX 1.4.2

Basic Principles Relating to Combination of the Corrections of the Fortin-Type Mercurial Barometer for Instrumental Error, Gravity, and Temperature

Consider two, wide-bore U–tube mercurial barometers under local and standard conditions, respectively, as depicted in fig. 12.1.4.2.1. Atmospheric pressure (P, in dynes/cm.^{2}) is assumed to be equal in the two cases. A vacuum is maintained at the top of each tube by means of a connection to a diffusion pump as indicated in fig. 12.1.4.2.1; and this portion of the tube may be considered to serve the same function as the upper closed part of the tube in a conventional Fortin or syphon barometer where an evacuated space exists. Effects of capillarity may be made negligible by using tubes whose bore is say 4.0 cm. or more in diameter, and by vibrating the column to equalize the meniscuses before each observation. Actual heights of the columns of mercury (B_a under local conditions, and B_o under standard conditions) are assumed to be measured by perfect scales, not subject to any temperature effects. Thus, the weights of the columns of mercury B_a and B_o are regarded as balanced against the atmospheric pressure which exists under the local conditions, and which sustains the columns by pressing upon the exposed surfaces of the mercury in the lower arms of the U–tubes.

We use the following notation:

P = local atmospheric pressures in dynes/cm.^{2} (1000 dynes/cm.^{2} = 1 millibar);

g_l = local acceleration of gravity, in cm./sec.^{2}; (Note: Chapter 3 explains methods for determining g_l).

ρ = density of pure mercury in grams/cm.^{3} at temperature t° C. under local conditions;

B_a = actual height of column of pure mercury, in cm., at temperature t° C. which balances against local atmospheric pressure (P);

g_o = standard acceleration of gravity = 980.665 cm./sec.^{2};

ρ_o = standard density of pure mercury at temperature 0° C;

ρ_o = 13.5951 grams/cm.^{3} by international agreement (see Appendix 1.4.1);

B_o = actual height of column of pure mercury, in cm., which would balance against pressure P if the entire column of mercury were at the standard temperature 0° C. under standard gravity g_o (980.665 cm./sec.^{2}). (Note: B_o is generally called "barometer reading reduced to standard conditions" or "barometer reading reduced to standard gravity and temperature.")

Regarding mercury as an uncompressible fluid, the hydrostatic equation yields the following relationships under the conditions specified above.

$$\rho g_l B_a = P = \rho_o g_o B_o \qquad (1)$$

Let

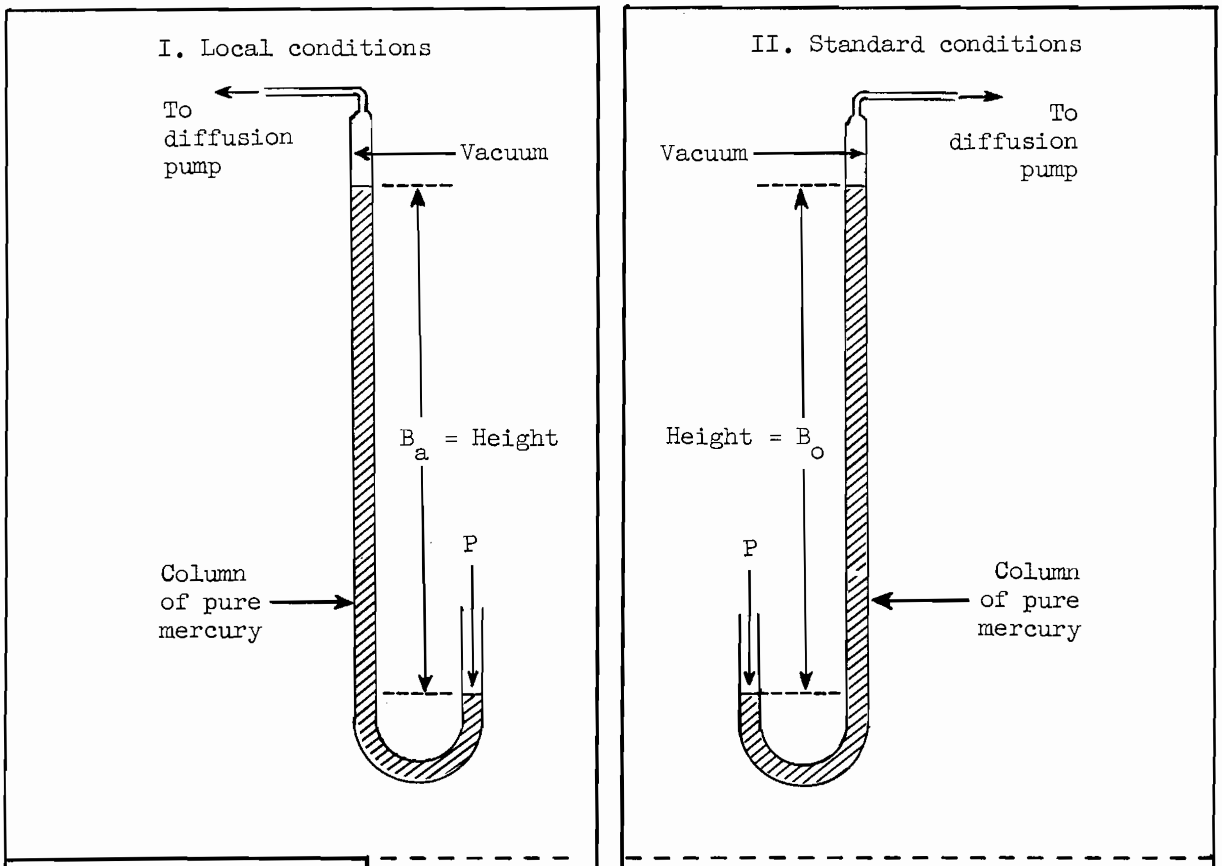
m = coefficient of cubical thermal expansion of mercury representing the relative change of volume with respect to temperature on the Celsius scale (m = 0.0001818 per °C.);

t = temperature of the mercury, in °C.,

then (see sec. A–2.5)

$$\rho/\rho_o = 1/(1 + mt) \qquad (2)$$

Suppose that the reading of a Fortin-type barometer with a brass scale were observed simultaneously with the primary barometers depicted in fig. 12.1.4.2.1. Let B = observed reading of the barometer, in cm., on the scale at temperature t° C., and let K_i = correction of the barometer reading for instrumental errors. Thus, K_i includes a correction for the error of location of the zero of the scale, and also a correction for capillarity (since capillarity tends to produce a depression of the mercury column).



	Local values	Standard values
Acceleration of gravity	g_1	$g_o = 980.665$ cm/sec^2
Temperature of mercury	t° C.	$t_o = 0°$ C.
Density of mercury	ρ gram/cm^3	$\rho_o = 13.5951$ gram/cm^3
Actual height of column	B_a	B_o = barometer reading reduced to standard conditions

General conditions: bore of tubes taken sufficiently large so that capillarity effects are negligible; and mercury free from impurities.

FIGURE 12.1.4.2.1. Primary barometers subjected to equal atmospheric pressure (P) under local and standard conditions, respectively.

In general the value $(B + K_i)$ is not equal to the actual height B_a, depicted in the figure, owing to the fact that the brass scale at temperature t (say 20° C.) is expanded with respect to the perfect scale free from temperature effects with which we have assumed B_a was measured. It is therefore necessary to find a relationship between $(B + K_i)$ and B_a. Suppose that the brass scale were graduated so that it read accurately on an absolute basis when at a temperature t_a in °C. Then, if we let l_a = coefficient of linear thermal expansion of the brass scale, representing the relative change of length of the scale with respect to temperature on the Celsius scale, for a scale accurate at temperature t_a °C, we find

$$B_a = (B + K_i)\ [1 + l_a(t - t_a)] \qquad (3)$$

The physical justification for equation (3) may be visualized by considering a uniform scale graduated on an elastic rubber band from which a reading $(B + K_i)$ is made at a given mark after the band is stretched. The actual distance of the mark above the zero of the scale is then B_a, provided the stretching factor is represented by the term in square brackets, depending on the stress.

In the case where $t_a = 0°$ C. in the foregoing expression, the term l_a must be replaced by l, which refers to a scale accurate at 0° C.; and in this event equation (3) becomes

$$B_a = (B + K_i)\ [1 + lt], \qquad (4)$$

where the relationship between l_a and l is given by the equation

$$l_a = \frac{l}{1 + lt_a} \qquad (5)$$

[Note: The last equation is easily demonstrated as follows: If a scale has a length L_o at 0° C., L_a at temperature t_a° C., and L at temperature t° C., then in accord with eq. (4) $L = L_o\ (1 + lt)$, and

$$L_a = L_o\ (1 + lt_a).$$

By dividing the first of these equations by the second we obtain

$$L/L_a = (1 + lt)/(1 + lt_a).$$

Compatibly with eq. (3) we desire l_a to have the property necessary to satisfy the equation

$$L/L_a = 1 + l_a\ (t - t_a).$$

On equating the last two expressions and solving for l_a, we obtain eq. (5).]

Laboratory experiments on typical specimens of brass scales show that for average purposes we may take $l = 0.0000184$ per °C., although individual specimens of brass may yield a coefficient that differs from this value by as much as 10%, depending upon the metal alloy. On this basis, if $t_a = 16.67°$ C. (62° F.), and we were to assume precision sufficient to yield $l = 0.000018400$ per °C., then $l_a = 0.000018394$ per °C. as calculated by means of eq. (5). Since this degree of precision is not warranted, we may consider the same rounded value for l and l_a, namely, 0.0000184 per °C. Solving eq. (1) for B_o we find

$$B_o = \frac{\rho}{\rho_o} \cdot \frac{g_l}{g_o} B_a. \qquad (6)$$

Substituting equations (2) and (3) in eq. (6) we obtain

$$B_o = \frac{g_l}{g_o}\ \frac{[1 + l_a(t - t_a)]}{(1 + mt)}\ (B + K_i). \ (7)$$

We find the identities

$$\frac{1 + l_a(t - t_a)}{(1 + mt)} = \left[1 - \frac{mt - l_a(t - t_a)}{(1 + mt)}\right] (8)$$

and

$$\frac{g_l}{g_o} = \left[1 + \frac{g_l - g_o}{g_o}\right]. \qquad (9)$$

Substituting eqs. (8) and (9) in (7), we obtain

$$B_o = \left[1 + \frac{g_l - g_o}{g_o}\right]\left[1 - \frac{mt - l_a(t - t_a)}{(1 + mt)}\right] \times\ (B + K_i) \qquad (10)$$

for temperatures in °C., and scale accurate at temperature t_a. When $t_a = 0°$ C., as is conventional for barometers expressed in metric measures, eq. (10) reduces to

$$B_o = \left[1 + \frac{g_l - g_o}{g_o}\right]\left[1 - \frac{(m - l)t}{(1 + mt)}\right] \times\ (B + K_i) \qquad (11)$$

for metric measure Fortin barometers, and temperatures in °C.

When B, K_i, and B_o are expressed in inches, and temperatures are in degrees Fahrenheit, the quantities t and t_a in the foregoing expressions must be replaced by $(t - 32°\text{ F.})$ and $(t_a - 32°\text{ F.})$ respectively; and m and l (or l_a) under these conditions assume values 5/9 as great as they have, respectively, when the temperatures are on the Celsius scale.

Thus, in the case of Fortin barometers in English measures, we may rewrite eq. (10) as

$$B_o = \left[1 + \frac{g_l - g_o}{g_o}\right] \times \left[1 - \frac{m(t - 32°\text{ F.}) - l_a(t - t_a)}{1 + m(t - 32°\text{ F.})}\right] \times (B + K_i) \qquad (12)$$

for temperatures in °F., where

$m = 0.000101$ per °F., and
$l_a = 0.0000102$ per °F.

With regard to English measure Fortin barometers constructed prior to the implementation of the "International Barometer Conventions" (see Appendix 1.4.1), it was the practice to take $t_a = 62°$ F. After those Conventions are put into effect, it will be necessary to graduate the scales so that $t_a = 32°$ F. In that event eq. (12) reduces to

$$B_o = \left[1 + \frac{g_l - g_o}{g_o}\right] \times \left[1 - \frac{(m-l)\,(t - 32°\text{ F.})}{1 + m(t - 32°\text{ F.})}\right] \times (B + K_i) \qquad (13)$$

for Fortin barometers graduated with scales accurate at 32° F., and temperatures given in degrees Fahrenheit, for which

$m = 0.000101$ per °F., and
$l = 0.0000102$ per °F.

Inspection of equations (10), (11), (12) and (13), reveals that the term in the second brackets involves the value unity (1) minus a function of temperature, depending upon the units of temperature (t) and upon the temperature (t_a) at which the scale is accurate. We may denote this function by the symbol $f(t, t_a)$ with the understanding that it is expressed in a manner that depends upon the appropriate conditions, as explained in particular with regard to equations (10), (11), (12) and (13).

Thus, those equations may be expressed in a general form as

$$B_o = \left[1 + \frac{g_l - g_o}{g_o}\right]\left[1 - f(t, t_a)\right] \times (B + K_i). \qquad (14)$$

In order to abbreviate the notation, denote $c \equiv \frac{g_l - g_o}{g_o}$ and $f \equiv f(t, t_a)$, as previously explained (see secs. 5.1 and 5.3); then eq. (14) may be written

$$B_o = (1 + c)(1 - f)(B + K_i), \qquad (15)$$

or,

$$B_o = [(1 + c)(B + K_i)]\,(1 - f). \quad (16)$$

Thus,

$$B_o = [(B + K_i) + c(B + K_i)]\,(1 - f) \qquad (17)$$

The term $c(B + K_i)$ is the correction for gravity applicable to the barometer reading corrected for instrumental error, that is, $(B + K_i)$. In view of the smallness of c (see Chapter 3) and the smallness of the relative variations in $(B + K_i)$ at a fixed station, it is sometimes the practice to replace the term $c(B + K_i)$ by the constant cB_x where B_x = normal annual value of the observed reading of the barometer (sufficiently accurate since K_i is negligible in comparison with B_x).

Clearly, if the variations of $c(B + K_i)$ from the assumed value of cB_x are of the same order of magnitude as, or smaller than, the errors in reading or setting the Fortin barometer, it is safe for practical purposes to replace $c(B + K_i)$ by cB_x. In that case eq. (17) becomes

$$B_o = [(B + K_i) + cB_x]\,(1 - f) \qquad (18)$$

to a close degree of approximation.

Denote

$$B_1 = [(B + K_i) + c(B + K_i)] = [(B + K_i) + cB_x] \text{ approximately,} \qquad (19)$$

which represents the barometer reading corrected for instrumental error and gravity.

Then eqs. (17) and (18) may be rewritten

$$B_o = B_1(1 - f) = B_1 - B_1 \cdot f \qquad (20)$$

where the term $-B_1 \cdot f$ involves the correction for temperature applicable to the barometer reading corrected for instrumental error and gravity, that is, B_1.

It is evident from eq. (15) that an alternative method of dealing with the corrections is to reverse the order, as shown by the equations

$$B_o = [(1 - f)\,(B + K_i)]\,(1 + c) \quad (21)$$

$$B_o = [(B + K_i) - (B + K_i)f]\,(1 + c), \qquad (22)$$

where $-(B + K_i)f$ represents merely the correction for temperature applicable to the barometer reading corrected for instrumental error, that is, $(B + K_i)$. Hence if B_{ct} denotes the barometer reading corrected jointly for instrumental error and temperature, we have

$$B_{ct} = [(B + K_i) - (B + K_i)f], \quad (23)$$

so that on substituting eq. (23) in (22) we obtain

$$B_0 = B_{ct}\ (1 + c) = B_{ct} + B_{ct} \cdot c \quad (24)$$

where the term $+B_{ct} \cdot c$ involves the correction for gravity applicable to the barometer reading corrected jointly for instrumental error and temperature, (B_{ct}).

It should be noted that equations (17) and (22), or (20) and (24) yield equally valid methods of applying the corrections, if one disregards the approximation determined by the last term in brackets contained in equation (19).

Useful results of a closely approximate character may be obtained from the relationships given above. To single out one of these, first let B_n = the normal annual value of B_{ct}. This may be interpreted as the normal annual value of the barometer reading corrected jointly for instrumental error and for temperature, but not corrected for gravity. Now let B_n replace the quantity B_{ct} in the last term of equation (24); then this expression may be rewritten

$$B_0 = B_{ct} + B_n \cdot c, \text{ approximately.} \quad (25)$$

When equation (23) is substituted in (25), one obtains

$$B_0 = B + (K_i + B_n \cdot c) - (B + K_i)f, \text{ approximately.} \quad (26)$$

Cognizance may now be taken of the fact that the correction for instrumental error, K_i, in ordinary meteorological practice is very small in comparison to the barometer reading, B. Therefore, one may generally neglect the term $-K_if$ in relation to the term $-Bf$; hence, on this basis equation (26) may be replaced by the nearly equivalent expression

$$B_0 = B + (K_i + B_n \cdot c) - Bf, \text{ approximately.} \quad (27)$$

In order to gain some idea of the degree of the approximation involved in equation (27), one may consider the case where $K_i = 0.7$ mb. and $B = 1000$ mb., when the temperature of the barometer is 35° C. (95° F.). Assuming that the scale of the barometer is true at 0° C., one finds that $Bf = 5.68$ mb., while $K_if = 0.004$ mb., which is negligible. With regard to the term $(K_i + B_n \cdot c)$, it will be noted that the strictly accurate value should be $(K_i + B_{ct} \cdot c)$; hence, the error in the former is $(B_n - B_{ct})c$. With a view to obtaining an idea of the magnitude of this error, let us suppose that during a hurricane the value of $(B_n - B_{ct})$ becomes 100 mb., which must occur very rarely. The factor c depends upon the latitude and the height of the station above sea level. To consider some specific cases suppose that one has sea level stations at four latitudes as indicated in the following: thus at latitude 15°, $c = -0.002329$; at latitude 30°, $c = -0.001367$; at latitude 45°, $c = -0.000050$; and at latitude 60°, $c = +0.001271$. Thus, one finds the following results in regard to the error $(B_n - B_{ct})c$ for the specified locations under the assumption that the factor in parentheses is 100 mb.: at latitude 15°, error = -0.23 mb.; at latitude 30°, error = -0.14 mb.; at latitude 45°, error = -0.005 mb.; and at latitude 60°, error = $+0.13$ mb. More frequently, the factor in parentheses is less than about 35 mb., hence, most of the time the error is less than one-third of the values just given.

From the foregoing examples one may draw the following conclusions: (a) In proceeding from equation (26) to equation (27) by dropping the term $-K_if$ only a negligible error is committed, provided the instrumental correction, K_i, is small in comparison to the barometer reading, B, as is usually the case in meteorological practice; however, the stated conclusion might not be valid when this proviso is not fulfilled, as could be the case in the calibration of altimeters or other work at low pressure where a mercury barometer is used for observational purposes. (b) The employment of the factor B_n in place of B_{ct} in equations (25), (26), and (27) constitutes an approximation, which yields satisfactory results for routine meteorological observational purposes in middle latitudes, where the gravity correction factor c is relatively small; however, at high or low latitudes where the absolute value of the factor c is significantly greater, the approximation may not be considered satisfactory for scientific work of the highest degree of absolute accuracy. For that type of work it would be desirable to revert to the use of the accurate equations, such as (17) and (22); or to employ equation (26) suitably revised by the application of the factor B_{ct} instead of B_n.

Equation (27) represents the basis on which the "Total Correction Table," described in sec. 5.4 of this Manual, is established (see Table 5.4.1, Chapter 14). It will be seen from the equation that the quantity $(K_i + B_n \cdot c)$ is a constant. If a constant "removal correction" as defined in Chapter 4 is utilized at a meteorological station to reduce pressure from the actual elevation of the barometer (H_z) to the adopted station elevation (H_p), then such a correction may be added algebraically to the quantity $(K_i + B_n \cdot c)$, yielding another constant, which we term "sum of corrections," denoted by the symbol K_r (see the examples in Chapter 5, and the Barometer Correction Card, shown in fig. 3.3.0). In that event the "sum of corrections" represents the algebraic sum of the corrections for instrumental error (K_i), for gravity $(B_n \cdot c)$, and for removal; also a "residual correction" may be included, if necessary (see sec. 4.4). An inspection of equation (27) reveals that when the term $(K_i + B_n \cdot c)$ is replaced by the "sum of corrections" as just defined, the atmospheric pressure (B_o) at the station elevation (H_p) may be regarded as a linear function of the observed reading (B) of the Fortin barometer, at any given temperature (t) of the barometer, assuming routine meteorological observations in which K_i is very small in relation to B. This result permits the construction of the "Total Correction Table," No. 5.4.1, applicable to the case where the "sum of corrections" (K_r) can be treated as a constant. In such a case the quantity $(K_r - Bf)$ is to be entered as a result beside the pertinent temperature correction $-Bf$ already tabulated in a column at the side of Table No. 5.4.1. That table is designed to eliminate the need for interpolation with respect to the variable B. Tables 5.2.1, 5.2.2, and 5.2.3 also present the correction for temperature, $-Bf$, but these require interpolation.

With regard to the gravity correction for mercurial barometers $(B_n \cdot c)$ as defined above, information is provided in Chapter 3 to permit determination of the gravity factor c; and Tables 3.1.1, 3.1.2, 3.2.1, 3.2.2, 3.2.3, 3.3.1, 3.3.2 are relevant to this subject.

Information concerned with methods for determining the correction for instrumental error (K_i) is given in Chapter 6; and in particular the correction for capillary depression is dealt with in sec. 2.7.1 and fig. 2.7.0. See also sec. 2.7.0, et seq., relating to the various sources of instrumental error.

The question of units in terms of which the barometer scale is read and of units of pressure frequently poses problems. Three systems for graduating the barometer scale are in general use: inches, millimeters, and so-called "millibars." It is important to distinguish between readings of the scale in linear units of this character, and values of atmospheric pressure in terms of real pressure units (see sec. 1.4). Thus, a reading (B) of the mercury barometer scale without any correction being applied to it cannot be regarded as a pressure (B_o), which is a fact clearly seen from equation (7), for example. According to equations (23)—(26), strictly speaking, one obtains the required atmospheric pressure (B_o) in true pressure units only after the corrections for instrumental error (K_i), for gravity $(B_{ct} \cdot c)$, and for temperature $-(B + K_i)f$, are applied to the observed reading of the Fortin barometer (B), although as pointed out above the term $-K_i f$ is generally neglected in meteorological practice.

A first consideration which must always be safeguarded in reference to units is consistency. Thus, if the barometer scale reading (B) is in inches, the various pertinent corrections must also be obtained in the same units; and after the corrections have been applied to B, one secures the atmospheric pressure (B_o) in *inches of mercury under standard conditions*, abbreviated (in. $\mathrm{Hg})_n$, or more simply (in. Hg), where it will be understood that normal standard conditions are assumed. Similarly, if the reading B is in millimeters, the corrections must be in the same terms; and then the value B_o under the given assumptions *will* be in *millimeters of mercury under standard conditions,* abbreviated (mm. Hg)$_n$, or more simply (mm. Hg), provided it is understood that normal standard conditions are taken as the basis for the data. In all of these cases, the following will be understood as (normal) standard conditions: (A) the temperature of the mercury under standard conditions is 0° C.(32° F.); (B) the standard acceleration of gravity (g_o) is 980.665 cm./sec.^{2}; (C) the mercury under standard conditions is regarded as an imcompressible fluid, having a density of 13.5951 grams/cm.^{3}, (designated previously by ρ_o). (See Appendix 1.4.1 for details.)

In the case of data based on readings of a mercury barometer graduated in so-called "millibars" (see figs. 2.4.2 and 2.4.3), it will be apparent that a distinction must be made between the linear unit used in graduating the scale (where 1 "millibar graduation" = 0.750062 millimeter), and the true pressure unit termed *millibar,* which has been defined as a pressure equal to 1000 dynes per square centimeter. As pointed out elsewhere, atmospheric pressure (B_o) is now generally expressed on the basis of the latter unit (*millibar*). The relationships derived above reveal that true pressure in these units is obtained from the data only after all of the necessary corrections have been applied to the readings in "millibar graduations" consistent with the relevant equations, such as (23)—(27).

An advantage of the barometer having a scale with "millibar graduations" is that it permits elimination of the need to convert the obtained pressure data from inches or millimeters of mercury to millibars. We are enabled to gain this advantage in view of the fact that the corrections for gravity and temperature are both proportional to certain barometric data (see for example equations (23) and (24)). Thus, the units of length involved in the scale reading determine the relative magnitudes of the corrections. It follows that any need to perform a conversion (as from millimeters of mercury to millibars) is obviated if the factor employed to convert from the length of 1 millimeter to the length of a "millibar graduation" is exactly the same as the factor valid for conversion from the pressure unit of *1 millimeter of mercury under standard conditions* to the pressure unit of *1 millibar* (1000 dynes/cm.^{2}). Conversion factors between various units of pressure and length, respectively, have already been given in sec. 1.4. For further information regarding the derivation of the conversion factors relating to pressure units the reader should consult the last two paragraphs of this Appendix.

There is another useful consequence of the fact that the corrections of the Fortin mercury barometer for gravity and temperature are proportional to certain barometric data such as ($B + K_i$) or approximately B, as indicated above. This consequence is that the same correction tables are valid both for barometers having scales with millimeter graduations and those with "millibar graduations," provided that in the case of the tables giving the correction for temperature the value of the parameter t_a used in computing the tables is the same as the temperature at which the scale of the barometer reads true units of length (see sec. 5.2).

It is sometimes necessary to apply the result indicated in the last paragraph when the available correction tables are based on units different from those in which the barometer is graduated. This may be illustrated by a particular example for which we assume that the parameter $t_a = 0°$ C. in the construction of the temperature correction tables and that this is the value of temperature at which the scale reads true. Now consider an observation yielding the following results: Observed reading of the attached thermometer 10° C.(50° F.); and observed reading of the barometer scale 1000.0 "millibar graduations." For these conditions, Table 5.2.2 yields a correction for temperature of −1.63 mb. Similarly, Table 5.2.3 indicates a correction of −.049 inch when the barometer scale reading is 30.00 inches for the same given temperature. The proportion of the scale reading, B, in the two cases is 1000/30; hence if one multiplies the latter correction (−0.049 inch) by the factor 1000 mb./30 inches, one obtains the appropriate correction −1.63 mb., which agrees with that obtained from Table 5.2.2. Sometimes this procedure will yield *slightly dif-*

ferent results owing to rounding of the tabular data.

[*Caution:* If t_a pertinent to the scale of a given barometer is not the same as the value of t_a on whose basis the table was constructed, the table should not be used as a source for the temperature correction pertaining to the given barometer. See Chapter 5.]

The conversion of pressure units from one system to another depends upon the assumptions made regarding standard conditions and in certain cases upon the proportion between metric and English units of length. One may derive the appropriate conversion factors in the following manner:

First, we commence with the hydrostatic equation (1), applied to a column of mercury *under standard conditions* as specified above (see also Appendix 1.4.1). We employ C.G.S. units at the start. Therefore, if the height of the column is given in millimeters (B_o mm. Hg), the height in centimeters is determined as (B_o mm. Hg)/10. The standard density of mercury is represented by ρ_o, and standard gravity by g_o, while the actual pressure produced by the column of mercury is denoted as P, initially expressed in *dynes per square centimeter*. In accordance with equation (1) we obtain on this basis

$$P, \text{ in dynes/cm.}^2 = \rho_o\, g_o\, (B_o \text{ mm. Hg})/10 \tag{28}$$

Since by definition 1 *millibar* (mb.) = 1000 dynes/cm.², we find from this

$$P \text{ in mb.} = \rho_o\, g_o\, (B_o \text{ mm. Hg})/10{,}000. \tag{29}$$

Substituting values $\rho_o = 13.5951$ grams/cm.³ and $g_o = 980.665$ cm./sec.², we obtain

$$P \text{ in mb.} = (13.5951 \times 980.665/10{,}000) \times (B_o \text{ mm. Hg}) \tag{30}$$

or

$$P \text{ in mb.} = 1.333224 \cdot (B_o \text{ mm. Hg}). \tag{31}$$

Thus, if B_o = 1 mm. of mercury under standard conditions, we obtain the corresponding pressure P = 1.333224 mb. Taking the reciprocal we find 1 mb. = 0.750062 (mm. Hg). Assuming the linear conversion factor 1 inch = 2.54 centimeters, or 0.3048 meter = 1 foot, we obtain the additional conversion factors: 1 inch of mercury under standard conditions = 1 (in. Hg) = 33.86389 millibars, or from the reciprocal, 1 mb. = 0.0295300 (in. Hg). On the basis of the same linear conversion factor, we have obviously 1 inch of mercury under standard conditions = 25.4 millimeters of mercury under standard conditions; and from the reciprocal 1 millimeter of mercury under standard conditions = 0.03937008 inch of mercury under standard conditions.

The definition of the pressure unit termed *one standard atmosphere* originated from the adopted value corresponding to 760 millimeters of mercury under standard conditions. Hence, the magnitude of the pressure in millibars equivalent to *one standard atmosphere* may be determined by substituting in equation (30) the quantity 760 mm. Hg for B_o mm. Hg; and thus we find that *one standard atmosphere* = 760 mm. Hg = 1013.250 mb. If one assumes the conversion factor 1 inch = 2.54 cm., one finds that 1 standard atmosphere = 29.92126 inches of mercury (standard). Sec. 1.4 presents a summary of the foregoing conversion factors.

APPENDIX 2.1

BACKGROUND HISTORY RELATING TO THE INVENTION OF THE BAROMETER AND SOME OF ITS MISCELLANEOUS TYPES

The history of the invention and development of the mercury barometer reveals the creation of a number of ingenious designs of apparatus which depended upon the action of ambient atmospheric pressure. It is the primary purpose in this appendix to present diagrams together with some explanatory information pertaining to this apparatus. Most of the information given will be brief and in the form of legends relevant to the figures.

For the sake of simplicity, certain symbols have been adopted for use in the figures generally; thus: *V* denotes *vacuum; P, atmospheric pressure; M, mercury; m, meniscus.*

Figs. 12.2.1.1–12.2.1.19 are arranged more or less in chronological order according to the date of invention, publication, or other pertinent development concerning the apparatus shown. Thus, it is possible to obtain somewhat of a historical perspective regarding the subject by studying the figures and their legends in the given order. Limitations of time and source material prevent this account from being complete.

Galileo invented the air thermometer as shown in fig. 12.2.1.1. Since this instrument is affected by the ambient atmospheric pressure as well as the temperature, it led later to the development of the sympiesometer after the liquid-in-glass thermometer was invented (see sec. A–2.11 and fig. A–2.11.0). Galileo was perhaps the first scientist to give deep consideration to the problem of the limited height to which a column of water would be elevated when a partial vacuum was produced at the top of the column by a suction pump, as illustrated in fig. 12.2.1.2(A). Other philosophers held the view, commonly, that nature abhors a vacuum, and hence that it was the "force of the vacuum" which supported the column of water. Galileo thought that one should also consider the force of cohesion which might put a limit to the height of the column of water; for if the water were attracted upward by the assumed "force of the vacuum," the height would be determined by the weight of the water column which the tensile strength due to the force of cohesion could sustain. He therefore devised an apparatus, depicted in fig. 12.2.1.2(B), for the

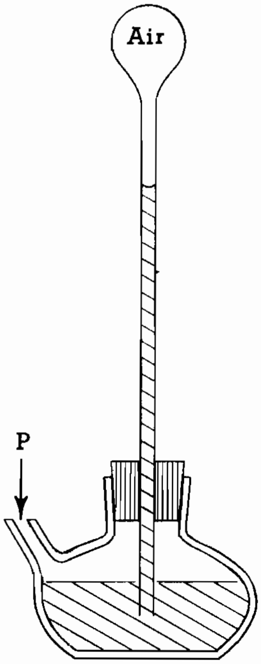


FIGURE 12.2.1.1. Galileo's original form of air thermometer (developed about 1593–1597) where the air in the bulb expanded both with increase in temperature and decrease in atmospheric pressure (*P*). A suitable colored liquid was used in the tube and vessel. While the changes in the level of the upper meniscus provided a sensitive indication of temperature variations, the effect of variations in *P* should also have been taken into account; but this was not known until the discoveries of later times.

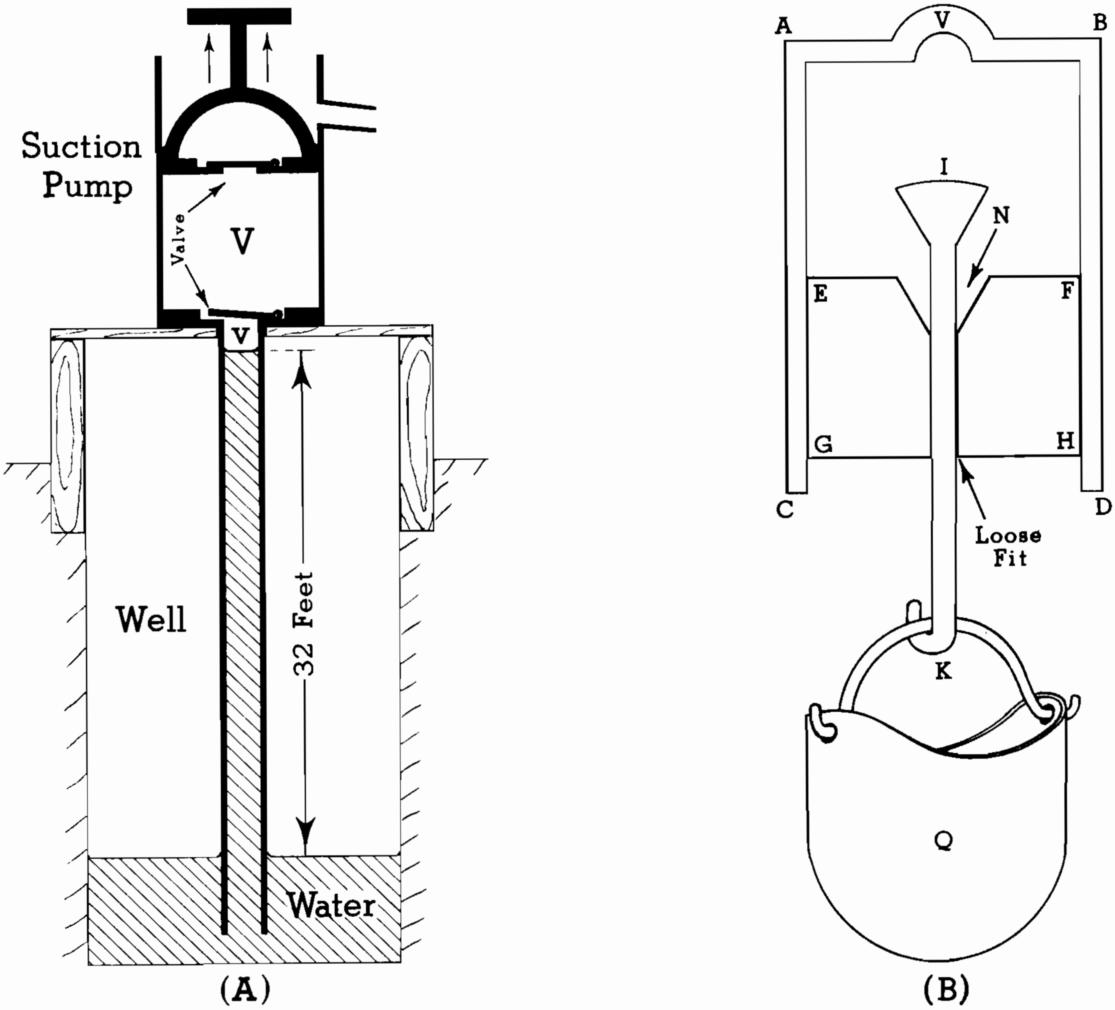


FIGURE 12.2.1.2. (A) *Left-hand figure:* Action of suction pump which revealed to Galileo the limit to which water could be raised under a vacuum, *V,* and led him to consider the cause, thus paving the way for his pupil, Torricelli, whose crucial experiments with tubes of mercury gave rise to the invention of the barometer (see fig. 12.2.1.3).

(B) *Right-hand figure:* Device suggested by Galileo about 1637 to measure the "force of the vacuum" when the space above the piston *EFGH* is filled with water and sealed by the cone at *N,* in order to determine whether this assumed "force" was sufficient to explain the sustaining action or whether the tensile strength of the material controlled the limit.

purpose of measuring the tensile strength (or "breaking strength") of water. By comparing this strength with the "breaking strength" of other substances like metals, stone, wood, glass, etc., he believed it would be possible to ascertain whether it was only the assumed "force of the vacuum" which acts to uphold suspended columns of various kinds of substance or whether the force of cohesion is also active in giving support.[1]

It is useful for a proper appreciation of the subject to gain some background regarding the scientific developments which gave rise to the experiments concerning the vacuum that culminated in the invention of the barometer. To this end the principal matters involved in this field are summarized or explained below:

(1) **Atomism and the Void.**—In order to explain the universe as they saw it certain ancient Greek philosophers expounded the theory that all matter was composed of atoms. They asserted that these were the smallest indivisible particles of the elements,

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[1] Galileo Galilei, "Dialogues Concerning Two New Sciences," (1638).

and that the atoms were moving continually, more or less at random, in an infinite void. Under this theory vacuous spaces of various sizes could conceivably exist and there might be a number of different worlds widely interspersed in the universe. (Among the classical Greeks who served as pioneers in this field of scientific thought we may name Leucippus and Democritus, who flourished about 440 and 420 B.C., respectively. The philosopher Epicurus, who lived from about 342 to 270 B.C., held somewhat similar views but differing in a few respects. Lucretius, a Roman who lived from about 96 to 55 B.C., described Epicurus' theory regarding the atoms and the void in his poem *De Rerum Natura*. There were others in the ancient world who developed the theory further but whom we will not name.

(2) **Plato's Theoretical Views.**—The famous Greek philosopher Plato (427?–347 B.C.) in his *Timaeus* expressed as the most probable theory the concept that there were four primary elements having particles of definite, symmetric, geometrical shapes. He specified these to be as follows: "fire," formed of the smallest particle consisting of a four-sided figure (pyramid) having equiangular triangles for its faces; "air," formed of the particle next larger in size, consisting of an eight-sided figure with similar triangular faces; "water," formed of the particle still greater than that of "air" characterized as a 20-sided figure also with similar faces; and finally "earth," consisting of the largest particle in the form of a cube. (We have put the common names of these ancient Greek elements in quotation marks in order to alert the modern reader to the fact that the terms cannot be taken literally. For example, Plato regarded water vapor and mist as forms of "air"; metals which flowed, such as mercury and molten lead, as forms of "water"; etc.) Plato taught that the individual particles of the elements were so small as to be invisible. An important aspect of his theory was that vacuous spaces could only exist in the form of the minute interstices between such particles when they were aggregated to give bulk matter. Otherwise he apparently thought that there did not exist any empty spaces within the universe, which he considered to be a living being with a soul. It was his view that transmutations (transformations) could occur between the different particles of the so-called "elements" having similar triangular faces, under the basic assumption that the superficial area was conserved in any such change. This idea may be illustrated by the simple situation where the faces obtained by the disruption of two particles of "fire" could provide the total number of faces required for the formation of one particle of "air." According to this theory the union of these faces would indeed yield the latter type of particle under certain conditions; and, conversely, the reverse process could also occur in favorable circumstances. Plato supposed that, by virtue of the fineness and nimbleness of the particles of "fire," they could readily penetrate the interstices in bulk matter which was not too strongly compressed. He believed that the sharp points and cutting edges of the pyramidal particles of this element rendered them especially effective in producing disruptions of the particles of the other elements. It is worthy of mention finally that Plato was of the opinion that only *like attracted like* in regard to the types (shapes) of the particles; that is, as though gravitational attraction was specialized in order to favor the motion of "earth" to "earth," "water" to "water," "air" to "air," and "fire" to "fire." These theories permitted him to explain the formations of the terrestrial globe, and outside that the spherical shells of water (ocean), air (atmosphere), etc., as well as the continual motions and changes observed in nature.

(3) **Aristotle's Theories.**—The Greek philosopher Aristotle (384–322 B.C.) wrote books on physics and astronomy which, during the period from about 1200–1650 A.D., exerted a powerful influence on the thinking of scientists and other scholars in Western Europe. In Aristotle's books on physics he presented a number of reasons and arguments leading to his conclusion that a void (perfect vacuum) could not exist anywhere in the universe. It was his contention that the universe was a *plenum*; in other words, that every nook and cranny of the world was always filled with some kind of material substance. That idea was in harmony with his

assumed axiom pertaining to motion: "Everything that is moved must be moved by something." We can interpret this as signifying that every body that is in motion must have acting on it in direct contact some other material substance which is itself in motion, and that when the latter ceases to move the body will also cease its movement. Accordingly, Aristotle argued that no physical object could move in a void, for in the case of a body projected into a perfect vacuum there would be no other substance which would be acting continuously on the body to maintain its motion.

Aristotle had assumed without any adequate experimental supporting evidence that the following dynamical principle governed the motion of bodies through a medium when they are impelled by an external motive power: the velocity V of any given body through a medium is directly proportional to the strength of the motive power (force F) acting on it and inversely proportional to the resistance (R) which the medium offers to the passage of the body; that is, $V = F/R$.

By adopting this erroneous principle as a premise, he argued that in the theoretical case of a body being projected into a void under the action of a finite motive power F, the resistance of the medium would be absent ($R = 0$) and, according to the assumed dynamical principal, there would be no upper limit to the velocity (that is, V would be infinite). Such an outcome is clearly impossible in nature. He reasoned in effect that the cause of the reaching of an impossible conclusion was the falsity of the original premise that a void existed.

Aristotle also put forth the argument that if a body were to attain a finite velocity in a void under the influence of a given motive power, then it would follow as a conclusion on the basis of his (assumed) dynamical principle that one could find a medium in which the body would have the same velocity as in the void when acted upon by a constant motive power. Since it is not good reason to consider that a body will have the same velocity in a medium as in a void when acted upon by a given force, he argued that the unreasonableness of the conclusion was due to the erroneous character (in his view) of the assumption of a void.

It actually turned out that Aristotle's assumed dynamical principle was entirely false, as shown by the investigations of Galileo, Newton, and others. Unfortunately, progress looking towards the invention of the barometer would be slow until the belief in Aristotle's ideas was demolished with regard to physics and astronomy in general, and the principles of dynamics and the void in particular.

(4) Support Given to Aristotle's Theories by His Followers.—We now wish to bring out the perhaps peculiar fact that a number of philosophical views disseminated by certain disciples of Aristotle served to boomerang, and eventually contributed to the downfall of the widespread credence pertaining to his teachings.

The strong denial by Aristotle that a vacuum could exist was firmly maintained by a number of philosophers and other scholars who acted as his faithful followers during the Middle Ages. One of the most prominent of these was the Moorish philosopher Averroes (1126–1198 A.D.) who lived for many years in Cordova, Spain, then under the domination of the Moslems. This philosopher praised Aristotle in the most extravagant terms, saying in effect that the doctrines which Aristotle had put forth represented the totality of truth because his was the topmost in all human intelligence. Furthermore, he expressed his considered opinion that Aristotle had been created by Divine Providence in order that we should know what it is possible to know. Averroes regarded his ancient preceptor as: ". . . the model that nature had produced to show the ultimate in human perfection." One can readily envisage why such statements were partly instrumental in generating opposition in the countries of Western Europe to the doctrines advocated by Averroes and his master.

A good part of Averroes' life was spent in delving into the works of Aristotle, and discussing them in large commentaries. These writings, originally in Arabic, were translated into Latin and were widely circulated in Western Europe, where they often accompanied translations of Aristotle's books, such as those on physics and astronomy. History reveals that the influence of both Aristotle and Averroes was strongest in the universities of Europe during the 13th and 14th centuries, lasting even until the 17th century. In the first of these periods the followers of those philosophers were most active at the University of Paris, led by Siger of Brabant (about 1266–1276) and later by John of Jandun, but during the Renaissance period (about 1300–1500 A.D.) their followers were most strongly entrenched in the schools of Northern Italy (e.g., at Padua).

Averroes' philosophy, as well as that of Aristotle, embraced a number of ideas that stood in direct conflict with the generally accepted beliefs of the religious leaders.

Although numerous scholars found themselves profoundly interested and affected by the teachings of both Aristotle and Averroes, this attitude was soon replaced in many instances by a critical one. Criticisms rose to such a high peak that in the year 1270 the Bishop of Paris issued a condemnation of 13 propositions maintained by the philosophers who followed their teachings.* Finally, in 1277 a commission of 16 theologians prepared a list of 219 propositions from the writings of these philosophers which the bishop also found it necessary to condemn as being contrary to the accepted doctrines of the Church.

The connection of these matters with the history of barometry covers a broad scope. First of all, the finding of objectionable doctrines among the propositions maintained by Aristotle, Averroes, and their followers led theologians and some others after about 1270 to scrutinize all of the teachings of those philosophers. Secondly, it became clear that many of those teachings implied a limitation on the power of the Almighty, which constituted a view utterly unacceptable among religious-minded people whose prevalent belief rested on an omnipotent deity who exercises providence over human acts. As a case in point it eventually was realized that the Almighty could, if he wished, create many worlds with voids between them. On these grounds it appeared, at least to a few thinkers, that Aristotle's denial of a void under any conditions might be false. Soon the popularity of Aristotle's teachings waned, especially after the 14th century when some obvious faults in his assumed dynamical principle and theories in physics were discovered.

(5) Some Highlights of Pertinent Advances in Physics of the Middle Ages.—Plato had said that the body of the universe was spherical and of limited size, while Aristotle had affirmed that the universe was a plenum limited by the outermost celestial sphere carrying the fixed stars in their orbits. According to these theories there was no place for plural worlds with voids between them. On the other hand, those thinkers who dissented from Plato and Aristotle during the 13th and 14th centuries gave consideration to the possibility that there might be many worlds. But, in this case, what lay between these widely separated worlds? Was it a void or some rarefied material medium? Some persons took a definite stand on this subject. For example, Richard of Middleton, who flourished about 1294 A.D., and Walter Burley, who lived about 1275–1344 A.D., said that it would be in contradiction to the infinite power of God to consider that He could not maintain an actual void if He so wished. Nicholas of Autrecourt (who died after 1350) took a stronger stand by supposing the probable existence of a void, saying: "There is something in which no body exists, but in which some body can exist."

The profound French thinker Nicholas Oresme (who died in 1382) expressed the view in an unpublished manuscript that by virtue of God's infinite power He could create an infinite space and within it as many universes as He chose. Oresme went on to speculate that beyond the sky there is an empty space, unlimited in extent. After affirming that space is infinite, Oresme was led by certain reasoning to the conclusion that the directions of down and up are only *relative* to a particular universe under consideration, as indicated by the motions of heavy (dense) and light (less dense or rarefied) bodies, and also by the natural distribution of heavy and light things (e.g., earth and atmosphere).

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* The character of the propositions thus pronounced to be wrong may be judged from the following examples: (a) "The will of man is not endowed with freedom of choice." and (b) "All terrestrial events occur necessarily, through the influence of the heavenly bodies." (For further information see: A. A. Maurer, "Medieval Philosophy," New York, Random House, Inc., p. 205 (1962).)

From this standpoint Oresme contended that gravity must be regarded merely as the tendency of heavier bodies to go to the center of spherical aggregates of matter (as illustrated by the terrestrial globe). In his view, therefore, movements due to this tendency were produced by gravity relative to the specific universe involved in the action; hence there could not be an absolute direction of gravity applicable to the entirety of space covering all universes.[#]

One can readily see an apparent similarity or connection between the concepts expressed by Oresme and those of Nicholas of Cusa, who lived in Germany (1401–1464). The latter believed that the proper approach to the subject was to regard gravitation as a local phenomenon around each body. On this basis each star would act as a center of gravitational attraction serving to keep together its parts. From such a premise it would obviously be but a short step to the conclusion that there could exist interstellar spaces having the character of a void (empty of matter).

In the field of dynamics the scientists of the Middle Ages soon found that Aristotle's ideas concerning motion, gravity, and the influence of external forces acting on bodies were incapable of providing satisfactory explanations of such phenomena as the acceleration of falling bodies, and the movements of such material objects as projectiles in space, depending on the various possible conditions. It was obvious that, if a void did indeed exist, Aristotle's assumed dynamic principle ($V = F/R$) could not be valid. During the sixth century A.D., John Philoponus of Alexandria (Egypt) had said in effect that a body in a void would have a falling speed of finite value depending upon its gravity, but if the body fell in air its speed would be less than that amount by a quantity proportional to the resistance of the medium. Under this assumption the dynamical principle would be amended to the statement that V is proportional to $(F - R)$; or $V = (F - R)$, depending upon the choice of units. A so-called "law of motion" in this form was recommended in the 12th century by Ibn Badga, a Spanish Arab (known in Latin as Avempace). His theory was supported by the famous Italian theologian Thomas Aquinas (1225–1274) who argued that motion could take place even in a void where there was no resistance, since all motion must take time because the moving object must traverse an extended distance.

Aristotle had held the view that the motion of a projectile through a medium could continue only as long as some suitable motion of the medium itself maintained a direct action on the object to propel it. Philoponus has the distinction of pointing out that this theory of Aristotle cannot be valid, as demonstrated by the fact that when one violently beats the air behind a stone, the stone does not move. He suggested, instead, that the agent causing the motion (such as the hand of a javelin or stone thrower) imparts to the projectile a motive power, which must be considered only as a form of borrowed "energy." It was the view of Philoponus that this borrowed motive power would then be decreased by the natural tendencies of the propelled body and by the resistance of the medium. Such a continued diminution of the remaining "energy" would finally reduce the motive power to a negligible amount and thus end the motion.

Ibn Sina (known in Latin as Avicenna), who lived in Baghdad (980–1037), presented the argument that a body projected into a void under the influence of a given initial motive power would continue in motion indefinitely at constant speed, since there would not be any medium to offer resistance ($R = 0$), and the original borrowed motive power would persist. We may envisage this as a forerunner of Newton's first law of motion.

Thomas Bradwardine (about 1295–1349) of Merton College, Oxford, made an interesting revision in Aristotle's assumed dynamical principal: he reasoned that if a given value of the ratio (F/R) yields a certain velocity V, then the ratio required to produce a velocity of twice V would be $(F/R)^2$; while the ratio required to produce a velocity of one-half of V would be the square root of F/R. These relationships can be written in more general form as $V = \log\ (F/R)$. This equation has

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[#] Oresme was ahead of his time by presenting reasonable arguments according to which it would be credible that the earth rotates daily about its axis while the distant stars are apparently fixed; these conclusions being in complete opposition to the teachings of Aristotle and Ptolemy that the Earth was rigidly fixed at the center of the universe. Despite this, Oresme in his final writings said, in effect, that there never was and never will be but a single material universe.

the apparent merit of indicating that the velocity would be zero (0) when the motive force is balanced by the resistance of the medium (i.e., when $F = R$) ; and that the velocity would assume a positive value when F exceeds R.

Considering the motion of a stone projectile through air, the Italian Franciscus de Marchia wrote in Paris about the year 1320 that he felt there was a fundamental error in Aristotle's theory regarding the motion of the projectile as due to the motion of the medium. He suggested, instead, that the passage of the projectile through the medium was caused *by the motion or impulse of a power left behind in the stone by the original mover* (i.e., the hand of the thrower). It was his belief that this "power left behind" did not become an essential part of the projectile, and would last only for a limited time, because it was opposed by the natural inclinations of the body.

Shortly after this time most important advances were made by Jean Buridan, who was the Rector at the University of Paris for two terms during the period 1328–1340 and who died about 1358. First of all, he demolished Aristotle's theory, mentioned above, regarding the cause of the continued motion of bodies through a medium. This he did simply by citing as experimental evidence against the theory the case of a grindstone which was set in rotary motion within a tight-fitting container and which maintained its rotation even when the container was closed to exclude the air, thus showing that the action of the medium was not essential to the motion.

A second advance made by Buridan was the introduction of the theory that the motion of a body could occur when the original mover (such as the hand of a projectile thrower) impressed on the body a sufficient *impetus.* This entity he regarded as a motive power which enabled the body to continue in motion until it was reduced to nought by extraneous opposing forces. An important part of his definition gave the measure of the impetus imparted to a body as *the product of the quantity of matter in the body and its given velocity.* Since "quantity of matter" was effectively considered as proportional to the density and volume of the body, one may now recognize Buridan's concept of "impetus" as a forerunner of our concept of linear momentum. From his viewpoint the impetus impressed on a projectile would be diminished by the resistance of the medium. In the case of a projectile thrown vertically upward the impetus of the body would also be continually decreased in time by the opposing gravity until brought to a halt. On the other hand, in the case of a falling body or a projectile thrown downward the resistance of the medium would tend to reduce its remaining impetus, whereas the action of gravity would impress on the body an added impetus that would grow in proportion to the velocity of the body, thus causing the body to accelerate downward. Buridan considered it most probable that the celestial spheres would continue in their rotatory motions eternally because the Creator had impressed on them at the time of creation an impetus which they would maintain indefinitely since there was no resistance acting to restrain them in the celestial regions.

By Buridan's suggestion that the impetus impressed on a body had the nature of an enduring thing unless it was diminished by an opposing resistive medium or force, one may consider that the groundwork was laid for the concept of conservation of momentum. On this basis it would be possible to envisage the continued motion of a body through a void, which did not appear possible according to Aristotle's theories. We cannot, however, consider that Buridan had any idea of inertia and inertial motion as developed by the psysicists centuries after his time. As a matter of fact Buridan accepted Bradwardine's dynamical principle equivalent to the relationship $V = \log (F/R)$, on the basis of which V would approach infinity as R approaches zero (0). From this absurd consequence we come to realize that Buridan had not yet escaped from the hold of Aristotelian physics.

Much discussion had taken place since ancient times regarding the causes of motion of objects after they are given a violent impulse, such as the case of the throwing of a stone, javelin, or other projectile. Plato and Aristotle had considered the possible mechanism that the object compresses the air in front of its leading surface, and that the *air then* circulates around it in such a manner that the air exerts a thrust on its rearward face, thus yielding a pressure which acts to keep the object advancing (as though the compression produced a vortex that would push the projectile ahead while moving with it). Aristotle had also mentioned the theory that the throwing agent would impart motion to the air which in turn would thrust the projectile along the initial path of the projection until the energy imparted was used up by resistance of the medium. Another theory considered by some natural philosophers during the Middle Ages was that of action at a distance assumed to be analogous to that observed when a magnet acts on a nearby piece of iron and attracts it, thus causing it to move. In this case the assumption was that some species of magnetic entity went out from the magnet through the medium and produced a certain change in the iron of such a character as to enable the iron to move itself. In explaining the motion of projectiles it was sometimes postulated that the throwing agent impressed on the object a certain "species" of some unknown nature which had the capability of pushing the projectile ahead of it after it had left the agent. Finally, a commonly held theory was that an *impetus* (impressed power) given to the projectile by the throwing agent kept it in motion until the supply of impetus was exhausted by the resistance of the medium.

A critical attitude concerning all of the preceding explanations of the motion of projectiles was taken by the English philosopher William of Ockham who lived from about 1284 to 1349. He pointed out that after the projectile separates from the throwing agent the object moves by itself. On the basis of economy of hypothesis, he indicated that it is not necessary to postulate any power in the body or relative to it as a direct cause of its continued motion. This way of looking at the problem may have played a significant role in the concept of inertial motion which came to be understood after the investigations of Galileo and Newton more than three centuries later.

(6) Relevant Advances at the Beginnings of the Modern Experimental Era.—Thus, early in the 17th century, Galileo studied the motion of rolling balls on both inclined and horizontal planes, the vibration of pendulums, the free fall of bodies in the air under the action of gravity, the balancing of weights on levers with arm lengths, the trajectories of cannon balls, and other problems in the field of physics and astronomy. On this basis he concluded that if there were no friction a ball once set in motion could continue to roll indefinitely on a horizontal plane in a straight line until it was disturbed by an extraneous force. (To be more precise he thought that such continuous motion could take place in a great circle on a spherical surface equidistant from the center of gravity of the system such as the earth, in effect along an equipotential surface.)

After giving thought to the problem of the free falling motion of bodies of different specific gravities in media of various densities ranging from dense to very rarified, and also performing (or having performed) some experiments with such bodies falling from several heights, Galileo came to the conclusion that all bodies would fall with the same velocity in a vacuum if released from a state of rest.

He introduced the concept of momentum, measured by the product of the weight and velocity of a body (which is proportional to "impetus" as defined by Buridan). This concept of momentum was regarded by Galileo as an index of the *effect* of motion (*not a cause* of motion as in the case of "impetus" according to the theory of Buridan). On this basis, the persistence of the uniform motion of an object on a frictionless horizontal plane could be specified as an example of persistence of momentum which we would term an illustration of the "conservation of momentum."

Galileo had an appreciation of the idea of inertia as one can determine from his remark to the effect that: ". . . the tendency of heavy bodies to move downward, for example, is equal to their resistance to being driven upward." (See Galileo's "Dialogue Concerning the Two Principal Systems of the World" (1632).)

An important advance occurred when Galileo gained an understanding of the concept of uniform acceleration of a body. It was this concept which he had envisioned as applicable to the case of any material object freely falling in a vacuum under the influence of the earth's gravity (that is, the case of the velocity V of a body increasing in direct proportion to its time of fall, t, from rest). The corresponding equation is $V = at$, where $a =$ acceleration (assumed uniform). From this he developed the relationship that the distance of fall of the body from rest, S, would be proportional to the square of t. Galileo showed that the force which produced the uniform downward acceleration was equal to the weight of the body measured when the body was at rest, this weight apparently being constant as closely as he could measure it. On the basis of the foregoing relationships it would follow as a reasonable conclusion that when a constant force was exerted upon a body of given quantity (mass) in a vacuum the body would undergo uniform acceleration (as in the case of a body freely falling in a vacuum under the influence of gravity which would provide a downward-acting force equal to the weight of the body). Such a conclusion was dealt with later by Isaac Newton in his treatment of the laws of motion.

Finally, Galileo's studies of motion of projectiles proved to be invaluable in the fields of dynamics and ballistics. He pointed out that if a heavy particle were projected along an unlimited horizontal plane without friction the particle would move along this plane with a velocity which is uniform and eternal. On the other hand, if the plane were limited and elevated above the ground, the particle would move uniformly without friction along a level until it reached the edge of the plane and thereafter it would have a resultant motion compounded of a uniform horizontal component and a vertical, downward accelerated component under the action of gravity provided, of course, that the effect of air resistance were negligible. He then came to the conclusion based on this ideal situation that: "A projectile which is carried by a uniform horizontal motion compounded with a naturally accelerated vertical motion describes a path which is a semi-parabola."[1]

It was also Galileo's conclusion, based on experiments and observations, that the resistance of the air acting upon a light-weight body freely falling in the atmosphere would slow the body down until it fell at a uniform vertical speed (i.e., upon attaining its terminal velocity, as in the case of a falling raindrop or small ball made of light wood). The results of these experiments were clearly in conflict with the teachings of Aristotle regarding the motion of objects in a medium.

We can thus recognize from the foregoing summary of some of Galileo's contributions that he laid the foundations of modern dynamics. Lastly, from our present vantage point it would appear that he provided enough relevant facts from the field of physics to nullify the spurious dynamical principal ($V = F/R$) assumed by Aristotle in constructing his arguments against the existence of a void. What remained to demolish completely the position of the followers of Aristotle was to furnish actual experimental evidence that a vacuum could be produced at will and maintained indefinitely.

(7) **Technical Advances Preliminary to the Crucial Experiments.**—We are concerned here with the technical developments that made possible the performance and provided forerunners of the crucial experiments in the period 1640–1644 carried out with regard to the vacuum. As will be seen later these experiments led to the invention of the barometer.

First of all, even primitive man had familiarity with the breath of life, and the flow of air and water in the ceaseless movements of the atmosphere, rivers, and oceans, which enabled him to gain an intuitive feeling for the pressure exerted by fluids. As early civilization progressed and technical knowledge grew, man made use of the properties of fluids, whether moving or still, in the invention of a number of devices such as the sail, the siphon, the syringe, the bellows, and the water clock. These were known in ancient Egypt and were further developed especially in ancient Greece and the neighboring Mediterranean region. During the period of ascendency of the ancient Greek city-states and the rise of the Romans some ingenious inventions were created or greatly improved.

Among the ancient Greek inventions that utilized fluid pressure, one may mention improved water clocks (clepsydra), air guns, hydraulic organs (i.e., organs wherein air was caused to flow by means of water pressure), and force pumps for fire-fighting, due to Ctesibius, born in Alexandria about the latter half of the third or second century B.C.; pressure chambers partly filled with air to maintain a steady flow of water driven through a section of pipe; bellows-operated organs; turbines operated by the reaction of jets of steam emerging from nozzles; and many other ingenious devices whose descriptions were compiled in the book on pneumatics written by Hero of Alexandria, who lived after Ctesibius.

The mathematical scientist Archimedes (287–212 B.C.) wrote a two-volume book on hydrostatics and flotation based on certain postulates still regarded as valid. These involved the fundamental idea that the whole weight of a vertical column of continuous fluid always pressed on every underlying part of the fluid, unless the fluid were enclosed or compressed by something else. Clearly, this concept provided a foundation stone for an understanding of hydrostatic pressure.

The applications of fluid pressure, it appears, were everywhere. Among the engineers of the ancient Romans, problems involving pressure were faced almost daily, as in the construction of aqueducts or pressure conduits for distributing water from the primary sources (such as springs and rivers) to reservoirs and other receptacles, thence to the places of its use, such as the public baths, fountains, pools, private houses, etc.

From the early part of the Middle Ages to the Renaissance there were on a wide front rapidly growing technical applications involving pressure. The power inherent in running streams was employed by means of the water wheel to operate mills for grinding grain and to operate devices for the raising of water, for example, with the aid of the Archimedean screw and the bucket elevator. Following these methods suction pumps and a variety of force pumps made of wood were developed in this epoch to lift and drive water, as for providing municipal water supplies, removing water from mines, draining water from lowlands inundated by the sea (e.g., the Netherlands), etc. The windmill came into use after about the 12th century in Western Europe as a source of power for such work on a limited scale in some areas.

Apart from this type of application during the era under consideration the technical uses of air under pressure grew importantly, especially in connection with metallurgy. Thus, from early times the furnaces used in metal processing received their draught by means of wind tunnels, often aided by hand bellows. Primitive ironworking by such processes yielded a spongy mass which had to be alternately heated and hammered numerous times to obtain a suitable grade of wrought iron. A great advance was made in the techniques of metalworking with the modification of furnaces designed to operate with air blasts under pressure which served to aid in the production of temperatures capable of melting the metal. This permitted the obtainment of reasonably pure iron directly, without the formation of an intermediate spongy mass secured under the old system which entailed so much labor in the working of the metal.

How were these air blasts obtained? First of all, the most common procedure was to compress the air by the weight of a column of water and to introduce it into the furnace, a method used in Italy and Spain before the 14th century. A second method was to boil vigorously the water contained in a long-necked vessel and to derive the blast from the flow of steam emerging from the orifice at the end of the long neck. Lastly, strong draughts of air for the blast furnaces were obtained with the aid of bellows provided with power in various ways, at first by human labor, then by means of a treadmill over which horses were continuously driven and, finally, by means of water wheels to operate the driving mechanism. The last development enabled the construction of much bigger furnaces than before because of the more powerful blast yielded, and had practically a revolutionary effect in metalworking, for example, by permitting the production of cast iron on a commercial scale.

We thus see that the technical advances up to the time of the Renaissance gave craftsmen, engineers, and scientists some familiarity with various manifestations of water, steam, and air under pressure. This point can perhaps be best illustrated by the case of the Dutch mathematician Simon Stevin (1548–1620), who gained vast experience in regard to the construction and use of dams, dikes, sluices, pumps, water wheels, windmills, and waterworks for controlling the water in his native land. Compatriots of Stevin thought very highly of him in regard to his design for utilizing the stored water in connection with the defense of the country (as by opening the sluices to flood the lowlying areas along the invading enemy's line of attack). The fruits of Stevin's investigations were rendered to posterity partly in his book on hydrostatics (published originally in Flemish in 1586 and translated into Latin in 1608) in which he showed how one could calculate the pressure exerted by water. This was based on the proposition that a level area at the base of a mass of water would support a weight (force) equivalent to that of the weight of a column of water whose horizontal profile is the same as the area at its base and whose height is represented by the vertical distance from the base to the surface of the water.

On the basis of hindsight it would appear that such a proposition ought to have suggested, by analogy at least, that the weight of the atmosphere exerts a pressure on the earth's surface since air has weight. Strangely enough, however, such a conclusion was apparently not reached by the very great majority of the readers of Stevin's book in his times. Few, if any, had a clear understanding of the existence of atmospheric pressure and the role it played in the operation of suction pumps, siphons, syringes, and the like. An exception was Isaac Beeckman (1588–1637), also from Holland. He had the interesting practice of writing in a diary extensive notes giving all of his reflections on scientific matters. This voluminous work, never published, reveals that Beeckman, even as early as the year 1613, believed that there could exist voids both separate as on a large scale in space and within the interstices of porous matter (Reference: C. de Waard, "L'Expérience Barométrique. Ses Antécédents et Ses Explications. Étude Historique," Thouars (Deux-Sèvres, France), Imprimerie Nouvelle, 1936, pp. 195).

Greatly influenced by Stevin's proposition Beeckman came to the conclusion that the weight of air causes the atmosphere to produce a pressure. To this he added the stipulation that pressure is exerted equally in all directions at any given point no matter what the fluid. When one compares these conclusions of Beeckman with the theories of his contemporaries, most of whom, like Stevin, believed that pressure within a mass of fluid was exerted only in a downward direction, one must grant that Beeckman had achieved a marked advance in understanding of the subject. As an application of these ideas he came to the view that the atmosphere, by exerting a pressure which acted in all directions, would cause the coherence of bodies immersed in it.

Beeckman envisioned the atmosphere as like a resilient sponge resting on a surface (the earth), and so affected by its weight that it would be more compressed below than above, thus causing its density to be greater near sea level than at higher levels. On this basis accordingly he considered the air to be endowed with the property of elasticity, as manifested by air contained in a vessel (like a jar) which is closed after being open to the atmosphere. To permit such explanations he considered material things to be composed of very small corpuscles (atoms) with void interstices between the particles.

Since Beeckman's father had been engaged in the trade of furnishing water to breweries and, since Beeckman had himself, for a time, worked in his family's business, he was very familiar with the pumping of water. This experience provided a basis for his views regarding the elasticity of air and for his conclusions relative to the existence of voids and also of atmospheric pressure acting in all directions. Accordingly, even as early as the years 1614–1616 he had apparently gained valuable insights into the principles on which pumps of various kinds functioned. In explaining the manner of operation of the suction pump (see fig. 12.2.1.2(A)), he considered that a vacuum would be created directly beneath the piston when the piston was raised and that the weight of the atmospheric air would push up the water (presumably by acting on the surface of the water in the cistern and impelling the water up into the inlet pipe at the base of the pump, thence to the lower part of the cylinder where there would be a partial vacuum in the form of attenuated air).

He attributed the cause of the resistance experienced in lifting the piston to the difference between the weight of atmospheric air acting on the top of the piston and the weight of the attenuated air beneath it. From these considerations we can conclude that Beeckman had worked out fairly realistic descriptions with regard to the formation of a vacuum within the cylinder under the piston and the role played by the weight of the atmospheric air in the functioning of the pump. On these grounds we must acknowledge Beeckman as being well ahead of his contemporaries and indeed well ahead of the great Italian scientist Galileo in respect to a proper understanding of the subject.

When Beeckman submitted his thesis for the degree of doctor of medicine at the University of Caen in Normandy on September 6, 1618, he wrote that water raised by suction was not attracted by the vacuum but was driven into the vacuous space by the air weighing upon the water (that is, upon its free surface in the cistern). To explain how the vacuum had its origin he also contended that a vacuum is always intermixed among the corpuscles of matter (i.e., he took the position that the interstices between the fundamental particles of matter are void, as had been assumed by Plato about 2000 years earlier). Beeckman defended his thesis publicly and also, over a period of years, expressed his views both in writing and orally to several noted scientists, including the Frenchmen Gassendi (1592–1655) and Descartes (1596–1650), and Mersenne, the latter of whom maintained a voluminous correspondence on learned subjects with numerous philosophers and scientists in many countries. Thus, it appears that there might have been some opportunity for others to hear about Beeckman's theories concerning the action of suction pumps as governed by the weight of the atmospheric air above the cistern. There appears to be indirect evidence that when he was asked how the pump would work if the cistern were closed off from contact with the atmosphere so that there would be only a small weight of air resting on the surface of the water, he took the view that the pressure due to the elasticity of the air contained in the cistern would tend to push the water up into the pump. Later he also foresaw that there would be transient raising and lowerings of the atmosphere (which would be associated with corresponding variations of atmospheric pressure). It seems regrettable that the profound reflections of Beeckman concerning these matters were not given due credence by the influential scientists to whose attention he brought his theories. We are forced to the conclusion that the prevailing views, so colored by Aristotelian physics, delayed for another generation the possible advance of science in this field.

(8) Crucial Experiments with Water in Tubes, Leading to the Water Barometer.—Historical research indicates that Beeckman was not the only person who believed that a vacuum could exist. It is well known that Galileo himself was convinced that a vacuum could exist both on a small scale in the form of void interstices between the particles of matter and on a large scale (as in the cylinder of a suction pump or a syringe when the piston was rapidly withdrawn). When the Italian scientist Baliani wrote to Galileo in 1630 and asked his opinion regarding the cause of the limit of about 33 feet to which a suction pump could raise water, Galileo replied to the effect that the weight of the column of water counterbalanced the force (resistance) of the vacuum under the piston. Galileo went on to state his theory that the force of the vacuum was limited and would not be sufficient to draw up water to a greater height. He believed that at the same time the column of water would break of its own weight like a suspended rope which, when too long, will rupture at a definite length by yielding at the point where the tensile strength of the material is reached. Baliani replied to Galileo in a letter dated 24th October 1630, expressing his view that the pressure of the air was exerted in all directions, that the admitted weight of the air was the cause of atmospheric pressure, and that the latter pressure should be considered *relative* to the pressure in the vacuum. One gains the impression from Baliani's letter that he had a fairly clear idea of the action of atmospheric pressure in elevating water by means of the suction pump.

Those who argued against Baliani, as they had against Stevin and Beeckman, took the attitude that water in water had no weight, that air in air had no weight and so on ad infinitum. They believed that a particle of fluid immersed in a medium of the same kind does not experience any *lateral* pressure due to the weight of the column of fluid, and they said that the fluid weighed and pressed only in a downward direction. As evidence of this, they pointed out that a person swimming in deep water does not feel any sensation of pressure tending to squeeze him together laterally, and likewise a person walking around at the base of the atmosphere (i.e., at the bottom of an ocean of air) does not feel such a lateral compressive effect due to the ambient fluid.

In the opinion of the opponents of Stevin et al., the downward exertion of the pressure due to the weight of a column of fluid was manifested when one placed his hand tightly over the stoppered hole at the bottom of a vessel of liquid and removed the stopper from beneath. Although Stevin had demonstrated in his book on "The Elements of Hydrostatics" (see ref. 2, pp. 153–8) that fluids in equilibrium exert pressure horizontally as well as vertically, the erroneous belief persisted even until Pascal's time that the pressure would act solely in a vertical direction. Those who argued against Stevin, Beeckman, and Baliani could not see how pressure would be transmitted horizontally from the water in the cistern across the opening of the pipe at the base of the suction pump and then vertically upward.

One may consider it fortunate that, in the light of the then-existing obstacles to scientific progress, steps leading to a resolution of the problem were forthcoming within a generation of the time that Baliani and Galileo engaged in their correspondence of 1630. The stimulus for the crucial experiments capable of demonstrating the correct theory regarding pump action came with the publication in 1638 of Galileo's book "Dialogues Concerning Two New Sciences." In that book he had cited the fact that suction pumps could raise water only to a height of about 18 cubits (equivalent to 9.745 meters or 32 feet). To explain this phenomenon Galileo gave the same reasons which he had indicated to Baliani, as outlined earlier (see also the second paragraph of this Appendix).

Galileo had assumed that a vacuum would develop directly beneath the piston of the suction pump when it was lifted, whereas Aristotle had denied that any vacuum could exist. Furthermore, Galileo had supposed that the vacuum in the cylinder of the pump would exert an upward force on the water in the pipe beneath it. He inferred from the common experience with the operation of the device that the so-called "force of the vacuum" had a finite limit. This, too, was contrary to the beliefs of many of his contemporaries who thought that "Nature abhors a vacuum" and hence that Nature would act to prevent the occurrence of a vacuum at any cost. In any event, he felt that the limited yielding strength of the material (e.g., water) under tension supported by such a postulated force would also govern the maximum length of the column of the substance that could be thus held up, due to the suction.

Those who read Galileo's theories regarding the action of the suction pump were faced with several questions: (1) Was a vacuum actually produced under the piston as it was raised? (2) Could a vacuum be maintained? (3) Was the height of the column of water elevated by means of the pump always 18 cubits? (4) What was the true cause of the raising of the water by means of the pump?

Rome, at the time of the appearance of Galileo's book in 1638–1639, was a place where dwelt many persons endowed with intense intellectual curiosity. Among these was mathematician in the employ of Cardinal Sacchetti, named Raffaello Magiotti (1597–1658), who was a close friend and a correspondent of Galileo. Judging by the available documentary evidence it appears that Magiotti acted as the principal promoter in the investigation because he felt that it was of great importance to seek an *experimental* answer to those questions. He engaged in discussions concerning the problem and thus about the year 1639 or 1640 he stimulated the young man Gasparo Berti (1609–1643) to undertake a crucial experiment with a view to obtaining an answer to the basic questions involved. Not only did Berti have youthful enthusiasm but also experimental skill and profound interest in the problem. He had as participants in the experiment the Jesuit Fathers Nicolo Zucchi (1586–1670) and Athanasio Kircher (1602–1680), as well as Magiotti. A young man by the name of Michelangelo Ricci, born in Rome in 1619, also rendered assistance. It appears probable that Berti received some advice from Galileo with regard to the design of the experiment.

Berti's preliminary aim was to determine the height to which water would be raised under a vacuum, for Galileo had said that it would be about 18 cubits (32 feet); Baliani had estimated that it ought to be somewhat more (perhaps of the order of 80 feet, which he judged by the density of the air); while those who believed the old saying that "Nature abhors a vacuum" had thought the possible height of the water column might be without any limit.

To prepare for the crucial experiment Berti obtained first of all a pipe made of lead, about 11 meters (36 feet) in length to be used in an upright position. We have no record of its diameter, but one may estimate it to have been of the order of 12 centimeters (nearly 5 inches) on the outside, and we can assume that the pipe had rather a thick wall to give it strength. Near the lower end of the lead pipe a slightly tapered hole was bored through it and a valve was inserted in the hole. This valve, denoted here by *V*, was like an elongated tapered stopper with a handle, so that it could be inserted or removed, and turned in order to tighten or loosen it. When the valve was inserted in the hole near the bottom of the pipe and tightened, the valve *V* was closed and no water could flow through the lower opening of the pipe; but when the valve was removed, water could flow freely through the opening.

The next step was to develop a suitable headpiece to mount at the uppermost end of the pipe. This was designed as a large hollow glass vessel, of roughly globular shape (like a spherically formed bottle) perhaps about 45 centimeters (18 inches) in horizontal diameter, and slightly more in vertical dimension. The bottom of this vessel had a neck provided with a suitably tapered opening so that the upper end of the lead pipe would fit snugly inside the neck. Solder was used to seal the joint between the neck of the glass vessel and the top of the lead pipe, in order to make the joint both airtight and watertight. At the very summit of the glass headpiece there was a vertical orifice in the glass, provided with a coarse thread. In order to close this opening there was obtained a screw plug (denoted here by *S*) made of copper or bronze, having a similar thread which permitted it to be screwed into the orifice and having also a handle at its top so that the screw plug could be tightened or loosened manually.

In getting ready for the performance of the experiment Berti erected the lead pipe at the front of his house in Rome and fastened it to the wall in such a position that the upper end of the pipe came to the level of a window. The globular, glass headpiece was mounted tightly into place by means of its neck fitted downward onto the top of the pipe, and the joint was soldered. A cask, perhaps about 75 centimeters (30 inches) in diameter, was installed on the ground directly beneath the bottom end of the pipe; and the cask was half filled with water so that the water covered the valve *V*.

The initial steps taken in the crucial experiment were as follows: (1) the valve *V* was closed and the cask was half filled with water covering the valve; (2) by working at the window level water was poured into the orifice at the summit of the headpiece until the entire lead pipe was filled and the headpiece was brimful; (3) the screw plug *S* was inserted into the orifice and screwed down tightly, thus causing the removal of any air that might have remained at the top of the headpiece and compressing the water in the apparatus; and finally (4) the valve *V* was opened.

Immediately the water level fell rapidly in the headpiece and thence into the upper part of the pipe, while a noise like a loud explosive thump was emitted from the headpiece attended by sounds like boiling and bubbling of water. Of course, the amount of water in the cask increased visibly, due to the quantity which issued from the bottom opening of the pipe. After the investigators inspected the headpiece, they could see nothing inside; it seemed to be empty.

By using a long rod as a measuring device Berti and his associates in the experiment were able to determine that the height of the column of water in the pipe was about 18 cubits above the level of the water in the cask, as Galileo had indicated for the case of water raised by means of a suction pump.

Then the investigators were faced with the question as to the nature of the contents of the headpiece. Was there a vacuum above the water standing in the pipe? After some discussions among the participants, Father Kircher suggested that a bell be installed within the headpiece with arrangements that would permit the bell to be vibrated in some manner. He thought that then they could tell from the absence or presence of sound emitted by the bell whether the space within the headpiece were vacuous or not.

To pursue this method of attack the apparatus was dismantled and the investigators undertook to have fabricated a suitable bell mechanism. This consisted in part of a bell suspended on a horizontal rod which could be mounted across the interior of the headpiece. The clapper of the bell was constructed of iron and had a pivoted lever-like projecting arm with a fairly massive hammerhead which could be attracted by means of a magnet (lodestone) brought close to it on the outside of the glass headpiece. After the bell mechanism was installed within the interior of the headpiece, and the experiment was repeated, the observers again noted that the water fell and left a column standing to a height of about 18 cubits. Apart from the bell mechanism within the interior of the headpiece, they could see nothing tangible in that space.

On bringing the loadstone up on the outside of the glass, the experimenters found they could indeed pull back the hammerhead due to the magnetic attraction of the material for the iron. When the loadstone was very suddenly withdrawn, the hammerhead fell under the control of the pivoted arrangement and hit the bell, whereupon the experimenters heard a weak sound of the bell ringing.

Fathers Zucchi and Kircher, who were essentially believers in the Aristotelian doctrines concerning physics and were inclined to doubt the existence of a vacuum, at once said that the sound of the bell ringing heard by the experimenters was evidence of the presence of some material medium within the headpiece, since sound cannot travel through a vacuum.

Long before the time of the experiment with the bell, the investigators had enlisted the aid of another person, namely, Father Emanuel Maignan, born in Toulouse in 1601 and known as a philosopher and mathematician. He did not believe in the Aristotelian doctrines and was inclined to consider that there was a partial vacuum actually present within the headpiece. To explain the sound of the bell-ringing heard by the experimenters Father Maignan put forth the theory that the vibrations of the bell had been transmitted by the solid rod serving as the support for the bell mechanism, and hence the rod could have produced vibrations of the headpiece which might have been heard. Father Maignan also agreed with Fathers Zucchi and Kircher that there might be some attenuated material substance within the headpiece after the performance of the experiment. There was a difference, however, between their explanations in regard to the nature and source of the postulated attenuated substance. Thus, Father Maignan thought it might have originated as a vaporous material from spume (foam) thrown up when the water appeared to boil and bubble at the instant the water fell so rapidly immediately after the valve *V* had been opened.

The participants were of varied opinions regarding the nature of the supposed attenuated material substance within the headpiece. Some thought it was air which had been present originally in the water or that it was a vaporous phase of water, released as a result of the boiling action manifested so suddenly after the valve *V* had been opened. Fathers Zucchi and Kircher apparently also considered the theory that some highly rarefied matter, like the "ether" postulated by the ancient Greeks, had somehow entered the headpiece by the action of Nature, which they believed would tend to prevent the existence of a vacuum.

Unfortunately, none of the experimenters was able to resolve the problem. From the vantage point of modern times one would be inclined to think that a partial vacuum had been formed above the falling water in the apparatus immediately after the valve *V* had been opened. Owing to the magnitude of the vapor pressure of the water relative to the much lower pressure in the partial vacuum, explosive evaporation, followed quickly by vigorous boiling of the water, would doubtless have occurred as the liquid fell so rapidly. Such an explosive evaporation would explain the loud noise heard by the participants as the water dropped so abruptly immediately after the opening of the valve. Moreover, the evaporation of the water into the space above its free surface in the apparatus would have added water vapor and probably released some air from that present in solution in the water and from that adsorbed on the inside face of the apparatus but freed when it became exposed.

If the space above the free water surface in the apparatus had thus become saturated with respect to water, the aqueous vapor pressure within the headpiece would have been about 31.67 millibars at a water temperature of 25° C., and 42.43 millibars at a temperature of 30° C. Saturated water vapor has a density of about 23 grams per cubic meter at a temperature of 25° C., and about 30.4 grams per cubic meter at a temperature of 30° C. On the basis of these data it is clear that if saturation with respect to water had occurred in the headpiece, there could have been sufficient density of water vapor to have permitted the propagation of acoustical vibrations through the vapor admixed with any residual air, thereby enabling the experimenters to have heard at least a weak sound from the bell. At best there was only a partial vacuum within the headpiece above the free water surface.

On the day following one of the experiments, Father Zucchi took note of the fact that the column of water had risen during the night. Such an increase in height of the column may have been due to a rise in the ambient atmospheric pressure and to a decrease of the vapor temperature and pressure within the apparatus, or both. Father Maignan was inclined to attribute the support of the column of water to the force of atmospheric pressure due to the weight of the atmosphere acting on the exposed surface of water in the cask. Probably the experimenters did not realize that they had, in effect, a water barometer, which was of momentous significance in the history of science and, in particular, of meterology.

Suggestions were considered for varying the experiment, and the following scheme was tried: (a) a fairly small hole, denoted here by *H*, was bored on one side of the original lead pipe at a level just below the neck of the headpiece; (b) one end of a length of small-bore lead pipe was inserted tightly into the specified hole; (c) the extension of this lead pipe was then bent into a siphon, that is, a shape something like that of a letter "n" but so adjusted that the free end of the pipe had a shorter leg than that which terminated in the bored hole *H*; (d) a valve, which we denote here by *L*, was installed near the free end of the siphon; (e) a vessel, such as a keg, which we denote by *K* was mounted on a window sill next to the window at which the headpiece was located; (f) water was poured into this vessel *K* and the free end of the siphon was immersed to the bottom of the water so that the valve *L* was well covered; (g) the valve *L* was closed; and finally (i) the experiment as originally performed was repeated. (See initial steps (1)–(4) as outlined above.)

As the water fell rapidly in the apparatus, it soon became apparent to the experimenters that the siphon had emptied of water from its summit to the hole *H*. When the valve *V* was closed and the valve *L* opened, water began to be drawn up into the siphon from the vessel *K*. The water then flowed through the siphon and entered the large lead pipe via the hole *H*. In a short time the water thus coming into the upper part of the apparatus completely filled the large lead pipe and reached up a considerable distance into the headpiece before it stopped.

It appeared as though the water had been sucked up from the vessel *K* by the siphon due to a partial vacuum in the apparatus above hole *H*. The water from this source, on being added to the water already present in the large lead pipe, enabled the headpiece to become partially filled, leaving a clear space within the upper part of the headpiece above the free water surface. There were prolonged discussions among the participants as to the nature of the clear space. Was it a vacuum? If not, was it air or vaporous material from water? Otherwise, was it "ether," a highly rarefied gaseous substance that somehow managed to penetrate the glass or lead in order that Nature might prevent the occurrence of a vacuum?

The experimenters could not reach unanimous agreement as to what actually held up the column of water in the apparatus at the conclusion of the original experiment. Neither could they agree as to the cause of the drawing of the water from the vessel *K* by the siphon in the second experiment. Finally, they were unable to resolve their disputes as to whether or not there was a vacuum at the top of the column.

Fortunately for the advance of science the mathematician and physicist Evangelista Torricelli (1608–1647) lived in Rome about the time that Berti and his collaborators performed the crucial experiment with the water barometer. It is known that he left Rome in June 1640 and returned about the end of February 1641. Torricelli was a very close friend of Magiotti, and also a friend of the young man Ricci, both of whom participated in the experiments in Rome. Documentary evidence reveals that Torricelli had friends in common with Father Maignan, such as Father Gio. Francesco Nicerone, a learned man in scientific and other matters. Letters preserved from the time under consideration indicate that Torricelli, Magiotti, and others of their scientist friends, such as Antonio Nardi, had corresponded with Galileo relative to various subjects. In view of these friendly relationships it can be inferred that Torricelli knew of the experiments with the water barometer carried out by Berti and his collaborators in Rome sometime during the period 1639–1641. One cannot be certain, however, that Torricelli had himself participated in any of those experiments when he lived in Rome.

It is quite certain that both Magiotti and Ricci had heard from Father Maignan the theory that the weight of the atmosphere produces a pressure which is exerted uniformly in all directions and that the atmospheric pressure served as the agency by means of which the column of water actually received support under the vacuum produced in the experiment. In view of the friendship between Magiotti, Ricci and Torricelli, it seems probable to the highest degree that Torricelli was informed of the above-mentioned theory expounded by Father Maignan. Not long after the time of the event related above Torricelli went to Florence in October 1641 to serve as an assistant to Galileo, then a very old man.

Galileo died in 1642, ending a long term as mathematician to the Grand Duke of Tuscany; and then Torricelli, his principal assistant, was appointed to this office. Berti, who had been so active in connection with the experiments in Rome, died shortly thereafter, sometime during the second half of 1643. It appears from the available evidence that Magiotti and Ricci then turned to Torricelli for advice concerning the possible resolution of the problems which remained following the experiments in Rome by Berti and his colleagues.

We emphasize these points because it has been all too common in the past to give almost complete credit to Torricelli for the invention of the barometer. In the light of the facts recounted above it is seen that after 1643 he was carrying on the work stimulated by Galileo's writings on the subject as brought to practical realization by the experimental undertakings of Berti and his collaborators with the water barometer. Because Torricelli must have known the essential features of the trials made in Rome with this apparatus, we cannot regard him as the actual inventor of the barometer, although we must credit him with perhaps a clearer grasp than his predecessors of the pertinent facts and physical principles involved.

It is worthwhile at this stage of the history to bring out the connection between the ideas expressed originally by Galileo, the experiments in Rome by Berti and his co-workers, and the steps taken afterward by Torricelli in Florence. With reference to the equipment depicted in fig. 12.2.1.2 (B) it will be recalled that Galileo had in mind, first of all, the introduction of a very thin layer of water within the cylinder and the removal of all traces of air through the narrow space around the wire *IK* as the piston was pushed to the top. He then proposed that the wire *IK* be pulled down so as to close the conical space *N* very tightly and that weights be added gradually to the vessel *Q*. It was his expectation that by this means a point would be reached at which the total weight *W* of all materials suspended below the water would become just sufficient to produce a vacuum between the lower surface of the water and the upper surface *EF* of the piston. According to his conception the value of the total weight *W* thus obtained would be indicative of the "force of the vacuum." After this stage was reached he contemplated that a similar idea might also be used to determine whether or not the "force of the vacuum" also was just sufficient to explain the breaking strength of a column of any desired solid material, such as marble or glass. This might be done, he believed, by forming columns of such materials having various lengths until breaking occurred because of their own weight, or by adding suspended weights progressively to a short column of the material until breaking took place. He conjectured, in effect, that if the sum of the suspended weights and the weight of the column of material were equal to the above-mentioned total weight *W* for the same cross-section area of material, it could be concluded that the "force of the vacuum" was just sufficient to hold the parts of the material together. If, on the other hand, the breaking of the column occurred when the sum of the suspended weights and the weight of the column of material were, say, $F \times W$, where F is a determined numerical factor exceeding unity, then it could be concluded that the "force of the vacuum" W for the given cross-section area accounted for only $1/F$ of the resistance offered by the material at the breaking point. In that case the excess amount $(F - 1)W$ would be attributable to some intrinsic force of cohesion of the material, or to the action of the vacuum in microscopic interstices.

In any event Galileo assumed as a matter of principle that the "force of the vacuum" measured by *W* for a given cross-section area of water supported under a vacuum provided a relative indication of the *lower limit* of the height of the column of any material which could thus receive its support. That is in effect, he said, that if the material is *N* times as dense as water, then the "force of the vacuum" will support a column of this material having a height of at least $18/N$ cubits, basing this conclusion on the fact that suction pumps would only lift water to a height of 18 cubits according to the experience of workmen who installed and operated such pumps.

This suggestion of Galileo turned out to be the means by which the questions raised by Magiotti and Ricci, in writing to Torricelli, were resolved. According to this idea the use in the tube of some liquid denser than fresh water should yield a column whose height is shorter than that observed by Berti, in inverse proportion to the specific gravity of the liquid. For this reason it appears that a proposal had been made by Berti that they try sea water in place of fresh water; and later some consideration was given to the plan of testing honey as the liquid instead of water. The crux of the problem, first of all, was for the investigators to have a clear understanding of the cause of the lifting of water by the suction pump and of the action of the apparatus employed by Berti at Rome. It then remained to demonstrate what role the vacuum played and to verify that consistent results could be obtained, depending upon the density of the liquid involved.

(9) Torricelli's Experiment with Mercury in the Tube, and Some Early Developments Relating to the Barometer.—During the period from October 1641, when Torricelli went to work in Florence under the guidance of his famous master Galileo until the time of the latter's death in 1642, there were doubtless occasions on which the two scientists had an opportunity to discuss the questions of mutual interest, such as the possible existence of vacuous spaces, the method of operation of suction pumps, and the significance of the experimental undertakings in Rome, described in the previous section. We do not know with certainty the exact date on which Torricelli took up the problem where it had been left upon the completion of the experiments in that city some time during the period about 1640–1641. We can be reasonably certain, however, that he was intensely interested in the subject and that he was further stimulated in pursuing the matter upon receiving in 1643 a request by mail from Magiotti and Ricci seeking suggestions with regard to additional work in connection with the apparatus employed by Berti and his friends.

At any rate, the happenings in Florence some time during the period about 1643–1644 reveal that Torricelli's co-worker Viviani was busily engaged in obtaining a supply of mercury and in helping to fabricate suitable glass tubes for a new experiment. Torricelli apparently had a very clear understanding of the causal mechanism by means of which the column of water used in the Roman experiment received its support, and we can assume that he devised the new experiment in order to test the theory, consideration being given to the ideas previously expressed by Galileo with respect to the effect of the specific gravity of the liquid employed, the volume of the vacuous spaces involved, and the strength of the material used.

It turned out that the essential point of the basic experiment in Florence hinged on Torricelli's grasp of the role played by the ambient medium in acting on the free surface of the liquid in the cistern. He believed that we live submerged at the bottom of an ocean of "the element" air, and he knew from the experiments of others that air has weight. On these grounds it is reasonable to expect that he came to the conclusion that the weight of the atmosphere gave rise to a pressure which is exerted on the free, exposed surface of the liquid (for example, the water in the well). Torricelli reasoned that this pressure could support the column while he also felt that since a vacuum has no weight or material existence, the vacuum would neither resist nor attract the column of liquid.[2] On this basis Torricelli reached the deduction that the height of the column of liquid supported under a vacuum ought to be determined by the weight of the column which would be in a state of balance or equilibrium with the pressure acting on the free, exposed surface of the liquid due to the weight of the atmosphere lying above a unit cross-sectional area of the surface. Assuming this deduction to be true it should follow that for any fixed atmospheric pressure and cross-sectional area the weights of the columns of all liquids which would be in equilibrium under this given pressure must be identical. The correctness of this deduction could be tested at least in part by comparing the weights of separate columns of different liquids in equilibrium under a vacuum at the same time. Torricelli knew that the density of mercury was about 14 times as great as that of water, and therefore if his hypothesis were true the height of a column of mercury which would be sustained by atmospheric pressure should be 1/14th as great as the height of a column of water supported at the same time. The famous experiment performed by Torricelli in 1643, illustrated in fig. 12.2.1.3 (B) was consistent with his hypothesis, and this led to the invention of the mercury barometer (see fig. 12.2.1.3 (A)), a matter of far-reaching importance for meteorology and other branches of science.

Torricelli proved by the experiment shown in fig. 12.2.1.3 (B) that neither the size nor the shape of the vacuum space had any effect on the height of the column of mercury, consistent with his view that there did not exist any "force of the vacuum" as assumed by earlier philosophers. By means of another experiment, illustrated in fig. 12.2.1.3 (C), he was able to demonstrate that it was actually the amount of pressure acting on the free, exposed surface of the liquid which controlled the height of the column, even though part of the pressure is not atmospheric.

The results of Torricelli were made known to scientists in many lands, and they stimulated great interest in the subject, which led along many paths to numerous develop-

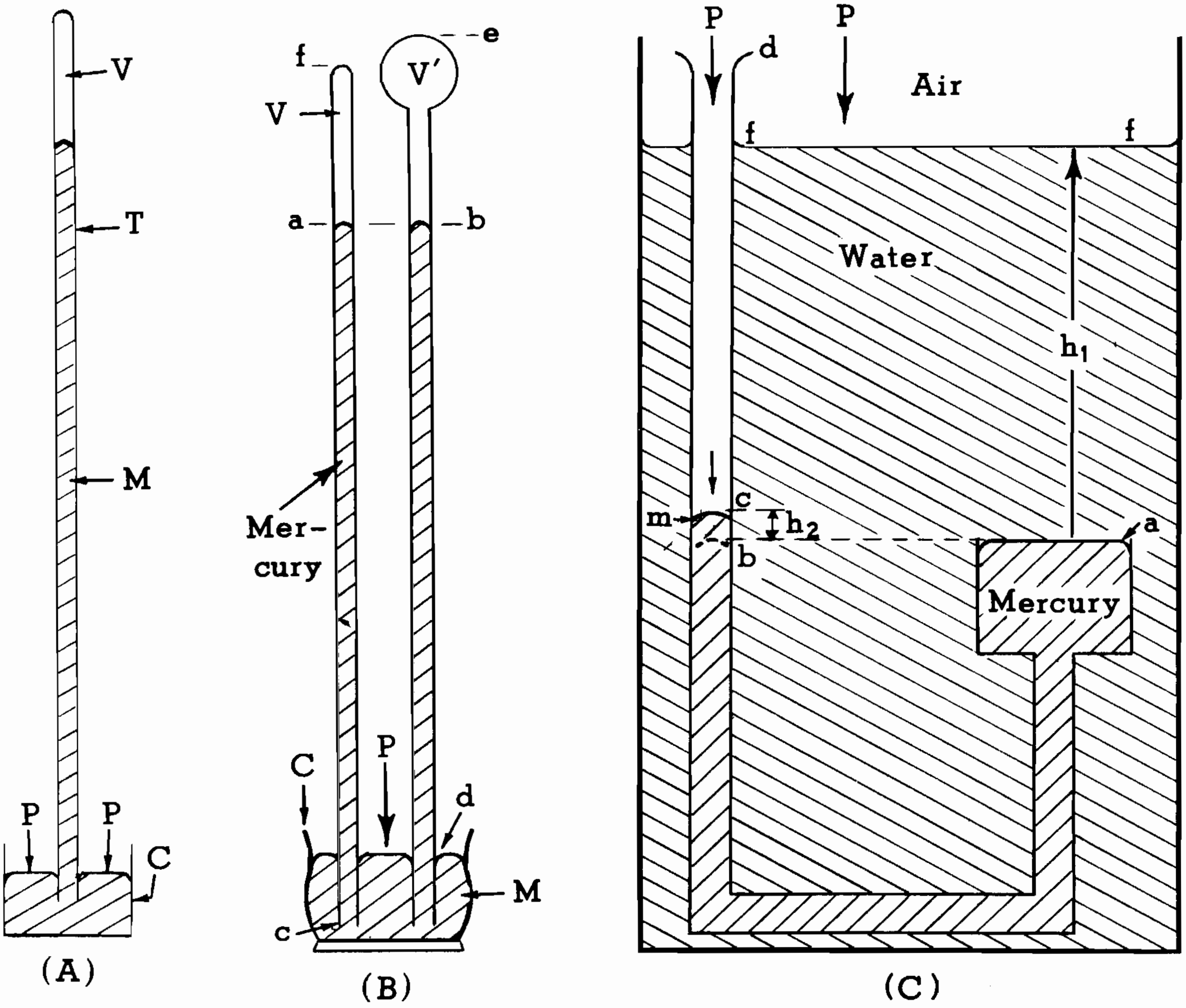

FIGURE 12.2.1.3. (A) Basic form of cistern barometer which arose from Torricelli's experiments in 1643, using (M) as the liquid.

(B) Famous experiment by Torricelli in 1643 which he used to demonstrate that the height of the mercury in the tubes is independent of the volume of the vacuum space (V or V'); also independent of the amount of *rarefied material* assumed to be in the space and thought by many philosophers to attract the quicksilver. Since the height of the mercury column is about 1/14 as much as that of the water column sustained under a vacuum, this indicated that the weights of the columns per unit cross-section area is the same in all cases at any time regardless of the substance and that the force supporting each of the columns on the given area is common to all, due to equilibrium with the pressure exerted by the weight of the overlying atmosphere.

(C) Experiment suggested by Torricelli in 1644 to prove that difference in pressures exerted on the two free surfaces (m and a) of a liquid in a U-tube controls the height difference (h_2) between the two surfaces. Observation reveals that the height difference is inversely proportional to the density of the liquid as indicated by the fact that h_2 is about 1/14th of h_1. This fact implies that difference in pressure is proportional to the product of the liquid density and the difference in height of the free surfaces, since the density of the mercury is about 14 times as great as that of water.

ments. Among these were the ingenious experiments conducted between 1657 and 1667 in Florence, Italy, by members of the Accademia del Cimento established under the protection of Grand Duke Ferdinand II of Tuscany. Many of the members were former pupils of Galileo. Some of the experiments are illustrated in figs. 12.2.1.4–12.2.1.7, which reveal first a desire to demonstrate beyond any doubt that it is not the vacuum at the top which supports the column of liquid, but rather the pressure ex-

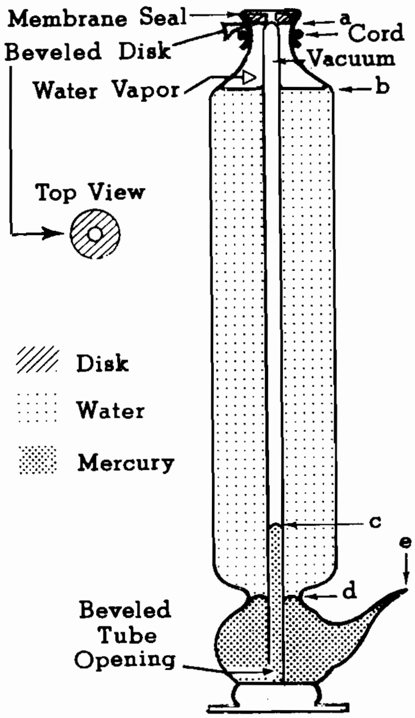

FIGURE 12.2.1.4. Experiment performed by the Accademia del Cimento of Florence, Italy, between 1657 and 1667, to demonstrate that the total pressure exerted on the surface of the mercury in the cistern determines the height of the column of mercury, provided there is a vacuum above the meniscus in the tube. At the beginning of the experiment, the preheated glass vessel above *d* is filled with vigorously boiling water through the hole in the beveled disk, and the membrane seal quickly and tightly secured by means of the cord at *a* for the purpose of excluding air from above the water. This leaves saturated water vapor in the space above *b* as the apparatus cools to room temperature. The height of the column of mercury is then *dc* (several inches), owing to the pressure on the mercury surface at *d* due to the weight of the column of water *db* plus the vapor pressure above *b*. When the membrane seal is punctured, the pressure due to the water vapor is replaced by that due to the atmosphere, and hence the meniscus *c* rises by an amount which is controlled by the difference between those two pressures. At the conclusion of the experiment, the height of the column of mercury above the mercury surface in the cistern exceeds the height of the column in a normal barometer by the amount equivalent to the pressure due to the weight of the column of water in the vessel.

erted on the free, exposed surface outside the tube containing the column. These experiments were capable of overcoming the views of existing philosophers who still believed in the idea that nature abhors a vacuum or that the so-called "force of the vacuum" sustains the column of liquid. A form of fixed-cistern barometer was constructed as illustrated in fig. 12.2.1.6 (A), while fig. 12.2.1.6 (B) indicates that the members of the Accademia made use of the difference in readings at the base and top of a tower for the purpose of determining the

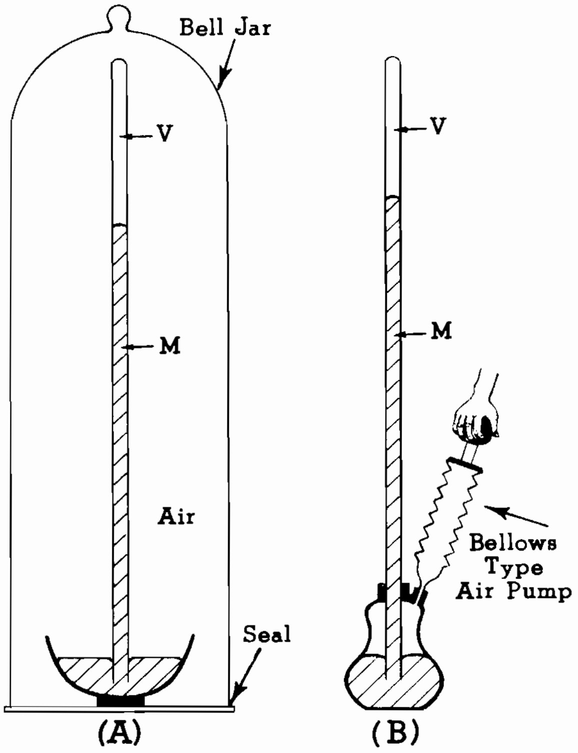

FIGURE 12.2.1.5. Experiments performed by the Accademia del Cimento of Florence, Italy, about 1657–1667, to determine what gave support to the column of mercury (*M*).

(A) *Left-hand side:* Demonstration that the pressure of the air contained under an airtight bell jar was sufficient to sustain the column and that the pressure of the atmosphere outside the jar played no part in the support of the column under these conditions.

(B) *Right-hand side:* By means of an air pump which could produce a greater or lesser pressure it was proved that the actual pressure exerted by the air on the surface of the mercury in the cistern controlled the height of the mercury in the tube. When the air in the cistern was heated with a flame, the mercury column rose, showing that increase of temperature of the mass of air caused increase of the pressure which it yielded; whereas when the air was cooled with ice, the column descended, showing that decrease of temperature of the air produced a decrease of pressure.

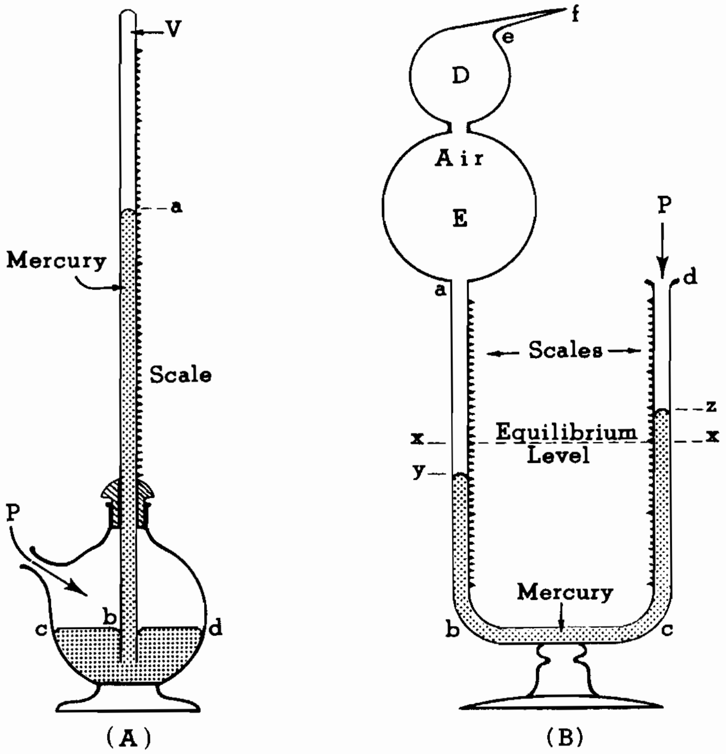

FIGURE 12.2.1.6. (A) *Left-hand side:* Large, fixed-cistern mercury barometer constructed by the Accademia del Cimento of Florence, Italy, between 1657 and 1667, in which the scale graduations were prepared of small beads of enamel.

(B) *Right-hand side:* A gas barometer device constructed by the Accademia del Cimento (1657–1667), used for the purpose of determining the heights of towers, hills, etc. Observations were made at the base and top of the eminence to ascertain yz. The latter is a measure of twice the increase in volume of the enclosed air with respect to the volume which exists when the menisci are at the equilibrium level, x–x. This observed quantity yz is also related to the difference between the outside atmospheric pressure, P, and the pressure of the enclosed air within E. Provided the apparatus is kept at a uniform temperature, it would be possible to relate the observed data at base and top to the corresponding ambient atmospheric pressures, by virtue of Boyle's law. (This law states that, in the absence of condensation, the product of the pressure and volume of a fixed mass of gas maintained at uniform temperature is a constant.) In order to determine accurately the heights of hills, etc., it is necessary to make use of the logarithm of the ratio of the ambient pressures at the base and top; taking account at the same time of the average temperature of the air between the two levels (see Appendix 7.1).

height of the tower. Investigations of this character represent some of the earliest work in the field of hypsometry.

Pascal,[2] who lived from 1623 to 1662, learned of Torricelli's famous experiment in about 1646 from M. Petit, chief of the Department of Fortification, in France; and together they repeated that experiment in 1646 at Rouen. From that time until some date in 1648 he performed many actual experiments and "thought experiments" which were crucial to an understanding of the subject. Thus, he obtained a glass tube 46 feet long and was able to prepare a water and wine barometer said to have contained 33 feet of wine in the upper portion and 13 feet of water in the lowest portion of the tube. Fig. 12.2.1.8 shows how he demonstrated that the actual height of the column of liquid is controlled by a balance with the outside pressure, depending upon the density of the liquid, but regardless of the lengths, sizes, shapes, and slopes of the con-

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[2] B. Pascal, "The Physical Treatises of Pascal. The Equilibrium of Liquids and the Weight of the Mass of the Air." (Originally published in Paris in 1633, by F. Perier.) Translated by I. H. B. and A. G. H. Spiers, with introduction and notes by Frederick Barry; Columbia University Press, New York (1937). Note: Torricelli's letters on the pressure of the atmosphere are quoted on pp. 163-170.

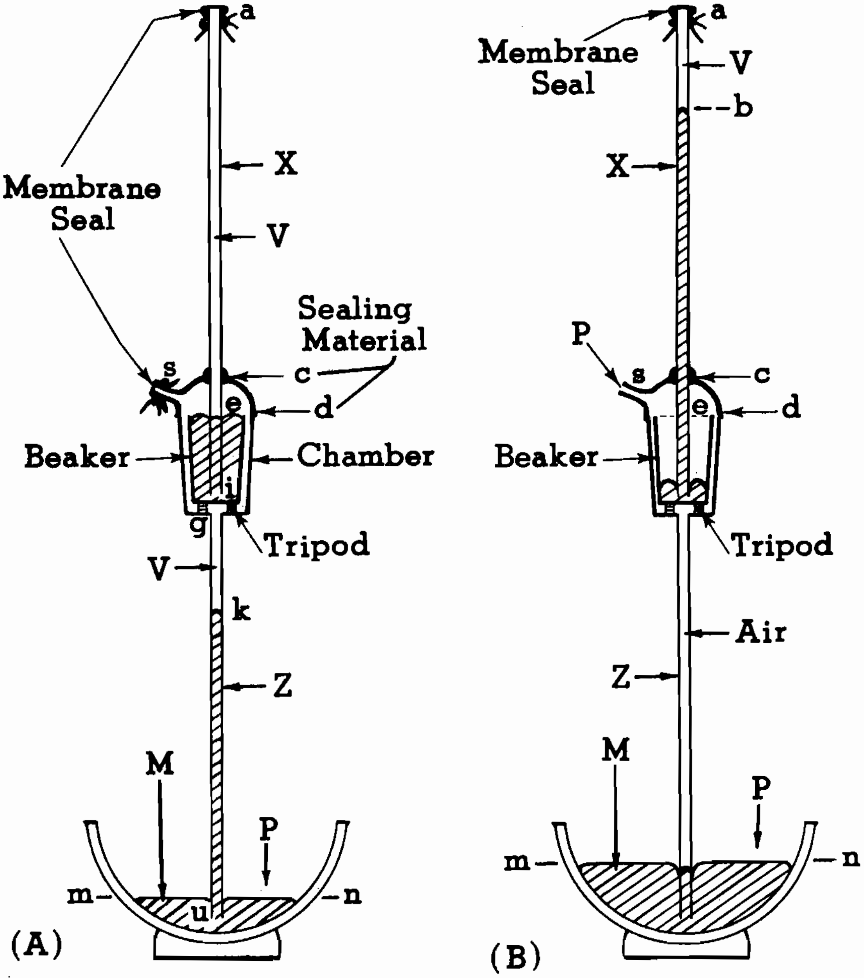

FIGURE 12.2.1.7. Experimental apparatus devised by the Accademia del Cimento of Florence, Italy, between 1657 and 1667, to demonstrate that the pressure exerted by the atmosphere sustains the column of mercury in a barometer; not the abhorrence by nature of a vacuum as many philosophers of the time assumed. (A) At the beginning of the experiment, the membrane seals were secured in place at points *a* and *s*, the tube was inverted, the system was completely filled with mercury through the open end of the tube (*u*) which was then closed, the system was erected, the end *u* was immersed in a basin of mercury, and the end *u* was opened. The mercury then redistributed itself to the condition shown by figure (A). A vacuum (*V*) was established in the vacant space indicated above the meniscus *k* within the system. The beaker was observed to be brimful of mercury to the level *e*, and there was no column of mercury in the tube extending from *e* to *a*, since there was a vacuum above the mercury meniscus at *e*. The height of the column of mercury from the surface *m–n* to *k* was about 30 inches at sea level. When the membrane seal at *s* was broken, air rushed into the chamber, and the mercury redistributed itself to the final condition indicated by figure (B). The height of the mercury column *X* below the meniscus *b* was found to correspond to that of the mercury column *Z* below meniscus *k* previously observed as indicated by figure (A). This revealed that the causes of the elevation of these two columns was the same, viz., the exertion of ambient atmospheric pressure, *P*. Since the mercury column *Z* sank into the basin after the membrane at *s* was punctured, it was clear the equilibrium of pressure within the tube below *Z* and upon the exposed surface *m–n* prevented the existence of a mercury column within the portion of the tube marked *Z*.

tainer. In fig. 12.2.1.9 there may be seen one of the ingenious experiments due to Pascal, designed to show that it is neither the "force of the vacuum" nor the abhorrence by nature of a vacuum which supports the column, but rather the pressure due to the atmosphere. He also conducted many experiments which involved the use of bellows, syringes, syphons, and tubes having various lengths, shapes and sizes, enclosing various fluids, such as air, mercury, oil, water, wine, etc. A pamphlet describing these experi-

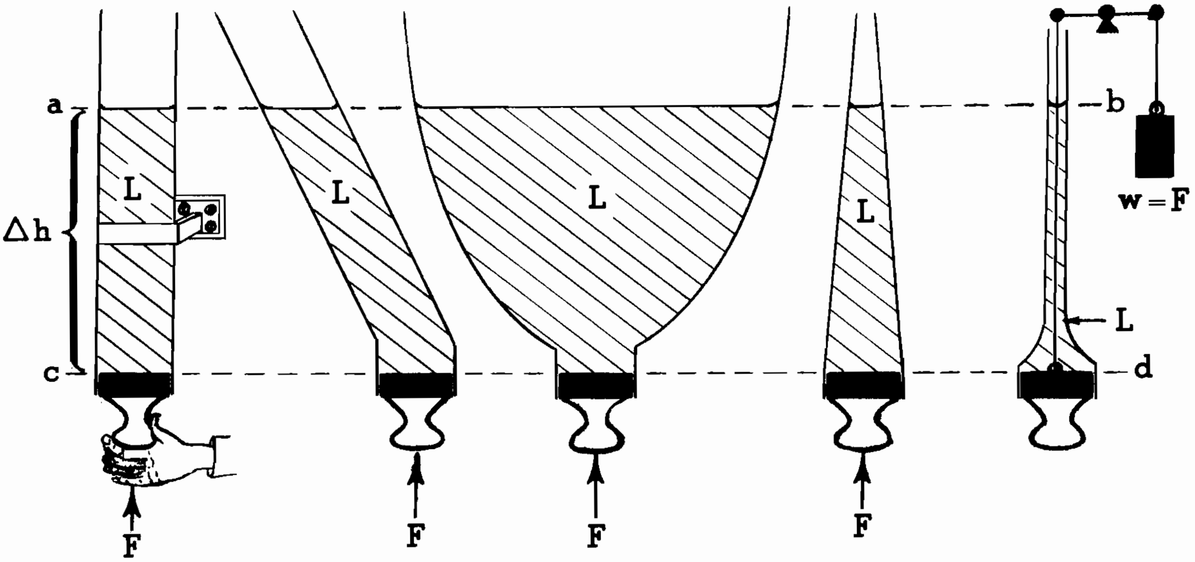

FIGURE 12.2.1.8. Pascal's conception published in 1663 of a means of proving by hydrostatics that the pressure which a liquid exerts on a surface is proportional to the height of the liquid above the surface and is independent of shape, size, or slope of the containing vessel, since the force, *F*, necessary to sustain the plunger at the bottom is the same for all of the vessels.

ments was published in 1647 by Pascal and given wide distribution.

Toward the end of that year he also thought of testing the variation of pressure with altitude in the atmosphere, since this would reveal whether it was the weight of the air which gave rise to the atmospheric pressure.* With this object in view, he requested his brother-in-law, M. F. Perier, to carry a barometer from the base to the top of the Puy de Dome, a mountain whose elevation is about 4800 feet, rising above the town of Clermont. On September 20, 1648, Perier climbed with a mercury barometer from the Convent of the Minim Fathers near Clermont to the top of the Puy de Dome, a difference in height somewhat over 3000 feet; and he observed that the mercury fell about 3.13 inches. During the course of the climb a barometer which had been left at the convent was observed continuously and the height of its mercury column was found to have remained essentially unchanged. Similar experiments on a smaller scale were performed at the base and top of the highest tower of the church of Notre Dame de Clermont, and at other places, all of which showed a systematic decrease of pressure with altitude as expected by Pascal. The latter also carried out such experiments at several towers of churches in Paris with results that confirmed those obtained by Perier. In this manner a foundation was laid for the understanding of the variation of pressure with altitude.

By virtue of the fact that the weight of the atmosphere should vary with its degree of heat and humidity, Pascal expected that the barometer reading should vary with different weather conditions. Perier began making regular barometric observations at the beginning of the year 1649 and continued until the end of March 1651. The aid of a friend of Perier was enlisted to perform similar observations at Paris, and these were continued from 1 August 1649 until the end of March, 1651. Messrs. Chanut and Descartes, at that time in Stockholm, Sweden, also collaborated by making barometric observations from October, 1649 until September, 1650. Thus, the first historical synoptic network was in effect during the overlapping period of these observations. It was clearly indicated by these observations that the height of the mercury column in the barometer did vary more or less in accord with the expectation of Pascal.

Information concerning the ideas and experiments of men like Torricelli, Pascal, &

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* It is only proper to point out that Descartes also had the idea that the height of the column of mercury should fall as the mercury barometer is carried to higher elevations.

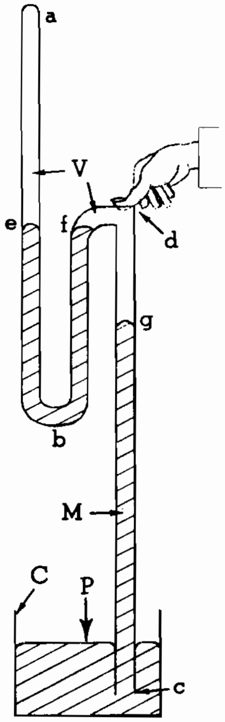

FIGURE 12.2.1.9. Apparatus designed by Pascal (published 1663) to demonstrate that the pressure exerted by the atmosphere sustains the column of mercury in a barometer rather than the commonly assumed nature's abhorrence of a vacuum. At the beginning of the experiment, the tube is inverted, the opening at *d* closed, the entire tube filled with mercury, the opening at *c* closed with a tightly sealed membrane, the tube raised erect, the end *c* immersed in mercury of the cistern, and finally the membrane removed. The figure shows how the mercury then distributes itself, with *g* normally about 30 inches above the mercury surface in the cistern when at sea level. Pascal's idea was to show that in case no air pressed on the lower meniscus in a U-tube barometer, e.g., by replacing the air with a vacuum, there would not be an elevated column of mercury; but instead the levels of the mercury on the two sides of the U-tube, as at menisci *e* and *f*, would be equal, owing to the equilibrium which exists by virtue of the vacuum *V* present in the spaces to which these menisci are exposed. On the other hand, if the atmosphere is enabled to gain access to the meniscus at *f* by removing the thumb from the opening at *d*, the vacuum in the space *fdg* will be replaced with air at atmospheric pressure, which will cause the meniscus *f* to sink and meniscus *e* to rise until the difference between their heights is the same as the difference between the heights of the menisci in a normal U-tube barometer observed at the same time and place. When the thumb is removed, the equality of pressure, *P*, exerted at *g* and on the exposed surface of the mercury in the cistern causes the column of mercury below *g* to fall into the cistern.

Descartes was widely and fairly quickly distributed by various correspondents who were interested in scientific matters (e.g., Mersenne, of France); hence much activity went on in scientific and other enlightened circles during the period from the time of Galileo to well into the next century. Great interest and immense stimulation of invention and scientific experimentation took place in England and in the countries of western Europe during this period. Some faint notion of the developments in these fields can be gained from a study of the figures, and from a knowledge of the scientific work with which the names of the persons involved are associated.

Mention may be made at this point of the invention of the earliest form of vacuum pump by Otto von Guericke of Magdebourg about 1654, and the numerous experiments which he performed with its aid after producing sizeable vacua by pumping the air out of various vessels. Further mention is owing to the famous English scientist Robert Boyle who greatly improved the vacuum pump which he used as a means of studying the elastic properties (spring) of air and many phenomena associated with the vacuum.[3] The discovery of the law, now known as Boyle's law (see sec. A–2.13 and Appendix 7.1), was announced in 1662.

Many exchanges of ideas and experimental facts took place between such well-known contemporaries as Boyle and Robert Hooke. Fig. 12.2.1.10 (A) illustrates the siphon barometer first described by Hooke in 1665; while fig. 12.2.1.10 (B) shows an early form of siphon, fixed-cistern barometer which appeared about the same era but probably a little later. In fig. 12.2.1.11 there is depicted Hooke's wheel barometer, described in 1665, and capable of giving magnified indications of the variations of the movement of the top of the mercury column. One should note that the wheel barometer utilizes a siphon form (U-tube).

An entirely different principle of operation is represented in fig. 12.2.1.12, which reveals that Boyle made use of the varia-

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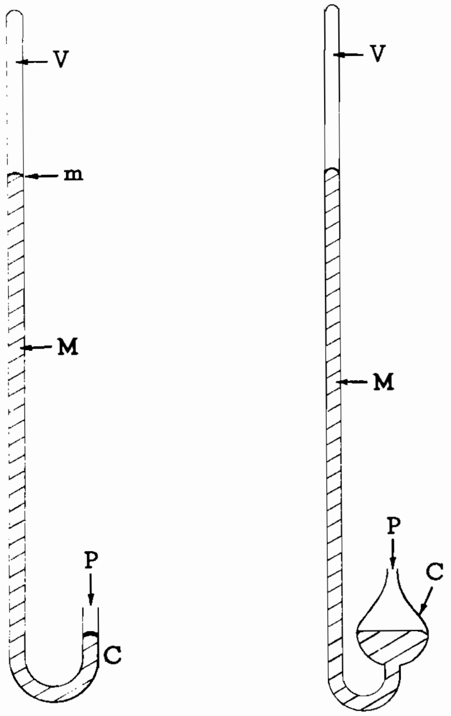
[3] R. Boyle, "New Experiments Physico-Mechanical Touching the Spring of the Air and Its Effects," Oxford, First Edition 1660; Second Edition 1662; Third Edition 1682.



(A) (B)

FIGURE 12.2.1.10. (A) *Left-hand side:* Basic form of siphon (U-tube) barometer. The siphon barometer with its U-tube of uniform cross-section area was first described by Hooke in 1665 (see wheel barometer).

(B) *Right-hand side:* An early form of siphon (U-tube), fixed-cistern mercury barometer. (Note: Failure to make the working portion of the cistern *C* cylindrical caused the scale of the barometer to be nonuniform.)

tions of the buoyancy of the air to cause his statical baroscope to function. He observed that the light, air-filled glass sphere would sink under certain conditions and rise under others. Actually we know that the changes in the weights required to establish balance served as an index of the variations in density of the air. On these grounds, it may be seen that the baroscope indications depend not only on pressure variations, but also on temperature and moisture variations.

There was much interest during the era about 1665-1710 in endeavors to develop methods of magnifying the movement of the barometer indication. One of the first of these was a water barometer about 33 feet high constructed by Otto von Guericke before 1660.[4] Figs. 12.2.1.13–12.2.1.15 and 12.2.1.17–12.2.1.19 are examples of the many ingenious efforts made to secure magnification as mentioned earlier (see sec. A–2.13).

In fig. 12.2.1.16 there is shown schematically Hooke's invention which was intended to be used on board vessels for the determination of atmospheric pressure. The principle of this instrument is similar to that of the sympiesometer, described briefly in sec. A–2.11. Basically, the fundamental underlying idea of this device is that the volume occupied by the dry air entrapped in the bulb is dependent on its temperature, the pressure exerted by the atmosphere on the free surface of the liquid in the tube, the height of the column of liquid, *L*, the density of the liquid, the capillary effect (see sec. 2.7.1), and the value of the local acceleration of gravity. The temperature and height of the column of liquid can be observed. Thus, it

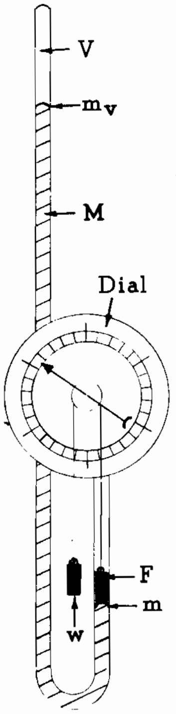


FIGURE 12.2.1.11. Wheel barometer invented by Hooke and first described in 1665. The float *F* was made of iron and the cord running over the pulley was held taut by the weight *w*. Although the movements of the menisci, *m* and m_v, were alike, that of the pen point indicator was relatively enlarged owing to the action of the pulley.

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[4] E. Gerland und F. Traumueller, "Geschichte der Physikalischen Experimentierkunst," Leipzig, 1899.

should be possible to calibrate the device by comparison with pressures determined by means of a properly corrected mercury barometer, taking account of both temperature and height of the liquid column. The device was suggested by Hooke since mercury barometers during his time suffered from effects of pumping and swinging when installed aboard ships during stormy weather, inasmuch as they were not equipped then with a restriction to damp out oscillations of the mercury (see secs. 2.6 and 2.7.6).

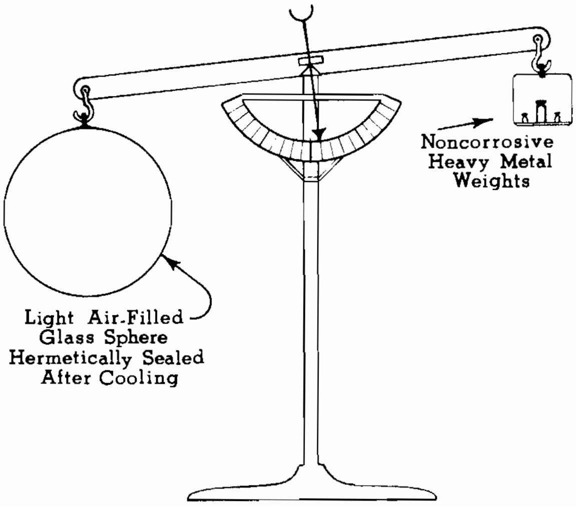
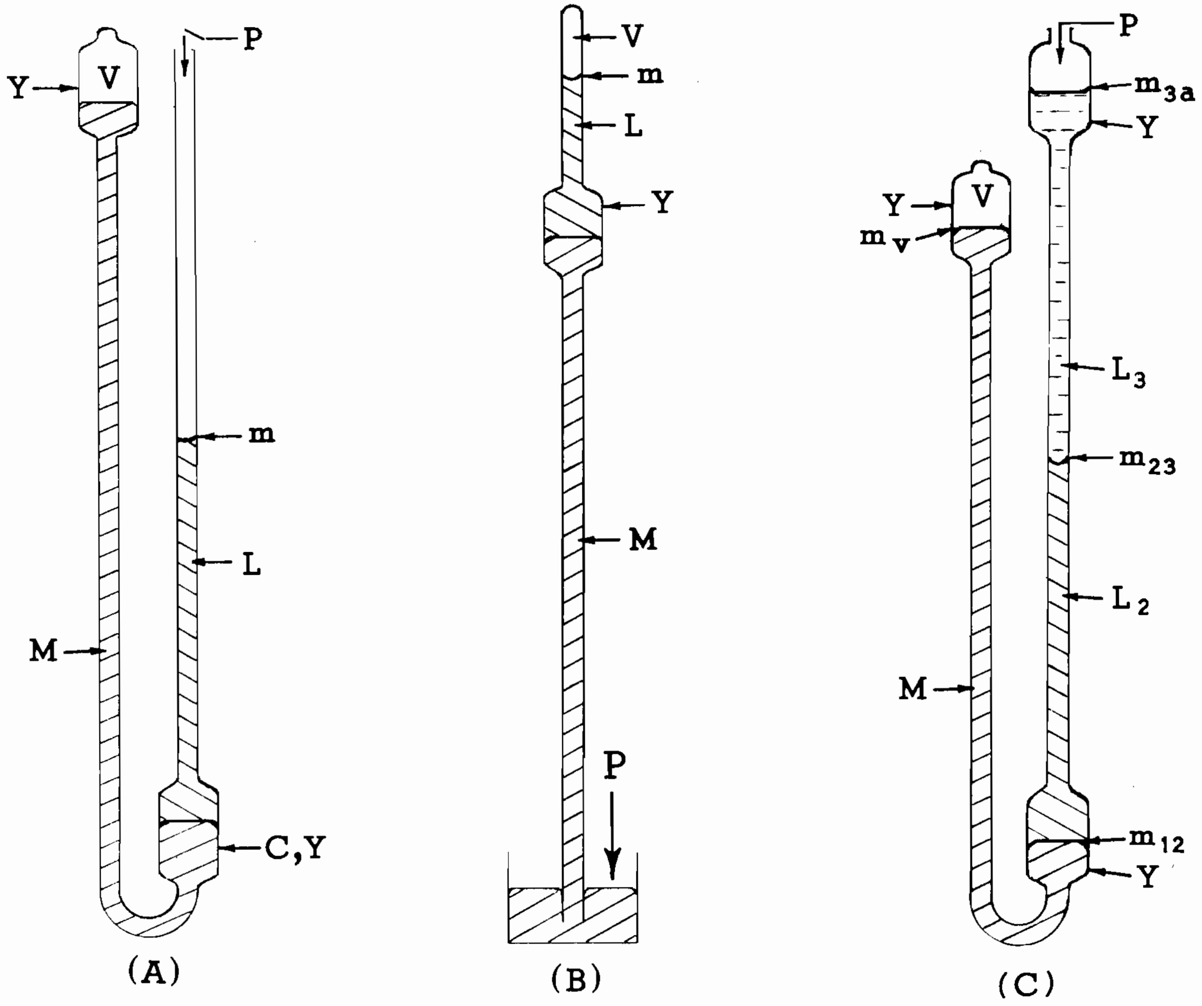


FIGURE 12.2.1.12. Statical baroscope due to Robert Boyle (1666), in which the total weight of metal on the right-hand pan necessary to balance the sphere on the left was negatively correlated with the density of the ambient air.



(A)

(B)

(C)

FIGURE 12.2.1.13, (A) A double U-tube barometer containing two liquids, invented by Huygens about 1666 (described in 1672). Either water or a mixture of water and nitric acid was used as the liquid *L*, and the cross-sectional areas of the upper cistern *Y* and of the lower cistern *C,Y* were the same. An expanded scale of movement of meniscus *m* was obtained owing to the fact that the cross-sectional area of *Y* was greater than that of the tube. Hooke invented a similar form of double barometer in 1668, but employed for *L* a mixture of oil of tarter and rectified alcohol obtained from wine by repeated distillation. Loss of *L* by evaporation was a disadvantage in both cases.

(B) A form of 2-liquid barometer suggested by Descartes and first constructed by Huygens about 1666 (described in 1672). Use of water as the upper liquid, *L*, rendered it unsatisfactory owing to its high vapor pressure and the release of dissolved air in the vacuum space, *V*. The enlargement of the upper cistern *Y* yielded an expanded scale of movement of the meniscus *m*.

(C) A compounded barometer invented by Hooke (1685) which involves the use of three liquids in decreasing order of density, *M* (mercury), L_2 and L_3. The cross-sectional areas of the three cisterns, *Y*, are all equal. Owing to the design, the movement of meniscus m_{23} is enlarged in comparison with that of the other menisci, m_v, m_{12}, and m_{3a}. Colored alcohol and water were used for liquid L_2; while turpentine was employed for L_3. The arrangement of tube and cisterns on the right-hand side of this apparatus permits the combined total height of the column of two liquids L_2 and L_3 above the meniscus m_{12} to remain essentially constant regardless of normal movements of m_{12} due to pressure changes. This reduces variations in the correction necessary to take account of the pressure effect of this column on the height of the meniscus m_{12}.

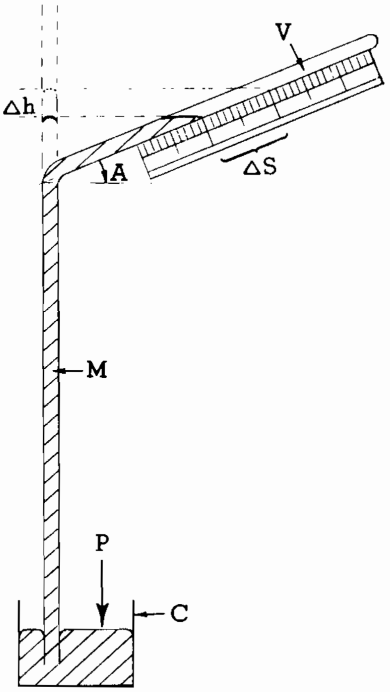


FIGURE 12.2.1.14. Diagonal barometer invented about 1670 by Sir Samuel Morland. While the height of the mercury column in a conventional barometer will rise Δh, the meniscus m in the sloping portion of the tube will move up a distance ΔS, where $\Delta S = \Delta h / \sin A$, in which A = angle of inclination of the sloping portion. Thus, if A = 30 degrees, $\sin A$ = 0.5, and $\Delta S = 2\ \Delta h$, yielding a two fold magnification of the movement. Use of a helical coil instead of the sloping tube to secure still greater degrees of magnification was suggested by Hicks in 1862.

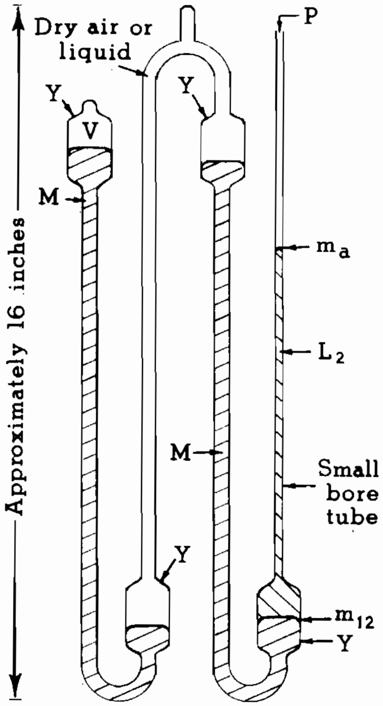


FIGURE 12.2.1.15. Shortened barometer developed by Amontons (1688) as an outgrowth of the earlier forms of double barometer (M = mercury, L_2 = light liquid; Y = cross-sectional area of cisterns, all equal). The shortness of the apparatus made it more portable than the conventional barometer; but this device suffered from the facts that the temperature correction was large and somewhat irregular, while the liquids used tended to leave a film on the interior of the working section of the glass tube, which hampered reading. Fouling of the observed meniscus m_a, the loss by evaporation of L_2, and temperature effects which were not clearly recognized at the time presented disadvantages that compensated for the gain resulting from enlargement of movement of m_a in comparison with that of m_{12}.

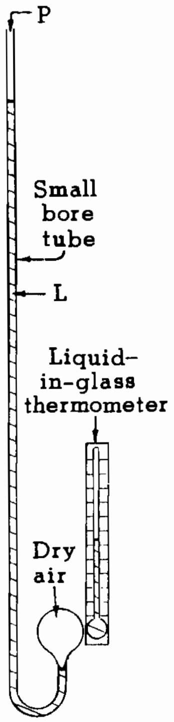


FIGURE 12.2.1.16. Combination of air thermometer and liquid-in-glass thermometer designed to serve as a marine barometer (invented by Hooke before 1700 and also described by Amontons in 1705). Liquid *L* should have small vapor pressure and low surface tension. The principle underlying the evaluation of the readings is the same as that of the sympiesometer.

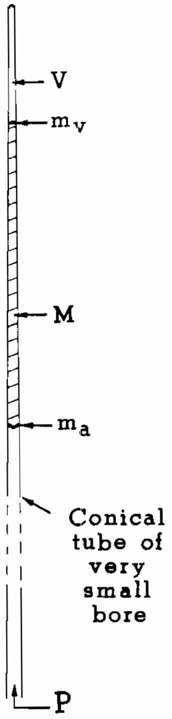


FIGURE 12.2.1.17. Conical mercurial barometer due to Amontons (1695). The movement of its upper meniscus m_v is greatly enlarged in comparison with that of the conventional barometer, for any given atmospheric pressure change. An increase in pressure causes the mercury to rise, but the fact that upper meniscus advances into a more and more restricted portion of the tube increases the vertical displacement of m_v relatively to that in a tube of uniform bore. When a decrease of pressure takes place, the reverse effect occurs. Effects of friction and capillarity make it practically impossible to calibrate the conical barometer of very small bore; and there is the added disadvantage that the fine thread at the top of the conical tube breaks readily.

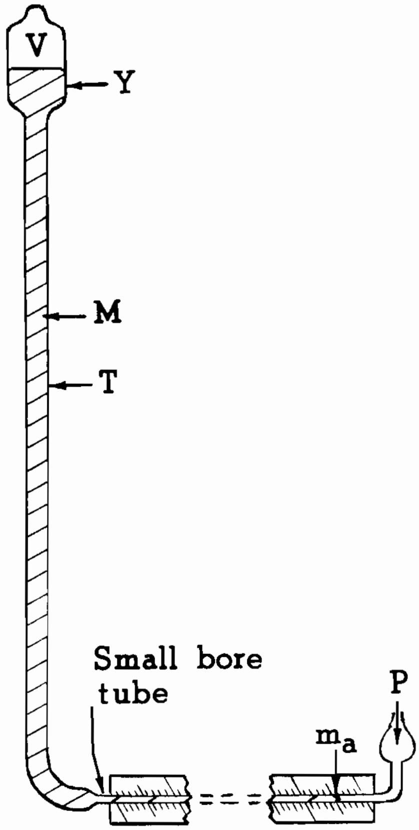


FIGURE 12.2.1.18. Instrument containing mercury (M), termed "horizontal," "rectangular," or "square" barometer, which provided a greatly enlarged scale of movement of the meniscus m_a compared to that of the conventional barometer. An apparatus of this type, however without the lower catch cistern (near P), was manufactured in London by Francis Hawksbee the Elder prior to 1704, when it was described in a book by John Harris. Instruments of the same general design have been attributed to J. Bernoulli and J. Dominic Cassini (1710). The magnification of movement is governed by the ratio of the cross-sectional areas at Y and at m_a. A disadvantage is the ease with which the mercury in the small-bore horizontal tube breaks when there is a very sudden change of pressure or the instrument is subjected to a shock.

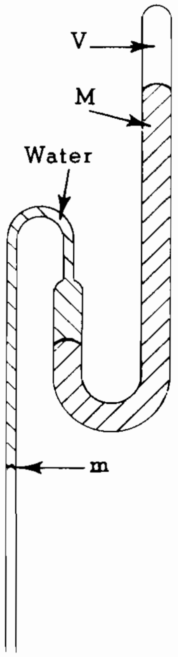


FIGURE 12.2.1.19. Compound barometer due to Rowning (1744), which involved the use of mercury (M) and a less dense liquid (water in his case) with large and small bore tubes, respectively, such that the displacement of the meniscus m in the small-bore tube is magnified in comparison with that of a conventional mercurial barometer for a given pressure change.

APPENDIX 2.8.1

EXAMPLE OF PERFORMANCE REQUIREMENTS FOR A PRECISION ANEROID BAROMETER OF STATION TYPE

The following paragraphs constitute a copy of the performance requirements extracted from U.S. Weather Bureau Specification 450.7203, revised October 1, 1955, pertaining to a station type precision aneroid barometer which is used primarily at land stations to determine the ambient barometric pressure as required for meteorological purposes. The least scale graduation of this instrument is 0.5 mb.; the scale diameter is nominally six (6) inches; and the pointer of the instrument is required to cover a traverse of not less than 330 degrees nor more than 360 degrees of arc on being subjected to the range of barometric pressure indicated in the little table now given:

Designation of instrument according to range:

	Pressure range (mb.)
572–0	1060–870
572–2	990–800
572–4	920–730
572–6	850–660
572–8	780–590

"PERFORMANCE REQUIREMENTS"

"**P.1.1 Positional Test.**—The barometer shall be so designed that when a reading is made while the barometer is in the normal wall-mounting position against a vertical plane surface with the midpoint of the scale at the top and with the pointer on scale within the pressure range for which the barometer is designed, tilting of the barometer 90 degrees from this position into a horizontal position with the dial facing up shall not cause a change in indication greater than 0.3 mb. Starting with the barometer in the normal wall mounting position described above and with the pointer on scale within the pressure range for which the barometer is designed, tilting of the barometer 45 degrees in any direction shall not cause a change in indication greater than 0.2 mb. The barometer shall meet this requirement at all pressures within the range of the scale.

"**P.1.2 Scale Accuracy at Room Temperature (20° C to 30° C) (68° F to 86° F).**—The barometer shall be compared with a standardized mercurial barometer. Both instruments shall be connected to the same pressure system and shall be exposed to the same pressures. During the test the temperatures to which the barometer under test and the standardized mercurial barometer are exposed shall not change more than 4 degrees C (7 degrees F) from their temperatures at the start of the test. The barometer under test shall have been at ambient room pressure and temperature for at least fifteen hours before the test is started and during this period no calibration adjustments shall have been made.

"For a period of one hour immediately before taking test data the barometer under test shall have been exposed to pressures within the scale range for which it is designed and during this period shall have been subjected to a number of pressure cycles of range equal to but not greater than the range of its scale. A cycle consists of decreasing the pressure from the highest point on the scale to the lowest point on the scale and then increasing the pressure back to the highest point on the scale. The purpose of cycling is to artificially condition the barometer to the pressures to which it will be exposed when installed at a station. The instrument ordinarily "creeps" during cycling. After cycling it has approximately the range that will be experienced after it has been installed at a station having pressures within the scale range of the barometer. The speed and time spacing of the cycles within the one hour period is optional except that the speed shall not be such as to damage the barometer. If the barometer is within the pressure range of its scale at ambient room pressure the calibration readings may be taken immediately after cycling the barometer *twice* without waiting for the one hour period. If the elevation above sea level of the manufacturing plant is such that the 572-0 type barometer is on scale at ambient room pressure the number of cycles given for the various ranged barometers shall be as given in Table I below:

TABLE I

Type:	*Number of cycles*
572–0	2
572–2	4
572–4	6
572–6	8
572–8	10

"It will be noted that the number of cycles increases by two for each successive scale range away from the ambient pressure of the manufacturing plant. If the elevation above sea level of the manufacturing plant is such that the ambient room pressure falls within the scale range of one of the higher elevation type barometers, cycling shall be done according to a new table having the two-cycle value opposite the type that is on scale at ambient room pressure. The number of cycles shall be increased by two for each successive scale range away from the two-cycle type. An example follows where the type 572-4 is on scale at ambient room pressure because the plant is at an elevation above sea level of 5000 feet:

Type:	*Number of cycles*
572–0	6
572–2	4
572–4	2
572–6	4
572–8	6

"After the necessary cycling has been completed, test data shall be taken during an additional cycle and scale errors determined at both increasing and decreasing pressures. In making acceptance tests, the ordering office reserves the right to select as many test points as deemed necessary to determine if the barometer meets the tolerance requirement herein. The barometer under test shall be gently tapped or vibrated before each recording is made. Test points at which data are taken shall have the same pressure value for both increasing and decreasing pressures within ±1.0 mb. Test points used to determine the calibration of the barometer shall include one within ±5 mb. of the midpoint of the scale, one within 3 mb. of the high end of the scale, and one within 3 mb. of the low end of the scale. The time interval between any two successive readings shall be not less than one minute for each 10 mb. change in pressure. When tested in accordance with the above procedure the largest difference between scale errors shall not exceed 1.0 mb. Within the readability of the instrument (approximately .1 mb.), errors determined at any two consecutive test points shall not change in magnitude by more than 0.75 percent of the pressure change between those points. This shall be true over the entire range of the scale. At any individual test point within the scale range of the barometer the difference between the error determined at decreasing pressure and that determined at the same point at increasing pressure or vice versa, shall not exceed 0.4 mb. No error shall exceed 1.5 mb. in magnitude.

"**P.1.3 Temperature Compensation.**—This test applies to all constant pressures within the scale range of the barometer. The barometer under test shall be compared with a standardized mercurial barometer that is connected to the same pressure system as the barometer under test. The barometer under test shall be maintained at a temperature of 40 degrees C (104 degrees F) for from one to one and a half hours in a chamber in which the air is stirred by an electric fan or other suitable means. During this test the temperature to which the barometer is exposed shall not vary more than ±3 degrees C (±5 degrees F) from the specified values. The equipment shall be arranged so that the standardized mercurial barometer and the barometer under test are exposed to the same pressure when readings are taken. During this period and before any readings are taken the barometer under test shall be cycled in accordance with instructions in P.1.2 unless the cycling has been done previously and the barometer has remained at pressures within the range of its scale since that time. After from one to one and a half hours the barometer under test shall be read at some selected point on the scale and the error determined. The temperature shall then be reduced to 10 degrees C (50 degrees F) and maintained for from one to one and a half hours. During this period the barometer under test shall continue to be held at pressures within the range of the scale but it shall not be cycled. After one hour but no longer than one and a half hours the barometer under test shall be read at a pressure within 1.0 mb. of the point at which the reading at 40 degrees C (104 degrees F) was taken and the error determined. The lapse of time between the readings taken at 40 degrees C (104 degrees F) and 10 degrees C (50 degrees F) shall not exceed one and one-half (1-1/2) hours nor be less than the one (1) hour specified. If the barometer under test is allowed to drift off scale to room values after the reading at 40 degrees C (104 degrees F) has been taken and before the reading at 10 degrees C (50 degrees F) is taken the barometer shall remain at room pressures for at least twelve (12) hours after which the cycling procedure used in preparation of the 40 degrees C (104 degrees F) reading shall be repeated exactly at the 10 degrees C (50 degrees F) temperature; otherwise the entire temperature compensation test shall be repeated. When tested as specified herein, the difference in the errors determined at 40 degrees C (104 degrees F) and 10 degrees C (50 degrees F) shall not exceed 0.7 mb. When tested as specified herein, in the range from 40 degrees C (104 degrees F) to 10 degrees C (50 degrees F), the change in error shall not exceed 0.35 mb. per 15 degrees C (27 degrees F).

"**P.1.4 Overpressure and Underpressure Test.**—The barometer shall not be damaged by subjection to pressures between 550 mb. and 1067 mb. and twenty-four hours after such test no scale error shall differ by more than 0.5 mb. from that determined at the same pressure before the test.

"**P.1.5 Case Tightness.**—The tightness of the case shall be such that if the pressure is reduced 40 mb. ±3 mb. at constant temperature and the tapped hole is sealed, the indication thereafter will not change more than 1 mb. in thirty minutes (.033 mb. per minute).

"**P.1.6 Friction.**—The movement of the pointer shall be free from backlash and any irregular motion when the pressure is varied uniformly. If the pressure is increased or decreased and is then gradually brought to a constant value without reversing direction while the barometer under test is free from vibration, light tapping or vibration of the barometer shall not cause a change in indication greater than 0.2 mb.

"**P.1.7 Aging Drift Guarantee.**—The contractor shall guarantee that, beginning at some time within one month after the time of delivery the change in calibration after six (6) months shall not exceed 0.6 mb. at all test points over the range of the scale. The change in calibration for the following six (6) month period shall not exceed 0.4 mb. at all test points over the range of the scale. Barometers found by the Government not to meet the requirements herein stated at the end of the six (6) and twelve (12) month periods, respectively, will be returned to the manufacturer for repair or replacement without additional cost to the Government, including transportation charges."

APPENDIX 2.11.1

CALCULATION OF INSIDE DIAMETER OF STATIC-PRESSURE SYSTEM TUBING

It is considered desirable that a rational basis be employed in choosing the inside diameter of the tube which is to be used for connecting the pressure-responsive equipment to the outside static-pressure head. One of the best methods of attaining this objective is to calculate the inside diameter of a tube capable of yielding a time-lag constant (or lag coefficient) which is equal to or less than a prescribed value that is considered acceptable under the given conditions of operation, depending on the type of application, whether it be for aircraft, ships, mountain stations, etc.

Before presenting details regarding the method of computing the time-lag constant, it is necessary to define the relevant terms and to indicate briefly some of their applications. In order to make the matter explicit let us consider that the tube is connected from the static-pressure head to a pressure-responsive instrument and possibly also an intervening chamber that contains air. We shall denote by the symbol V the air-capacity volume of the system reckoned by adding together the air capacity of the instrument, the air capacity of the chamber, and one-half of the volume of the connecting tube. The value of one-half of the volume of the tube is an unknown quantity when the inside diameter of the tube is not known, even though the length of the tube can be determined from measurements of the extent of the line which will be taken by the tube in making the connections. However, despite the fact that the value of one-half of the volume of the tube is unknown at the beginning, one can make an estimate of its amount on the basis of one-half of the product of the length and the estimated value of the inside cross-section area of the tube. This cross-section area can be readily calculated from the estimated inside diameter of the tube (for example 0.2 cm.), by making use of the well-known formula for the area of a circle in terms of its diameter, d (that is, area $= \pi d^2/4$, where $\pi = 3.14159...$).

A procedure is described later in this appendix for computing the required inside diameter, d, of the tube in accordance with certain criteria. The equation given for computing d involves V as previously defined. But since V will be at first merely an approximation owing to the fact that the value of one-half of the volume of the connecting tube is initially estimated, the resultant value of d computed by means of the equation will be an approximation. The value of d thus calculated may then be employed to determine a better approximation of one-half of the volume of the tube; and hence when use is made of the latter, it is possible to ascertain a better approximation of the volume V as previously defined. Finally when this better approximation of V is utilized in the equation for computing d, a second approximation of d is calculated. Usually, this step yields a value of the inside diameter which is sufficiently accurate for practical purposes.

In order to introduce the concept of the time-lag constant, we shall consider two different situations; first, one in which the static-pressure head is abruptly changed from an exposure at a given fixed pressure to an exposure at an entirely different fixed pressure; and second, one in which the static-pressure head is exposed to an ambient pressure which varies at a uniform rate.

Thus, first of all, suppose that the system, including the static-pressure head, connecting tube, pressure-responsive instrument, and chamber (if any), has been originally in pressure equilibrium with a pressure denoted by P_0. Then, if the static-pressure head were abruptly exposed to a different value of the ambient air pressure denoted by P_a, the indicated reading yielded by the pressure-measuring equipment in the system would lag behind the actual pressure, P_a, to which the static-pressure head is subjected. Let P_i denote the pressure indicated by the equipment at time t, in seconds, measured from the instant at which the head was suddenly changed from original pressure P_o to ambient pressure P_a. As time progressed the value of P_i would vary from its original value P_o and asymptotically approach P_a. The relative rate of approach of P_i to P_a depends upon a number of factors involved in the system, including principally the following: the length of the tube, the volume V as previously defined, the inside diameter of the tube, the ambient static pressure, and the viscosity of the air in the tube. If there are one or more constrictions and/or sharp bends in the tube, these will have an effect on the relative rate of approach.

Let A denote the time-lag constant of the system with respect to pressure changes, then the rate of change of the indication of the pressure-measuring instrument with time is given by the equation

$$\left(\frac{dP_i}{dt}\right) = -(1/A)\ (P_i - P_a). \qquad (1)$$

The dimension of the time-lag constant, A, is that of time, t; hence in the present case both are specified in seconds. We shall assume that the ambient air pressure P_a remains constant. If equation (1) is integrated on this basis, it is found that

$$(P_i - P_a) = (P_o - P_a)e^{-t/A}, \qquad (2)$$

where e = base of natural (Napierian) logarithms ($e = 2.718281828...$); and P_o = original pressure at time zero ($t = 0$).

Equation (2) may be interpreted as signifying that with increasing time t greater than the time-lag constant, A, the indicated pressure value P_i approaches asymptotically the ambient pressure P_a. This conclusion is drawn owing to the fact that when the ratio t/A exceeds unity (1) and increases without limit, the exponential factor $e^{-t/A}$ approaches zero as a limit. This behavior of the exponential may be readily grasped from the following list which shows pairs of values of (t/A) and the corresponding exponential factor, respectively, for a succession of progressively increasing values of the ratio (t/A): 0.00, 1.000; 0.50, 0.6065; 1.00, 0.3679; 1.50, 0.2231; 2.00, 0.1353; 2.50, 0.0821; 3.00, 0.0498; 4.00, 0.0183; 5.00, 0.0067; 7.00; 0.0009; and 9.00, 0.0001.

In order to extend further the application of the time-lag constant let us consider the case in which the static-pressure head is exposed to an ambient pressure that changes at a uniform rate. Suppose that the initial pressure was P_o and that the constant rate of change of ambient pressure with time t is denoted by r; then the ambient pressure (P_a) is represented by the equation

$$P_a = P_o + rt. \qquad (3)$$

Now when equation (3) is substituted in equation (1), which is valid in this case as in the previous one, we find

$$\left(\frac{dP_i}{dt}\right) = -(1/A)\ [P_i - (P_o + rt)]. \quad (4)$$

We shall assume that the system was in equilibrium with the ambient pressure initially; hence we have at time $t = 0$, $P_i = P_o$. When differential equation (4) is solved on this basis, we obtain

$$(P_i - P_a) = -rA(1 - e^{-t/A}). \qquad (5)$$

Equation (5) is valid under the conditions which were assumed; namely, that (a) the ambient pressure varies linearly with time as indicated by equation (3); and (b) the system was in equilibrium with the original pressure of the surrounding air, P_o, at the instant regarded as the beginning of the time measurement, $t = 0$.

The quantity $(P_i - P_a)$ represents the error in the pressure indicated by the measuring equipment within the system due to lag caused by the tubing, connecting volume occupied by air, etc., under the assumptions outlined above.

After an interval of time considerably in excess of the amount A, the value of the exponential $e^{-t/A}$ becomes small relative to unity (1) as previously indicated; in fact, the exponential approaches zero as a limit as the ratio t/A exceeds one (1) and approaches infinity. Therefore, it follows from equation (5) that after an interval of time characterized by a value of the ratio

t/A much in excess of one (1), the limiting value of the error due to lag is represented very nearly by the equation

$$(P_i - P_a) = -rA. \qquad (6)$$

In order to visualize the application of equation (6) let us consider the case of a system whose time-lag constant, A, is equal to 10 seconds, where the system is exposed to an ambient pressure which is falling at a uniform rate of 36 millibars per hour; that is, where $r = -0.01$ mb. per second which is possible in a hurricane, tornado, etc. On the basis of these data equation (6) yields the result that after a time interval of the order of much more than 10 seconds (say 1 minute), the error due to lag, $(P_i - P_a)$, will approach the limiting value $-rA = 0.1$ mb.

We shall suppose that as a rule of thumb for application at surface stations or ships rendering pressure observations and equipped with a static-pressure system the error due to lag should be smaller by at least an order of magnitude than the value obtained in the case of the foregoing example. *Therefore, it is suggested as a recommended practice that the inside diameter of the tubing be chosen so as to yield a value of the time-lag constant, A, not exceeding one (1) second for land stations or ships.* However, when the static-pressure system is to be employed on board an aircraft which can be subjected to values of r much greater than 0.01 mb. per second in absolute magnitude, due to rapid ascent or descent of the craft, it is suggested that a sufficiently larger inside diameter of the tubing be used to yield a commensurately smaller value of the time-lag constant, A, with a view to keeping the value of the product rA within a limit of the order of 0.1 mb. in absolute value.

It is possible to calculate the approximate value of the time-lag constant, A, under most operating conditions, provided that certain relevant data representing the parameters of the static-pressure system, such as the inside diameter and length of tubing, are known. Conversely, if one chooses a value of the time-lag constant, A, to be employed for the system, one can calculate the inside diameter of the tubing which can yield this value of A, provided that the values of the remaining parameters are known. The latter procedure is recommended in connection with the design of the static-pressure system. With this objective in view we shall first show how the time-lag constant, A, may be computed, and then indicate how one may calculate the inside diameter of the tubing which would cause the time-lag constant to have the value chosen.

We shall consider a system consisting of a static-pressure head, a pressure-responsive instrument such as an aneroid barograph or altimeter, and tubing which connects the foregoing elements, together with any air chambers joined or connected along the line. According to Wildhack[1] the time-lag constant of such a system in respect to changes in ambient pressure at the static-pressure head is given by the following equation

$$A = (128\, kLV/\pi\, d^4P). \qquad (7)$$

where, in centimeter-gram-second units,

A = time-lag constant of system, in seconds;
k = viscosity of the air in the tubing and connected equipment, in gram sec.$^{-1}$ cm.$^{-1}$;
L = length of tubing, in cm.;
d = inside diameter of tubing, in cm.;
V = volume of the air capacity of the pressure responsive instrument and any connected air chambers within the system, together with one-half of the volume of the inside of the tubing, in cm.^{3};
P = ambient static pressure to which the static-pressure head is exposed, in dynes/cm.^{2}

Equation (7) is based on the assumptions that use is made of straight tubing with a smooth inside bore, and that the flow regime within the tubing is *laminar* and isothermal when a pressure difference exists between the two ends of the tubing. If these conditions are not fulfilled, a different set of relationships must be employed for the time-lag effects and the attendant pressure drop in the tubing. (See further discussion and the literature existing on the subject.) Wildhack gives a method of computing the pres-

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[1] W. A. Wildhack, "Pressure drop in tubing in aircraft instrument installations," National Advisory Committee for Aeronautics, Washington, D.C., Technical Note No. 593, Feb., 1937.

sure drop in a line when the flow is *turbulent,* as will be the case usually for instruments which operate on a steady flow of air generally supplied by either venturi tubes or vacuum pumps.

The application of equation (7) to the present problem may be seen from the following considerations: Suppose that in making the installation of tubing to connect the static-pressure head to the pressure-responsive instrument it is found that a certain length of tubing, L, is necessary; and suppose further that the values of k, V, and P are determined by the system together with the average ambient conditions in regard to temperature and pressure. Then, if a choice is made regarding an acceptable value of the time-lag constant, A, for satisfactory operational use under the maximum probable rate of variation of ambient pressure which may be encountered, the solution of equation (7) for the quantity d will yield the corresponding *minimum, tolerable inside diameter.* Hence if the actual inside diameter of the tubing put into service is made greater than the value of d computed with the aid of equation (7), the error due to lag will be maintained less than a maximum acceptable amount even though the extreme rate of ambient pressure variation is experienced.

The viscosity, k, is dependent upon the temperature of the air in the system as illustrated by the following abbreviated table:

Temperature		Viscosity, k
°Kelvin	°C	gram sec.$^{-1}$ cm.$^{-1}$
230	−43.16	0.0001494
240	−33.16	0.0001547
250	−23.16	0.0001599
260	−13.16	0.0001650
270	− 3.16	0.0001700
280	+ 6.84	0.0001750
290	+16.84	0.0001798
300	+26.84	0.0001846
310	+36.84	0.0001893
320	+46.84	0.0001939
330	+56.84	0.0001985
340	+66.84	0.0002030

For the sake of simplicity we shall assume that the temperature of the air which controls the viscosity, k, and the ambient static pressure, P, in equation (7) *when applied to sea-level stations or ships* have the values considered standard for mean sea-level conditions (see Appendix 8.0.1). Therefore, for such applications we shall assume the air temperature in the system to be 15° C. (59° F.) for which the corresponding value of the viscosity, k, is 0.0001793 gram sec.$^{-1}$ cm.$^{-1}$; and the ambient pressure to be 1,013,250 dynes/cm.^{2}, pertinent to normal sea-level conditions.

We shall designate by the symbol A_0 the value of the time-lag constant calculated by means of equation (7) under the assumption that the viscosity k and the ambient air pressure P have the magnitudes specified in the previous paragraph for *application when the station or ship is at sea level.*

On this basis equation (7) may be rewritten to satisfy this special assumption; thus, in the case where units are expressed in the centimeter-gram-second system

$$A_0 = (7.21 \times 10^{-9}\, LV/d^4), \qquad (8)$$

valid for standard sea-level conditions.

In accordance with the recommended practice we shall choose for the time-lag constant the value 1 second; hence on this basis under standard sea-level conditions we have $A_0 = 1$ second.

The application of equation (8) for these conditions may be illustrated as follows: suppose that in the case of the installation of the static-pressure system on a ship it is determined that $V = 200$ cm.^{3} and that the length of tubing necessary is 100 feet. By converting the latter value to centimeters we find $L = 3048$ cm. (See Table 1.3.1.) Now the problem is to compute with the aid of equation (8) the inside diameter of the tubing which would yield the chosen value of the time-lag constant given by $A_0 = 1$ second, under the assumed standard sea-level conditions. When equation (8) is solved for d^4, one obtains

$$d^4 = 7.21 \times 10^{-9}\, LV/A_0 \qquad (9)$$

where the data are expressed in the centimeter-gram-second system. If we take $L = 3048$ cm., $V = 200$ cm.^{3}, and $A_0 = 1$ second, equation (9) yields the result $d^4 = 43.95 \times 10^{-4}$ cm.^{4} By extracting the fourth root of the latter quantity we obtain the answer $d = 0.2575$ cm. Since 2.54 cm. = 1 inch, this value of d converts to 0.1014 inch. One may regard the value $d = 0.2575$ cm. (0.1014 inch) as the *minimum, tolerable inside diameter* for the particular case under consideration. Thus, in such a case we can draw the final conclusion that if use is made of tubing whose inside diameter is greater, say 1/8 inch, the time-lag constant will be smaller than 1 second under the given conditions.

It should be noted that if the tubing is to be employed at an elevation where the ambient static pressure is lower than the assumed standard sea-level value of 1.01325×10^6 dynes/cm.^{2} (see sec. 1.4 and Table 3.3.3), the constant in the last equation must be replaced by one pertinent to the mean air pressure at the actual elevation. Thus, if p is the mean air pressure at the actual elevation *in millibars*, then the appropriate value of the constant will be given by $7.21 \times 10^{-9} \times (1{,}013.25 \text{ mb.}/p \text{ mb.})$, provided one assumes the mean air temperature in the tube to be about 15° C., as was done in computing the constant shown in equation (8).

It is a recommended practice that the pertinent minimum value of the inside diameter of the tubing, d, be computed with the aid of equation (7) or (8), whichever is relevant. For routine meteorological use at land stations or on ships, it is a recommended practice that the chosen value of the time-lag constant for such calculations be 1 second. In the case of use on board aircraft, a much smaller value of the time-lag constant must be employed, depending upon the maximum rate of ambient pressure fall or rise which may be encountered during ascent or descent, in order to keep the product rA from exceeding an acceptable tolerance such as 0.1 millibar, the actual tolerance being a matter of choice by the agency concerned.

If there are kinks or bends of small radius of curvature in the tubing, or if there exist reductions and constrictions in the cross-sectional area of the tubing or the system elsewhere, some allowance must be made for the increased lag due to the effects of these deviations from a straight, smooth tube of uniform diameter which was assumed in the derivation of equation (7) representing the time-lag constant. Such an allowance can be made by adding a suitable amount to the inside diameter of the tube computed in the manner indicated above. It is difficult to state a general rule regarding the amount that ought to be allowed for the effects of kinks, bends, constrictions, lack of smoothness within the tube, etc. Therefore in cases of meteorological installations, this matter is left to the discretion and good judgment of the engineer responsible for making the installation. However, in cases where lag is critical, as for example in high-speed aircraft which have high rates of climb and descent, it is considered essential to base the design and size of the static-pressure system and the necessary connecting tube upon experimental laboratory investigations and flight tests, if it is at all practicable to have such work performed.

Whenever there are fairly sharp bends in the tubing or constrictions in the system, marked changes in the flow characteristics from laminar to turbulent, or vice versa, can occur within the system for flows which yield Reynolds numbers near the critical value for the tubing. Thus, if v' denotes the mean velocity of the fluid (air) within the tube, ρ the density of the fluid, k the viscosity of the fluid, and d the inside diameter of the tubing, then the Reynolds number is defined by the expression Reynolds number $= \rho\, dv'/k$. Laminar flow will occur for values of the Reynolds number from zero up to about 2,500; while turbulent flow will generally occur for values of the Reynolds number between about 3,000 and 100,000. For values of the Reynolds number which lie between about 2,500 and 3,000, that is, at critical values of the Reynolds number, the flow changes its character sharply and is generally widely different from any steady state. It is when the Reynolds number falls within or very close to this critical range that serious effects in regard to lag, fluctuations, etc., may be expected from kinks, bends, and constrictions, as well as from the tube itself which may manifest abrupt shifts in flow regime under these conditions. If these phenomena are likely to occur fairly frequently during operating conditions, it is considered desirable to make due allowances by employing a larger inside diameter of tube than would be the case under ordinary operating conditions involving either entirely laminar or entirely turbulent regimes of flow. An experimental basis for such design and field testing of the equipment under controlled conditions is recommended for critical work.

The following references to the literature are relevant:

(1) W. A. Wildhack, Pressure Drop in Tubing in Aircraft Instrument Installations, NACA Tech. Note 593, Washington, Feb., 1937.

(2) W. R. Weems, The Effect of Tubing on the Indications of an Airspeed Meter, Jour. of the Aeronautical Sciences, Vol. 3, p. 165, 1936.

(3) G. Kiel, Measurement of the True Dynamic and Static Pressures in Flight, NACA Technical Memorandum No. 913, Washington, Oct., 1939.

(4) H. L. Turner and G. A. Rathert, Jr., Pressure Lag in Tubing Used in Flight Research, NACA RB 5F15, Washington, July, 1945.

(5) I. Taback, The Response of Pressure Measuring Systems to Oscillating Pressures, NACA Tech. Note No. 1819, Washington, Feb. 1949.

APPENDIX 7.1

THE HYPSOMETRIC EQUATION; ITS DERIVATION, TOGETHER WITH DEFINITIONS OF THE PARAMETERS INVOLVED

The hypsometric equation may be regarded as a general expression which indicates the variation of barometric pressure with height in the atmosphere, as governed by the existing, usually given, conditions of pressure (p), temperature (T), and moisture content in terms of mixing ratio (w). As will be clear from what follows, these variables are involved since they control the density of moist air.

When we wish to take account of the variables for the purpose of calculating the air density, we shall find it convenient to make use of the concept of "virtual temperature," designated by T_v; and later when we wish to deal with the mean value of virtual temperature for an entire vertical air column, we shall designate the mean virtual temperature for such a column by T_{mv}.

Virtual temperature T_v pertaining to any given sample of moist air is defined as the temperature which dry air must have at the given barometric pressure p in order to have the same density as the moist air at the same pressure p, and given temperature T, and mixing ratio w, provided the dry air and moist air behave in accordance with the perfect gas equation of state.[1]

The mixing ratio w employed to express the moisture content of the moist air is defined as the ratio of the mass (m_v) of water vapor to the mass (m_a) of dry air with which the water vapor is associated; thus $w = m_v/m_a$; or in other words, the mixing ratio is the mass of water vapor associated with unit mass of dry air.[2] As is well known, the ratio of the molecular weight of water vapor to that of dry air is 0.62197, and in what follows we shall designate this ratio by k.

It will be recalled from general physics that the perfect gas equation of state may be written

$$pv = (m/M)R^*T,$$

where for a given sample of gas p is the pressure, T the absolute temperature, v the volume, m the actual mass of the gas, and M the molecular weight of the gas; while R^* represents the universal gas constant per mole for an ideal gas and has the value

$$8.31439 \times 10^7 \text{ erg} \cdot \text{mol}^{-1} \cdot {}^\circ\text{K}^{-1},$$

provided absolute temperature on the Kelvin scale (°K) is defined in such a manner that the ice point corresponds to 273.16 °K.

However, it is necessary to digress at this stage to indicate a revision affecting the foregoing value. Thus, the Tenth General Conference on Weights and Measures, Paris, in 1954 decided to define the thermodynamic temperature scale by means of the triple point of water as the fundamental fixed point, by assigning to it the temperature 273.16° K., exactly. This determines the size of a degree. In addition, the Ninth General Conference on Weights and Measures, Paris, in 1948, had decided that the zero of the thermodynamic Celsius scale should be defined as being the temperature 0.0100 degree below that of the triple point of pure water. By virtue of these two actions, the zero of the thermodynamic Celsius scale is in effect defined as having an absolute thermodynamic temperature of 273.15° Kelvin (°K.). The zero of the thermodynamic Celsius scale as thus defined may be nominally termed the "ice point." According to the two decisions just described, it follows that after

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[1] Smithsonian Meteorological Tables (SMT), Sixth Revised Edition, (1951), p. 295.

[2] Smithsonian Meteorological Tables, Sixth Revised Edition, (1951), p. 347; and International Meteorological Organization, Publication No. 79, "Values of some Physical Functions and Constants used in Meteorology. Definitions and Specifications of Water Vapour in the Atmosphere," Lausanne, Switzerland (1951), p. 20, and pp. 54–60.

1954 thermodynamic temperature (T) in degrees Kelvin will be equivalent to the algebraic sum of 273.15° and the thermodynamic Celsius temperature (t) in °C.; that is, $T = (273.15 + t° \text{ C.})$, in °K. When one adopts the definition of the temperature scales in harmony with this relationship in which the "ice point" is regarded as having an absolute thermodynamic temperature of 273.15° Kelvin, it turns out that the corresponding value of R^* is given by the expression $R^* = 8.31470 \times 10^7$ erg mol^{-1} °K^{-1}.

With regard to units, it will also be recalled that

$$1 \text{ erg} = 1 \text{ dyne} \cdot \text{cm.}$$

where

$$1 \text{ dyne} = 1 \text{ gram} \cdot \text{cm./sec.}^2;$$

hence

$$1 \text{ erg} = 1 \text{ gram} \cdot \text{cm.}^2/\text{sec.}^2$$

Inasmuch as we are concerned with the properties of moist air, which may be regarded as a mixture of dry air and water vapor under the assumption that these substances behave as perfect gases, we must consider the respective molecular weights (M) of these two constituents.

We shall consider a quantity of moist air which occupies volume v at temperature T and barometric pressure p. Let m_a denote the mass of dry air and m_v the mass of water vapor in the moist air, whose total mass is obviously $(m_a + m_v)$. Also, let p_a denote the partial pressure of the dry air, and p_v the partial pressure of the water vapor. We shall assume that the dry air and water vapor behave as perfect gases, both occupying the same volume v. Thus, the molecular weight of water vapor, denoted by M_v, is 18.0160; while the molecular weight of dry air, represented by M_a, is 28.966; hence it will be seen that their ratio, k, is a numerical constant defined by $k = (M_v/M_a) = 0.62197$.

On the basis of Dalton's law of partial pressures for a perfect gas we have

$$p = (p_a + p_v) \qquad (1)$$

or

$$p_a = (p - p_v). \qquad (1a)$$

Then, in accordance with the perfect gas law as applied to the dry air

$$p_a\, v = (p - p_v)\, v = (m_a/M_a) R^* T. \qquad (2)$$

Since the dry air and water vapor coexist in the same volume v, we have on the basis of the perfect gas law applied to the water vapor

$$p_v\, v = (m_v/M_v) R^* T. \qquad (3)$$

Substituting eq. (3) in (2) we obtain

$$pv = m_a (R^*/M_a) T\, [1 + (m_v/m_a)(M_a/M_v)]. \qquad (4)$$

It will be recalled that the total mass of moist air in the volume v is $(m_a + m_v)$. Suppose that this mass were entirely in the form of dry air at the same barometric pressure p and in the same volume v as the moist air. Since density is defined as the ratio of mass to volume, it follows that the density of the moist air and the density of the dry air will be equal, since both are assumed to have the same mass and volume.

Now, let us apply the perfect gas law to the hypothetical dry air of mass $(m_a + m_v)$ in volume v at pressure p. Since its density is equal to that of the moist air, the definition of virtual temperature (T_v) requires that the temperature of the dry air be represented by T_v. Therefore, in accordance with the perfect gas law, we have for this hypothetical quantity of dry air

$$pv = (m_a + m_v)(R^*/M_a) T_v. \qquad (5)$$

Now, let us equate eqs. (4) and (5), and take cognizance of the two definitions

$$(m_v/m_a) = w = \text{mixing ratio} \qquad (6)$$

and

$$(M_v/M_a) = k; \qquad (7)$$

whence we obtain the result

$$m_a T (1 + w/k) = (m_a + m_v) T_v. \qquad (8)$$

It follows that

$$T_v = T(1 + w/k)/(1 + w). \qquad (9)$$

Now, dividing eq. (3) by (2), and taking account of eqs. (6) and (7), we obtain

$$w = k p_v/(p - p_v). \qquad (10)$$

By substituting eq. (10) in (9), and denoting $n = (1 - k) = 0.37803$, we find

$$T_v = T/(1 - n p_v/p). \qquad (11)$$

Eqs. (9) and (11) permit one to evaluate the virtual temperature as a function of the observable independent variables (T, w) or (T, p_v, p).

We shall denote $R = (R^*/M_a)$, which may be termed the gas constant for 1 gram of dry air. When we make use of the values previously given for the quantities involved, and consider that C.G.S. units are employed, then we find that $R = 2.8704 \times 10^6$ cm²/sec.² °K, when it is assumed that the ice point on the absolute temperature scale has the value 273.16° K. However, if it is assumed that the ice point has the value 273.15° K, as adopted by the Tenth Conference on Weights and Measures, Paris, in 1954, then we find that $R = 2.8705 \times 10^6$ cm²/sec.² °K. Since the tables employed in this publication (see Table 7.5) were prepared prior to 1954, we make use of the older value in this book, consistent with the assumption that the ice point is 273.16° K. Mention should be made here that the important thing in the present context is to employ consistent values of R and the ice point in the calculations, since the product of R and the ice point is the same under both the old and the new definitions of the absolute temperature scale.

Now, let us consider a sample of moist air in the atmosphere, whose pressure is p in dynes/cm.², virtual temperature T_v in degrees Kelvin (°K) and density is ρ in grams/cm³. As previously specified the volume occupied is v in cm.³, which contains m_a grams of dry air and m_v grams of water vapor; therefore, the total mass is $(m_a + m_v)$. Since the density is defined as the mass per unit volume, eq. (5) yields the result

$$\rho = (m_a + m_v)/v = p/RT_v, \qquad (12)$$

provided one first makes the substitution $R = (R^*/M_a)$ in eq. (5).

To derive the hypsometric equation we make use of the differential form of the hydrostatic equation

$$dp = -\rho\, g\, dz \qquad (13)$$

where

z = geometric altitude (or height), in cm., measured with respect to mean sea level;

g = acceleration of gravity, in cm./sec.², at altitude z;

ρ = density of air, in grams/cm.³, at altitude z;

dp = differential of atmospheric pressure in altitude interval dz.

The quantity g is a function of the geographic coordinates and the altitude referred to mean sea level. In order to eliminate complications which stem from this fact, it is convenient to make use of the concept of "geopotential" introduced by V. Bjerknes, and for present purposes one may define it by means of the equation

$$H = \frac{1}{G}\int_0^Z g\, dz \qquad (14)$$

where

H, the geopotential, represents a measure of the work done against gravity in lifting unit mass from mean sea level to a point in the atmosphere at an altitude Z, the latter being in geometric units measured vertically with reference to the datum at mean sea level; g denotes the acceleration of gravity at altitude z (the latter being a variable ranging from 0 to Z in the present problem); and G is a constant which serves merely to fix the size of the unit chosen for geopotential in terms of the unit involved in the product gz. It is conventional to employ the "geopotential meter" (abbreviated gpm) for the unit of H; hence if z and Z are given in centimeters, while g is given in cm./sec.², the definition of the "geopotential meter" requires that the value of G be taken as 98,000 cm.²/sec.² per gpm, in order for eq. (14) to yield proper results (see SMT, p. 217).

Taking the differential of eq. (14), one obtains

$$G\, dH = g\, dz. \qquad (15)$$

Substituting eqs. (12) and (15) in eq. (13), there results, after a simple transformation, the basic differential equation underlying the hypsometric formula

$$dp/p = d(\log p) = -(G/R)\ (dH/T_v). \qquad (16)$$

It will be understood that *log* in this and subsequent equations refers to natural or Napierian logarithms. In the left *hand member*

ber, the units of dp and p must, of course, be consistent.

Since the value of R is dependent upon the value chosen for the ice point as indicated above, the same is true of the ratio (G/R). With the understanding that H is here expressed in terms of the unit "geopotential meter" (gpm) and T_v in terms of the absolute thermodynamic degree Kelvin (°K), then taking $G - 98{,}000$ cm.^{2}/sec.^{2} gpm., we find that (A) when the ice point is assumed to be 273.16° K as was done previously, $(G/R) = 0.0341416$ °K/gpm; and (B) when the ice point is fixed as 273.15° K in accordance with the internationally adopted value, $(G/R) = 0.0341404$ °K/gpm. (In the ratios there has been carried an extra figure for guard purposes, even though it may not be significant.)

For purposes of further development, we may regard T_v as a function of H.

Integrating eq. (16) one obtains the hypsometric equation

$$\log (P_1/P_2) = (G/R) \int_{H_1}^{H_2} \frac{dH}{T_v} \qquad (17)$$

where P_1 is the barometric pressure at a base level H_1, and P_2 the barometric pressure at an upper (higher) level H_2.

When the vertical line connecting the two levels lies entirely in the atmosphere, one can speak of the "air column" in referring to a vertical column of air of unit cross-sectional area extending from level H_1 to level H_2. Then it is physically meaningful to define the so-called "mean virtual temperature of the air column" (symbol T_{mv}) on the basis of the following equation:

$$\frac{(H_2 - H_1)}{T_{mv}} = \int_{H_1}^{H_2} \frac{dH}{T_v} \qquad (18)$$

Substituting eq. (18) in eq. (17), one obtains the familiar form of the hypsometric equation

$$\log (P_1/P_2) = (G/R)\ (H_2 - H_1)/T_{mv}. \qquad (19)$$

When the base level refers to sea level (that is, $H_1 = 0$) and the geopotential of the upper level is given in general by H, i.e., $(H_2 = H)$, then denoting the pressure at sea level by P_o and the pressure at the upper level by P, the last equation assumes the form

$$\log (P_o/P) = (G/R)\ (H/T_{mv}) \qquad (20)$$

Clearly, it is valid to apply either equation (19) or (20), in conjunction with the definition of T_{mv} given by eq. (18), so long as the data refer to an actual atmospheric air column in hydrostatic equilibrium. However, this is not necessarily the case when any portion of the range of geopotential $(H_2 - H_1)$ covers a vertical column of liquid or solid material in the earth, since the virtual temperature is not defined for such a medium.

Up to the present stage all of the logarithms used herein have been *natural* (Napierian) logarithms; that is, to the base $e = (2.7182818....)$. For some purposes it is convenient to employ logarithms to the base 10, especially for routine calculations. Then, to convert from one base to the other we make use of the relationship

$$\log_{10} x = (\log_{10} e) \log x,$$

where $\log x$ denotes the natural logarithm of quantity x, and the quantity in parentheses is a constant, $\log_{10} e = (0.43429448.....)$.

Now, we denote the constant K by the expression

$$K = (\log_{10} e)\ (G/R). \qquad (21)$$

Making use of the foregoing relationship regarding logarithms and eq. (21) in conjunction with equations (19) and (20), we obtain

$$\log_{10} (P_1/P_2) = K(H_2 - H_1)/T_{mv} \qquad (22)$$

and

$$\log_{10} (P_o/P) = KH/T_{mv}. \qquad (22a)$$

Let us denote r by the expression

$$r = 10^{K(H_2 - H_1)/T_{mv}} = 10^{(KH/T_{mv})}, \qquad (23)$$

then eq. (22) may be rewritten

$$(P_1/P_2) = (P_o/P) = r, \qquad (24)$$

or

$$P_1 = P_2 r, \text{ and } P_o = P\ r. \qquad (25)$$

The hypsometric equation was originally given by Laplace in a somewhat different form than eq. (20).[3] Laplace employed geometric altitude (Z) in lieu of geopotential (H), and therefore he had to take explicit account in his formula of the variation of the acceleration of gravity with latitude and altitude. It will be obvious that the use of geopotential permits one to write the formula in a simpler expression than when the geometric altitude is employed for the height parameter. Appendix 1.3.1 indicates how one may derive a formula for the geopotential in terms of the latitude and altitude; while in Chapter 1, secs. 1.3–1.3.6 illustrate practical means of calculating the geopotential with the aid of such a formula, and provide additional information.

In order to evaluate K, we make use of the values previously given for (G/R) and $\log_{10}e$; whence we find in case the ice point is taken as 273.16° Kelvin, $K = 0.0148275$ °K./gpm; and in case the ice point is taken as 273.15° Kelvin, $K = 0.0148270$ °K./gpm.

Table 7.5 is based on the use of the degree Rankine (°R) instead of the degree Kelvin for T_{mv}. As is well known, both represent absolute temperatures, but the size of the degree Rankine is the same as that of the degree Fahrenheit, hence it is 5/9 as large as the Kelvin degree. Therefore, it follows that the value of T_{mv} in degrees Rankine is a quantity 9/5 times as great as the value in degrees Kelvin. Consequently, the value of the constant K defined in eq. (21) may be given for use with T_{mv} expressed in degrees Rankine by multiplying the value of K pertinent to degrees Kelvin by the factor 9/5. Therefore, we determine that when Rankine temperature data are employed in case the value of the ice point is taken as 273.16° K. (491.688° R.), then $K = 0.0266895$ °R./gpm; while in case the value of the ice point is taken as 273.15° K.(491.67° R.), then $K = 0.0266886$ °R./gpm. It is appropriate to mention here that Table 7.5 was constructed on the basis of the value of K given by 0.0266895 °R./gpm. Consistent with this, the relationship between temperatures in degrees Fahrenheit (°F.) and degrees Rankine (°R.) is given by

$$T\ ^\circ\text{R.} = (459.688 + t^\circ\ \text{F.}).$$

However, when the ice point is taken as 273.15° K. (491.67° R.), the relationship is given by

$$T\ ^\circ\text{R.} = (459.67 + t^\circ\ \text{F.}).$$

Reverting to the hypsometric equation, it is useful to have it in the form of an equation adapted to the situation in which the virtual temperature varies linearly with geopotential. Under this condition one has

$$T_v = [T_{v1} - a(H - H_1)] \qquad (26)$$

where

T_v = virtual temperature at geopotential H;

T_{v1} = virtual temperature at geopotential H_1 (regarded as the base level);

a = rate of *decrease* of virtual temperature with increase of geopotential.

Substituting eq. (26) in eq. (16) and performing the indicated integration, one obtains the pertinent form of hypsometric equation for this situation:

$$\log(P_1/P_2) = (G/aR)\ \log\left\{T_{v1}/[T_{v1} - a(H_2 - H_1)]\right\}. \qquad (27)$$

A particular case of this arises when the base level is at sea level (for which H_1 becomes zero).

Then, denoting

P = barometric pressure at geopotential H (which replaces H_2 in eq. 27)

P_o = barometric pressure in sea level, geopotential zero ($H_1 = 0$, in eq. 27)

T_{vo} = virtual temperature at sea level;

equation (27) transforms to

$$\log(P_o/P) = (G/aR)\ \log[T_{vo}/(T_{vo} - aH)]. \qquad (28)$$

It is of use for later consideration to treat an example of eq. (28) in which T_{vo} is regarded as unknown but where the virtual temperature at the upper level (H) is known. For later convenience we employ the following notation:

H_s = geopotential of the upper level (replacing H or H_2);

T_{vs} = virtual temperature at the upper level H_s;

P_s = barometric pressure at the level H_s; and

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[3] Laplace, "Mécanique céleste," 2ᵉ Partie, Livre IX, Chap. IV. See also: International Meteorological Tables, Paris, (1890), p. B. 32.

P_o = barometric pressure at the level where the geopotential is zero (0).

Under these conditions, the base level being at sea level, one has $H_1 = 0$; and in eq. (26) T_{vo} replaces T_{v1}, while T_{vs} replaces T_v. Then, eq. (26) yields

$$T_{vo} = (T_{vs} + aH_s); \qquad (29)$$

and when eq. (29) is substituted in eq. (28) one finds

$$\log (P_o/P_s) = (G/aR) \log [(T_{vs} + aH_s)/T_{vs}]. \qquad (30)$$

This is a form of the hypsometric equation especially useful for reduction of pressure under the classical concepts, in the case where a, the rate of decrease of virtual temperature with geopotential, is constant. Under these circumstances, one may regard P_s as representing the station pressure, H_s as the geopotential of the station, T_{vs} as the absolute virtual temperature at the station, a as the assumed lapse rate of virtual temperature, and P_o as the pressure reduced to sea level.

APPENDIX 7.2

THEORY UNDERLYING THE "CORRECTION FOR PLATEAU EFFECT AND LOCAL LAPSE RATE ANOMALY"

1. Introduction

All conventional systems of reduction of pressure to sea level involve some assumption regarding the effective local lapse rate within the fictitious air column (see fig. 7.0.1 and secs. 7.0.0–7.0.5.4). In the system adopted by the United States in 1900 this was accomplished by the employment of another assumption which was essentially equivalent to the former, namely by assuming that the difference between the mean temperature of the fictitious air column and the station temperature argument (t_s) is a function of the mean temperature of the fictitious air column, at least in the case of stations whose height above sea level was over 1,000 feet. Furthermore, in the system of reduction adopted by the United States in 1900, a special allowance for the effect of high elevation, termed the "plateau correction," given in the form of an algebraically additive quantity having pressure units, was also applied to the initial value of pressure reduced to sea level calculated by conventional means on the basis of the assumed effective lapse rate, or the equivalent.

The purpose of this appendix is twofold: first, to show how one can convert the abovementioned "plateau correction" to a temperature correction having essentially the same effect on the pressure reduced to sea level as the original "plateau correction" when applied in the form of an algebraically additive quantity; and second, to show how another temperature correction can be derived which is equivalent in effect to the above mentioned assumption that the difference between the mean temperature of the fictitious air column and the station temperature argument is a function of the mean temperature of the fictitious air column. These two temperature corrections can be regarded as two components of a single temperature correction, which is a combination of the former two and is termed herein the "correction for plateau effect and local lapse rate anomaly," designated by $F(t_s)$. In this appendix both component corrections specified above are embraced within $F(t_s)$, and they are calculated simultaneously in the form of the algebraic sum designated by this symbol, with no effort being made to indicate the two components separately in numerical form, since it is the combination which is of most practical value for present purposes. (Note: Pressure reduced to sea level is designated by P_o while station pressure is denoted by P_s, and mean virtual temperature of the fictitious air column is represented by T_{mv}.)

In the conceptual history of the *reduction of pressure to sea level* the earliest ideas that led to the introduction of the so-called "plateau correction" were those of Ferrel.[1] [2]

Ferrel expressed his concept of reduction of pressure to sea level in the following words:[1]

"It is seen . . . that the reduction to sea level requires a knowledge of both the temperature and the hygrometric state of the atmosphere at the earth's surface, and in the formula it is assumed that these decrease with increase of altitude at a regular rate. Usually the reductions required are those of observations made at stations on land of greater or less elevation, or on mountain tops and on plateaus. In such cases it is somewhat difficult to conceive what reduction to sea level means, since there is no air

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[1] Wm. Ferrel, "Recent Advances in Meteorology," Washington, D.C., U.S. Printing Office, 1886. (United States of America, War Department, Annual Report of the Chief Signal Officer, 1885, Appendix 71.)

[2] Wm. Ferrel, "Report on Reduction of Barometric Pressure to Sea Level and Standard Gravity," Appendix 23 of Annual Report of the Chief Signal Officer, 1886, U.S. War Department, Washington, D.C.

pressure there. But since what is wanted by such reduction is something comparable with surrounding places where there is no elevation, it cannot mean anything more than the determination of what the barometric pressure would be if there were no mountain, or land surface, above sea level. Upon this hypothesis, therefore, we do not know the proper temperature and hydrometric state to be used, even for the upper station, for these are different on the plateau or mountain top where the observations are made from what they would be if the plateau or mountain were away, and from what they are in the open air around about at the same altitude as the station. We have here all the difficulties which were found . . . in the reductions of temperature to sea level."

If one accepts Ferrel's interpretation, it would appear that the values of assumed lapse rate (a) and virtual temperature at the station (T_{vs}) appropriate for use in the reduction formula should be representative of the conditions in the "open air around about" provided "the plateau or mountain were away." Since the latter proviso cannot be fulfilled in actual practice, the problem is not really solved on this basis.

Ferrel pointed out that both the mean annual and mean diurnal ranges of temperature are greater on any land surface than in the open air at a comparable level. It follows that if one treats the assumed lapse rate (a) for high stations as invariant with respect to T_{vs}, the apparent mean annual and mean diurnal ranges of pressure reduced to sea level will be greater than those actually observed at lowland stations. This is largely the case owing to the facts that the mean annual and diurnal ranges of mean virtual temperature of actual free air columns over the lowland areas are less than the mean annual and diurnal ranges of T_{vs} pertinent to the highland areas. Stemming from these relationships are the conclusions that the mean annual and diurnal variations of P_0 will not generally reflect, respectively, the true mean annual and diurnal variations of station pressure (P_s), for places on plateaux and mountains.

As is well known, aerological observations have revealed that the lapse rate tends to be greatest during the hot summer days and least during the clear, cold nights of winter; indicating that as a general rule the lapse rates in the free air increase with temperature at the surface. In some cases this fact has led to the introduction of the view by some that the assumed lapse rate (a) employed in the reduction of pressure to sea level should be treated as a monotone increasing linear function of the temperature (T) or virtual temperature (T_{vs}) at the station. It is clear that if this view is adopted the mean annual and mean diurnal ranges of variation of T_{mv} for the fictitious air column will be greater than those of T and T_{vs}. At the same time the use of such a function would tend to cause P_0 to have a relative minimum during the hottest months and during the hottest part of the day, respectively, disregarding the actual annual and diurnal variations of station pressure. Thus, under these circumstances the mean annual and mean diurnal variations of P_0 may be out of phase with respect to those of station pressure (P_s).

About the year 1886 Ferrel[2] completed an investigation regarding the reduction of pressure in the United States of America, based on the premise that an appropriate value of the assumed lapse rate (a) for the fictitious air column is 1° F. per 600 feet (that is, 0.3038° C./100 m.). By applying this lapse rate to the mean monthly temperatures for January and July, also to the mean annual temperatures, for a network of stations, he computed the corresponding values of T_{mv}; and on this basis he reduced the mean station pressures to sea level for the specified months and the year. After he calculated the differences (January–annual) and (annual–July) pressures reduced to sea level for the various stations, Ferrel observed that generally speaking these differences were positive and apparently correlated with the height of the station above sea level. He found that when the results were averaged the normal difference obtained at the station having a relatively low height above sea level was approximately 0.073 inch of mercury (2.47 mb.). However, in the case of stations at considerable heights above sea level the differences were much larger; and he apparently came to the conviction that the amount of the difference in excess of 0.073 inch of mercury was an error; that is, he made the assumption in effect that the proper value for the differences as defined above should be 0.073 inch of mercury at all stations, regardless of their height above sea level. Ferrel's point of view is best explained in his own words: "Since in January the observed temperatures are too low, and in July too high, to be used as open-air temperatures, it is reasonable to assume that they differ from the open-air temperatures in proportion to the deviation of the observed temperature above or below the annual mean. The error in reduction to sea level is sensibly proportional to the error in the temperature used in computing this reduction. It is also in proportion to the altitude of the station." These considerations led Ferrel to decide that one should apply a correction to the results obtained for the pressure reduced to sea level on the basis of the observed surface temperature averaged over a period of time such as a day or a month, and making use of the specified value of assumed lapse rate for the fictitious air column to compute T_{mv}. According to the assumptions made by Ferrel in the remarks quoted above the correction is defined by the following equation:

$$\text{Correction} = c(T_s - T_{sn})H \qquad \text{(i)}$$

where

c = an appropriate constant determined empirically;

T_s = surface temperature argument pertinent to the observation;

T_{sn} = annual normal value of surface temperature;

H = height of the station above sea level.

On the basis of data for 43 stations distributed over a wide range of heights Ferrel ascertained by the method of least squares that c has the value 0.00000105 inch of mercury/°F. foot, provided the temperatures are given in degrees Fahrenheit, heights in feet, and barometric pressures in inches of mercury. The mean value of the (January - annual) and (annual - July) normal difference at sea level of barometric pressure specified above (namely, 0.073 inch of mercury) was also determined in the same manner.

Underlying Ferrel's adoption of the correction given by equation (i) are certain premises: (a) In the case of any station located on a plateau or in mountainous terrain, the proper temperature for use in reduction of pressure to sea level is that which would exist in the free air at the same level as the station, if the mountain or plateau were away; (b) the mean annual temperature is essentially the same at the station as in the free air at the same level, if the mountain or plateau were away; (c) the use of the correction specified by equation (i) in effect permits one to apply practically the assumptions implicit in items (a) and (b).

Another consideration presented by Ferrel[2] was that if observed temperature was employed as the temperature argument, the apparent variations of pressure reduced to sea level caused by the diurnal variations of surface temperature would be spurious, and that in order to overcome the effect of the latter variations it would be necessary to use for the temperature argument a value approximating the daily mean. He observed that the amplitude of the diurnal range of temperature was generally much greater at the high stations than at stations close to the sea level. Therefore, he advocated the use of a temperature argument which would have the same diurnal range for the high stations as the actual diurnal range of temperature observed at or near sea level. At the time Ferrel made these recommendations (about 1886) synoptic observations were made in the United States of America at the hours of 7 a.m., 3 p.m., and 11 p.m., 75th Meridian Time; and the plan was adopted of using as the temperature argument "the mean of double the current observations of temperature, and the sum of the two preceding ones." This method of computing the temperature argument remained in effect until July, 1888, when synoptic observations were begun at 8 a.m. and 8 p.m., 75th Meridian Time, and since then the temperature argument in the United States of America has been the mean of the current temperature and the temperature 12 hours *previously.*

About 1900 Bigelow[3] made a comprehensive investigation of the barometry of the United States of America, Canada, and the West Indies. He improved upon Ferrel's techniques in regard to the reduction of pressure by adopting several schemes, the principal one of which was the use of a variable lapse rate for the fictitious air column, treating it as a function of surface temperature argument. Owing to the complications involved, we shall not endeavor to describe the methods employed by Bigelow to determine this function, separately for each station whose height above sea level was 305 meters or more. For stations at lower heights he assumed that the lapse rate had the constant value of zero (0). Bigelow accepted the use of the correction recommended by Ferrel and given in equation (i), except that he replaced T_s by T'_m, and T_{sn} by T'_{mn} in the present notation, where T'_m denotes the mean temperature of the fictitious air column, and T'_{mn} the normal annual value of T_m. The correction for humidity was treated as a function of the surface station temperature argument (T_s).

Bigelow called the function represented by equation (i) the "plateau correction," and we shall employ the same term with reference to it. He differs from Ferrel in his assignment of reasons to justify the "plateau correction." According to his view, the assumed lapse rate in the fictitious air column (A) for the plateau should generally be less than the annual mean, actual lapse rate in the free air over the neighboring lowlands, since he apparently believed that the mean annual temperature of the surface of the plateau was higher than that of the free air at the same level over the surrounding low-lying areas.

It was Bigelow's contention that the assumed lapse rate in the fictitious air column should vary with the location of the station, the height above sea level, and the month. He maintained that Ferrel's consideration of the January temperatures as being too low and the July temperatures as too high for purposes of reduction to sea level was owing to the latter's use of a single mean assumed lapse rate applicable to all stations and all months of the year. Bigelow felt in effect that if the assumed lapse rate (A) were permitted to vary in an appropriate manner with the station temperature argument (T_s), depending on the station, it would not be necessary to regard the monthly temperatures as anomalous. He developed an elaborate method of determining ($T'_m - T_s$), the difference between the mean temperature of the fictitious air column (T'_m) and the surface temperature argument (T_s), as a function of T'_m for each station having a height of more than 1000 feet (305 m.) above sea level. This system permits one to express the effective assumed lapse rate in the fictitious air column as a function of T_s. Suffice it to say that the results yielded by Bigelow's method are only as valid as the underlying assumptions and that the latter can only be verified by suitably designed tests to ascertain whether the results are compatible with other meteorological variables or parameters based upon direct observations.

No effort will be made at this point to examine critically the consistency of the various arguments and reasons advanced by Bigelow in favor of or in explanation of the need to employ a "plateau correction." (The interested reader will doubtlessly wish to scrutinize for himself Bigelow's original work regarding these matters.[3])

For present purposes it will suffice to consider that Bigelow introduced the "plateau correction" as a practical measure to overcome some of the apparent defects in pressures reduced to sea level as determined at high plateau stations by conventional methods of reduction. Bigelow, like Ferrel, adopted the view that the "plateau correction" should be expressed as an algebraically additive quantity in terms of units of pressure. Later in this appendix it will be shown that correction can, in effect, be given in terms of temperature, if desired. Such a scheme has several advantages.

Bigelow's specification of the "plateau correction" is shown in equation (2) below, written in the notation adopted for the present appendix, not in Bigelow's original notation.

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[3] F. H. Bigelow, "Report on the Barometry of the United States, Canada, and the West Indies," volume II—Report of the Chief of the Weather Bureau, 1900-1901, Washington, D.C.

Since a number of parameters are involved, it is desirable to utilize a convenient notation, given in a later paragraph. For the sake of consistency with chapter 7 and Appendix 7.1, temperatures in degrees Fahrenheit (°F.) are designated by lower case t. Absolute temperatures measured relative to absolute zero, but expressed in degrees of the same size as that used in the Fahrenheit scale, are designated here by capital T; and such temperatures in degrees of this size expressed in "degrees Rankine," or °R.; hence $T°$ R. = (459.688° + $t°$ F.).

Primed quantities are to be understood as referring to entities whose definitions are in essential agreement with the definitions effectively applied to those entities by Bigelow.

2. Development of Theory

In order to facilitate development of the subject the following notation will be employed herein:

P_o = pressure reduced to sea level (in inches of mercury);

P_s = station pressure (in inches of mercury);

P_{sn} = annual normal value of station pressure, noting that this is the annual normal of P_s, determined on the basis of climatological data;

H_p = station elevation (height above sea level, in feet);

H_{pg} = geopotential of station (in geopotential feet);

t'_m = mean temperature of the fictitious air column, determined according to Bigelow's procedure (in °F.);

T'_m = mean temperature of the fictitious air column, determined according to Bigelow's procedure (in °R.);

t'_{mn} = annual mean temperature of the fictitious air column, determined according to Bigelow (in °F.);

T'_{mn} = annual mean temperature of the fictitious air column, determined according to Bigelow (in °R.);

J = so-called "plateau correction" according to Bigelow (in inches of mercury);

T'_{mv} = mean virtual temperature of the fictitious air column equivalent in effect to that determined according to Bigelow's procedure (in °R.), noting that this differs from T'_m only by including a correction for humidity (see Chapter 7);

T'_{mvn} = annual mean virtual temperature of the fictitious air column equivalent in effect to that determined according to Bigelow's procedure (in °R.), noting that this is merely the annual mean value of T'_{mv} and may be regarded as a constant for each station ascertained on the basis of climatological data;

t_s = station temperature argument (in °F.), which was, in effect, defined by Bigelow as the mean of the current temperature at any given observation and the temperature 12 hours previously;

t_{sn} = annual normal station temperature argument (in °F.); that is, the annual normal value of t_s determined from climatological data;

T_o = 459.688° R., that is, the absolute temperature (in °R.) corresponding to 0° F.;

T_s = $(T_o + t_s)$ = station temperature argument (in °R.);

T_{sn} = $(T_o + t_{sn})$ = annual normal station temperature argument (in °R);

e_s = aqueous vapor pressure observed at the station;

C_h = suitable function of station elevation (depending upon season, temperature, etc., if desired), such that

e_sC_h = $(T'_{mv} - T'_m)$; (termed the "correction for humidity," see sec. 7.0.5.3);

a = standard lapse rate assumed in the standard atmosphere (that is, 0.0065° C. per meter, or 0.00356616° F. per foot);

A = $A(t_s)$ = effective lapse rate of the fictitious air column for stations having elevations in excess of 1,000 feet, considered as a function of t_s, and consistent with Bigelow's data (see equations (7) - (10) below);

K = hypsometric constant (see equation (15) and Appendix 7.1);

T_{mv} = mean virtual temperature of the fictitious air column (in °R.) as used in equation (15).

Note: T_{mv} will be defined operationally in such a manner that it includes a correction, in temperature units, whose effect when applied in the hypsometric equation (see equation (15)) is very nearly equivalent to that of Bigelow's "plateau correction" (see equation (2)). T_{mv} will also include a correction for the "effective lapse rate" depending on the difference $(t'_m - t_s)$ assumed by Bigelow to be pertinent at the observed value of t_s.

For purposes of reduction of pressure to sea level Bigelow[3] recommended the following formula (which is written in the special notation adopted for this appendix, not necessarily in the original one of Bigelow):

$$P_o = P_s\, 10^{mq} + J \qquad (1)$$

where the so-called "plateau correction" is

$$J = c(t'_m - t'_{mn})\ H_p \qquad (2)$$

as defined by Bigelow, in which

c = constant = 1.05×10^{-6} inches of mercury per °F. per foot;

and where

$$m = H_p/(56517 + 123.3\ t'_m + 0.003\ H_p)$$

and

$$q = (1 - b - s)$$

where

$b = 0.378 \times$ (mean value of the ratio of the aqueous vapor pressure to the barometric pressure in the fictitious air column);

and

$$s = 0.0026 \cos 2\phi$$

where ϕ = latitude. H_p is given in feet and t'_m in °F.; while b constitutes a correction for humidity and s a correction for gravity.

In order to simplify later calculations one may replace the "plateau correction" by the following expression

$$J = c(T'_{mv} - T'_{mvn})H_{pg} \qquad (2a)$$

which is a close approximation of the quantity defined in equation (2). A comparison of the results yielded by equations (2) and (2*a*) can be readily made by means of an example. Thus, if H_p = 5,000 feet, and $(T'_{mv} - T'_{mvn})$ exceeds $(t'_m - t'_{mn})$ by 4° F., equation (2*a*) will yield a magnitude which is 0.02 inch of mercury greater than that yielded by equation (2). This deviation is of no consequence in the present problem for at least three reasons: (a) the magnitude of the deviation is very small in relation to the magnitude of P_o which normally is of the order of 30 inches of mercury when evaluated by means of equation (1); (b) if the definition given by equation (2*a*) were used at all stations instead of the definition specified by equation (2), the effect of this change on horizontal gradients of P_o would be negligible since the differences between stations should tend to cancel; and (c) equation (2*a*) is a rationalization of equation (2) inasmuch as it includes an effect due to humidity, which, according to reason, ought to be involved, if the theory of the plateau correction is valid.

A scrutiny of the first term in the right-hand member of equation (1) reveals it to be unduly complicated in contrast to the form of the hypsometric relationship presented as equation (20) of Appendix 7.1. Therefore, for the sake of simplicity equation (1) is replaced by the following, very nearly equal expression:

$$P_o = P_s\, 10^{KH_{pg}/T'_{mv}} + c(T'_{mv} - T'_{mvn})H_{pg}. \qquad (3)$$

For present purposes this may be regarded as a modern version of the formula recommended by Bigelow for the reduction of pressure to sea level.

One may consider equations (1) and (3) to be equivalent, provided one accepts equation (2*a*) in lieu of equation (2) for the definition of J. The equality of equations (1) and (3) affords an operational means of defining T'_{mv}.

As an outgrowth of a study of the climatological and other data involved in the problem, Bigelow[3] in effect came to the conclusion that the *departure* of the mean temperature of the fictitious air column from the station temperature argument must be considered to be a continuous function of the mean temperature of the fictitious air column. In other words he came to regard $(t'_m - t_s)$ as a function of t'_m, capable of being shown either by graphical means or by tabular data, provided the function were properly determined for each station, respectively. (It is immaterial that Bigelow actually dealt with $(t_s - t'_m)$ rather than $(t'_m - t_s)$.)

Bigelow[3] investigated the climatic and synoptic data available on January 1, 1900 for all existing meteorological stations in the United States, Canada, and the West Indies. With respect to all stations whose elevation was over 1,000 feet above sea level, Bigelow developed a very elaborate procedure for constructing graphs and tables which gave the quantity $(t_s - t'_m)$ as a function of t'_m, in accordance with his hypothetical views concerning the problem of reduction of pressure to sea level. No effort will be made here to describe his procedure.

If one accepts Bigelow's view that $(t'_m - t_s)$ is a continuous function of t'_m this may be expressed by the relationship

$$(t'_m - t_s) = f_1(t'_m). \qquad (4)$$

Now consider the identity

$$t_s = t'_m - (t'_m - t_s). \qquad (5)$$

Substituting equation (4) in equation (5) one finds

$$t_s = t'_m - f_1(t'_m). \qquad (6)$$

It may be shown that if t_s is *not* constant with respect to t'_m but rather is a continuous dependent function of t'_m over a certain range of the variables, then equation (6) is capable of being solved to yield an expression which gives t'_m as a continuous function of t_s, within that range. On this basis it is possible to show that

$$(t'_m - t_s) = f(t_s) \qquad (7)$$

where $f(t_s)$ is a continuous function of t_s within the range referred to above.

Now consider the continuous function of t_s denoted by $A(t_s)$, or simply A, defined by the expression

$$A = A(t_s) = 2f(t_s)/H_{pg}. \qquad (8)$$

Substituting equation (7) in (8) one obtains

$$A = A(t_s) = 2(t'_m - t_s)/H_{pg}. \qquad (9)$$

If the vertical temperature gradient in the fictitious air column depended upon t_s but were uniform throughout the column for any given value of t_s, the function $A(t_s)$ defined by equation (9) would represent the lapse rate. Therefore, one may term $A(t_s)$ as the "effective lapse rate" in the fictitious air column, regarded as a function of t_s, on the basis of Bigelow's assumption that $(t'_m - t_s)$ is a function of t'_m.

From equation (9) one finds

$$t'_m = (t_s + AH_{pg}/2), \qquad (10)$$

where, in the light of equations (7) and (8), it will be understood that A is a function of t_s.

By definition of absolute temperature

$$T'_m = (T_o + t'_m) \qquad (11)$$

Substituting equation (10) in (11) one obtains

$$T'_m = (T_o + t_s + AH_{pg}/2). \qquad (12)$$

For the sake of simplicity let it be assumed that under suitable restrictions the correction for humidity in the fictitious air column may be expressed as the product of e_sC_h.[4]

Under this assumption

$$T'_{mv} = (T_o + t_s + AH_{pg}/2 + e_sC_h). \qquad (13)$$

Bigelow[3] assumed that the correction for humidity could be regarded as a function of t'_m. Therefore, in the light of the foregoing considerations this is also tantamount to assuming that the correction for humidity can be regarded as a function of t_s.

On the foregoing grounds it will be seen that Bigelow's assumptions would lead to the result that the right-hand member of equation (13) is a function of t_s.

For the present one may regard equation (13) as the specification of the function T'_{mv} which appears in equation (3), in essential conformity with Bigelow's assumptions.

Suppose that J is replaced by $J(P_s/P_{sn})$ which is nearly equal in value to the former. Then, equation (3) can be rewritten in the closely approximate form

$$(P_o/P_s) = [10^{KH_{pg}/T'_{mv}} + (c/P_{sn})(T'_{mv} - T'_{mvn})H_{pg}]. \qquad (14)$$

The consequence of replacing P_s by P_{sn} in the right-hand member is of little consequence since P_s is usually within about 3 or 4 per cent of P_{sn} and the second term in the bracket is small in comparison to the first term.

It will be noted from equations (21)—(25) of Appendix 7.1 that the ratio (P_o/P_s),

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[4] World Meteorological Organization, "Reduction of Atmospheric Pressure," Technical Note No. 7, Geneva, Switzerland, 1954.

apart from any consideration of the "plateau correction," can be written

$$(P_o/P_s) = 10^{KH_{pg}/T_{mv}}, \qquad (15)$$

where

T_{mv} = mean virtual temperature of the fictitious air column (in °R.).

Now let equations (14) and (15) be set equal, subject to the specification of T'_{mv} by equation (13), where T'_{mv} is considered to be a function of t_s, in essential agreement with Bigelow's assumptions.

Under these conditions the setting of equations (14) and (15) to be equal, carries with it the implication that T_{mv} is a function of t_s, in accordance with Bigelow's assumptions.

Now define a function $F(t_s)$, (that is, F a function of t_s), which satisfies the equation

$$T_{mv} = [T_o + t_s + aH_{pg}/2 + e_sC_h + F(t_s)] \qquad (16)$$

subject to the conditions that equations (14) and (15) are identically equal, and that T'_{mv} as defined by equation (13) is a function of t_s.

The function $F(t_s)$ has been introduced in order to obtain a temperature correction which produces essentially the same effect on the pressure reduced to sea level as the combination of the "lapse rate anomaly" $(A - a)$ and the plateau correction.

By virtue of this characteristic the function $F(t_s)$ is termed the "correction for plateau effect and local lapse rate anomaly." One may justify this nomenclature on the following grounds: First of all, equation (14) specifically includes the "plateau correction," while equation (15) which is set equal to equation (14) does not. This forces T_{mv} to acquire an increment in contrast to T'_{mv}, where this increment acts as a component having the same effect on the pressure reduced to sea level as the "plateau correction" embodied in equation (14). Secondly, T'_{mv} as defined in equation (13) and used in equation (14) contains a term involving $AH_{pg}/2$ which relates to the effective lapse rate, whereas equation (16) contains instead the term $aH_{pg}/2$. Since equations (14) and (15) are set equal, this forces $F(t_s)$ involved in T_{mv} to contain a component dependent upon the difference $(A - a)H_{pg}/2$. On the other hand the terms T_o, t_s, and e_sC_h are common to both T'_{mv} and T_{mv}, hence they introduce no components in $F(t_s)$.

From equations (13) and (16) it is easily found that

$$F(t_s) = T_{mv} - T'_{mv} + (A - a)H_{pg}/2. \qquad (17)$$

Owing to the equality between (14) and (15), this last relationship enables one to compute $F(t_s)$ for various values of t_s over the range for which the functions e_sC_h and $A(t_s)$ are known. See Tables 7.2.1—7.2.5 and Bigelow's Chart 36.

Briefly the following instructions may be pursued to compute $F(t_s)$ for any given station for which H_p exceeds 1000 feet:

(a) From Bigelow's work[3] extract the data giving $(t'_m - t_s)$ as a function of t'_m. (See data in his Chart 36, which yield the negative of this function.)

An example of a table giving $(t'_m - t_s)$ as a function of t'_m for one station according to Bigelow[3] is the following:

Lander, Wyoming
Station Elevation, H_p = 5372 feet

t'_m	$(t'_m - t_s)$
°F.	°F.
−40°	6.3
−30°	6.05
−20°	5.7
−10°	5.2
0°	4.65
+10°	4.2
20°	4.1
30°	4.35
40°	5.2
50°	6.45
60°	7.8
70°	8.7
80°	8.9
90°	8.8
100°	8.4

(b) By means of the identity

$$t_s = t'_m - (t'_m - t_s)$$

calculate the values of t_s which correspond to various chosen values of t'_m, making use of the data obtained under step (a).

(c) Compute $2(t'_m - t_s)/H_{pg}$ from the values of $(t'_m - t_s)$ used in step (b), and plot the results as functions of t_s, for the values of t_s as calculated by means of step (b). Construct a smooth curve through the plotted points, and by virtue of equation (9) read off from the curve values of the "effective lapse rate" $A(t_s)$ for various arguments of t_s (such as every 5° F.).

(d) With the aid of the data compiled in Table 7.2.1–7.2.5 and sec. 7.0.5.3 determine the humidity correction e_sC_h for various arguments of t_s.

(e) By making use of the results obtained by means of steps (c) and (d), calculate T'_{mv} on the basis of equation (13) for various arguments of t_s.

(f) Plot $(T'_{mv} - T_s)$ as a function of t_s and draw a smooth curve through the points. Determine t_{sn} from climatological data in Table 7.1.3; read off the value of $(T'_{mv} - T_s)$ corresponding to t_{sn}; then compute T'_{mvn} by adding T_{sn} to the value of $(T'_{mv} - T_s)$ thus read from the smooth curve.

(g) Substitute in equation (14) the results obtained by steps (e) and (f) for various arguments of t_s, thus securing the corresponding values of the ratios (P_o/P_s). (Note: The operation of calculating the first term in the right-hand member of equation (10) is facilitated if one employs a table giving 10^x as a function of x. See NBS Applied Mathematics Series No. 27.)

(h) Equate each of those ratios respectively to equation (15), and solve for the corresponding value of (KH_{pg}/T_{mv}) from this relationship. This is to be done separately for each argument of t_s. (Note: The evaluation of T_{mv} by such a procedure is facilitated if one makes use of a table of common logarithms.) Then from the stated quantity (KH_{pg}/T_{mv}) compute T_{mv} by division.

(i) Finally, substitute into equation (17) the results obtained by means of steps (c), (e), and (h), for various arguments of t_s. This yields $F(t_s)$ as a function of t_s for those arguments. Samples of such functions are compiled in Tables 7.4.6–7.4.8. (See also Tables 7.4.1–7.4.5.)

The foregoing procedure gives an outline of the method employed in the construction of Tables 7.4.6–7.4.8, referred to above.

With regard to applications, one can use the function $F(t_s)$ as a term involved in the computation of T_{mv} by means of equation (16); and then the resultant value of T_{mv} is substituted in equation (15) for the purpose of reducing pressure to sea level. See Chapter 7, secs. 7.0.0–7.0.5.4.

It has been indicated that $F(t_s)$ includes components due to both the "plateau correction" and the "local lapse rate anomaly" $(A - a)$. Therefore, the term $F(t_s)$ permits one to take effective account of those two components without the need to employ the more cumbersome procedure implicit in equations (1) and (2). See figs. 7.2.7(a) and 7.2.7(b).

APPENDIX 8.0.1

ICAO STANDARD ATMOSPHERE: ITS SPECIFICATIONS AND THE DERIVATION OF THE "PRESSURE-ALTITUDE RELATIONSHIPS"

Introduction

In this Appendix there is first presented a summary of the so-called "Pressure-Altitude Relationships" (see equations Ia, Ib, IIa, and IIb). Secondly, the basic specifications of the ICAO Standard Atmosphere are given, particularly as they determine these equations. Thirdly, derivations of the equations are set forth. For additional details concerning these subjects the reader should consult the following reference: National Advisory Committee for Aeronautics, Report 1235, "Standard Atmosphere—Tables and Data for Altitudes to 65,800 Feet," published in 1955 by the U.S. Government Printing Office, Washington 25, D. C.

1. SUMMARY OF "PRESSURE-ALTITUDE RELATIONSHIPS"

These relationships are equations which give the pressure (P) as a function of the geopotential (H), which is expressed in units of standard geopotential meters (symbol m' or m'). This unit is explained in par. 2.7. Equations (Ia) and (Ib) apply to the *troposphere* (i.e. for the layer up to 11,000 m' wherein the lapse rate is assumed to have the constant standard value a representing 0.0065° C. per m'); while equations (IIa) and (IIb) apply to the *isothermal* portion of the stratosphere (i.e. for the layer from 11,000 m' to 20,000 m' wherein the temperature is assumed to have the constant value —56.50° C.).

To summarize the results concerning these equations, developed in the pages which follow, the relationships are now presented for convenience in reference:

Troposphere Pressure-Altitude Relationships (Valid up to 11,000 m')

$$\frac{P}{P_o} = \left(\frac{T_o - aH}{T_o}\right)^n \qquad \text{(Ia)}$$

where

n = 5.2561 (a dimensionless constant; see eq. 10)

P = pressure at geopotential H (in units of m')

P_o = standard pressure at sea level
= 29.921 inches of mercury = 1013.250 mb.

T_o = standard temperature at sea level
= 288.16° K.

a = standard lapse rate in the troposphere
= 0.0065° C. per m'

Alternatively, from (Ia),

$$H = \frac{T_o}{a}\left[1 - \left(\frac{P}{P_o}\right)^{1/n}\right] \qquad \text{(Ib)}$$

Isothermal Stratosphere Pressure-Altitude Relationships (Valid from 11,000 up to 20,000 m')

$$\log_{10}\frac{P}{P_o} = n \log_{10}\left(\frac{T^*}{T_o}\right) - B(H - H^*) \qquad \text{(IIa)}$$

where

n = 5.2561 (a dimensionless constant);

P = pressure at geopotential H (in units of m');

P_o = standard pressure at sea level,
= 29.921 inches of mercury = 1013.250 mb.;

T_o = standard temperature at sea level
= 288.16° K.;

T^* = standard temperature at the standard tropopause (11,000 m') and in the superjacent isothermal stratosphere,
= 216.66° K.;

B = $0.6848317 \times 10^{-4}\ (m')^{-1}$; (a constant; see eq. 17)

H^* = 11,000 m' = geopotential of standard tropopause.

Alternatively, from (IIa),

$$H = H^* + \frac{1}{B}\left[n \log_{10}\left(\frac{T^*}{T_o}\right)\right] - \frac{1}{B}\log_{10}\left(\frac{P}{P_o}\right) \qquad \text{(IIb)}$$

2. SPECIFICATIONS OF THE ICAO STANDARD ATMOSPHERE

The specifications outlined here are restricted to those which bear mainly on the information summarized in sec. 1 above. Some additional notes are included, however, relating to certain constants.

2.1.1 Composition of Air.—The air of the standard atmosphere is assumed to be *dry*. Its composition for all altitudes considered herein is deemed to be as follows, where the numbers following the constituent gases refer to the mol fraction in percent†: nitrogen, 78.09%; oxygen, 20.95%; argon, 0.93%; carbon dioxide, 0.03%; neon, 1.8×10^{-3}%, helium, 5.24×10^{-4}%; krypton, 1.0×10^{-4}%; hydrogen, 5.0×10^{-5}%; xenon, 8.0×10^{-6}%; ozone 1.0×10^{-6}%; radon, 6.0×10^{-18}%.

2.1.2 Molecular Weight of Dry Air.—On the basis of the atomic weights determined by chemists for the constituent gases listed above, and the composition as specified in par. 2.1.1 the apparent molecular weight of dry air (M) is calculated as $M = 28.966$ grams per mol#.

2.2 Absolute Temperature Scale

The scale of absolute temperature (T) in degrees Kelvin (°K.) is given by

$$T(°\text{K.}) = T_i + t(°\text{C.}) \qquad (1)$$

where T_i = absolute temperature (°K.) of the melting point of ice under a pressure of 1,013,250 dynes per cm.^{2} (1013.250 mb.); and t(°C.) = temperature on the thermodynamic Celsius scale (°C.). For the first of these quantities a suitable constant must be taken; accordingly, there was adopted the relationship

$$T_i = 273.16° \text{ K.} \qquad (1a)$$

(See sec. 7.0.1 of Manual of Barometry.)

2.3 Standard Pressure at Sea Level (P_o)

The standard pressure at sea level is taken as P_o = 1,013,250 dynes cm.$^{-2}$ (1013.250 mb.). This corresponds to the pressure exerted by a column of mercury 760 mm. high, having a density of 13.5951 gm. cm.$^{-3}$ and subject to a gravitational acceleration of 980.665 cm. sec.$^{-2}$

2.4 Density as a Function of Pressure and Temperature

Dry air is assumed to behave like a perfect gas, obeying the following relationship‡ between its density, pressure and temperature,

$$\rho = \frac{1}{R}\frac{P}{T} \qquad (2)$$

where

ρ = density of air, gm. cm.$^{-3}$
P = pressure, dynes cm.$^{-2}$
T = absolute temperature, °K.
R = gas constant for 1 gram of dry air, in ergs gm.$^{-1}$ (°K.)$^{-1}$.

2.5 Gas Constant for Dry Air

The gas constant for 1 gram of *dry air* has the value $R = 2.8704 \times 10^6$ ergs gm.$^{-1}$ (°K)$^{-1}$. This is determined by the equation $R = R^*/M$ where R^* = gas constant for 1 gram mol of ideal gas, and M = apparent molecular weight of dry air. Taking $R^* = 8.31436 \times 10^7$ ergs mol^{-1} (°K.)$^{-1}$ on the chemical scale of atomic weights, and M = 28.966 grams mol^{-1}, one finds by means of the equation in the second sentence the value for R cited in the first sentence of this paragraph. *Note:* While ICAO accepted for R^* the value $R^* = 8.31436 \times 10^7$ ergs mol^{-1} (°K.)$^{-1}$, a slightly different value is given by other authorities, for which the reader may consult the following references: J. W. M. DuMond and E. R. Cohen, Revs. Modern Physics, *25*, 691 (1953); and E. R. Cohen, J. W. M. DuMond, T. W. Layton, and J. S. Rollett, Revs. Modern Physics, *27*, 363–380

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† For practical purposes mol fraction may be regarded as nearly the same as fraction by volume. The mol fraction of any constituent in any mixture is defined as the number of molecules, or mols, of that constituent divided by the total number of molecules, or mols, in the mixture.

In principle, one may consider that a mol (or mole) refers to certain definite fixed number of molecules of the substance. It is the number of molecules contained in exactly 32 grams of oxygen gas under normal conditions of pressure and temperature. The number of molecules in a mol has been determined as about 6.02322×10^{23} molecules per mole, this quantity being termed "Avogadro's number."

The foregoing specification of a mol of oxygen is based on the "old" scale of atomic weights under which natural oxygen is assumed to have an atomic weight of 16, exactly, by definition. Under the new scale of atomic masses adopted in 1961, based on the value 12, exactly, for the carbon–12 isotope, one mol of natural oxygen gas has a mass of 31.9988 grams.

‡ Equation (2) is considered as one way of writing the perfect gas law.

(1955). When $T_i = 273.16°$ K., one obtains from the data cited by these authorities the value $R^* = 8.31439 \times 10^7$ ergs mol^{-1} (°K.)$^{-1}$, on the chemical scale of atomic weights. On this basis, the value of R given above in this section is still valid to the fourth decimal place.

2.6 Hydrostatic Equation

The air is assumed to be in hydrostatic equilibrium and to satisfy the differential equation:

$$dp = -\rho g \, dZ \tag{3}$$

where, in the C.G.S. system of units

P = pressure, dynes cm.$^{-2}$
ρ = density, gm. cm.$^{-3}$
g = acceleration of gravity, cm. sec.$^{-2}$
Z = geometric altitude, cm.

2.7 Geopotential, and Unit of Vertical Displacement

Let H = geopotential at a point whose geometric altitude is Z in the atmosphere, where g is the acceleration of gravity at the point. Next, we introduce the quantity G, a dimensional constant, whose magnitude determines the size of the unit of H in terms of units of length and time. The relationships between these quantities are given by the equations:

$$G \, dH = g \, dZ \tag{4}$$

and

$$H = \frac{1}{G} \int_0^Z g \, dZ \tag{5}$$

In the last equation use is made of the fact that we consider H to assume the value zero (0) when the point is at mean sea level; that is, where altitude $= Z = 0$. (Note: In regard to a further discussion of geopotential the reader may review secs. 1.2.1 and 1.3 of the Manual of Barometry, and also consult the references cited there.)

Eq. (5) reveals that H is correlated with Z, depending upon the latitude, since g is a function of latitude as well as of Z. The value of G in metric measures has been so chosen that when Z increases by 1 meter, the value of H increases by very nearly one metric unit of geopotential termed "the standard geopotential meter" (symbol *m′*). Similarly, the value of G in English measures has been selected so that when Z increases by 1 foot, the value of H increases by very nearly one English unit of geopotential, termed "the standard geopotential foot" (symbol ft′). Thus, restricting our attention to the metric measures, as applied to eqs. (4) and (5), the value employed for the dimensional constant is $G = 9.80665$ m.^{2} sec.$^{-2}$ per standard geopotential meter, to be used in connection with g in m. sec.$^{-2}$, Z in meters (m.), and H in standard geopotential meters (m′). Since we have the conversion

0.3048 meter = 1 foot for units of Z,

we also obtain the relationship

0.3048 m′ = 1 ft′ for units of H.

Note.—Meteorologists employ a slightly different metric unit for H, namely the "geopotential meter" (symbol gpm), for which G takes the value $G = 9.8$ m.^{2} sec.$^{-2}$ per gpm. Thus, the "standard geopotential meter" is a unit slightly larger then the "geopotential meter" of the meteorologists,
for

$$1 \text{ m}' = (9.80665/9.8) \text{ gpm}$$

and

$$1 \text{ ft}' = (9.80665/9.8) \text{ gpft.}$$

Thus $\quad 1 \text{ ft}'/\text{gpft} = 1 \text{ m}'/\text{gpm}$
$\qquad = (9.80665/9.8) = 1.00068$

2.8 Standard Absolute Temperature at Sea Level (T_o)

The standard Celsius temperature at sea level is assumed to be 15° C. (59° F.). It follows that the corresponding absolute temperature at sea level is, in accord with eq. (1),

$$T_o = (273.16 + 15)° \text{ K.} = 288.16° \text{ K.} \tag{6}$$

where

T_o = standard absolute temperature at sea level, in °K.

2.9 Standard Density of Dry Air at Sea Level (ρ_o)

One may calculate density on the basis of eq. (2). We have

P_o = standard pressure at sea level
= 1,013,250 dynes cm.$^{-2}$; (see par. 2.3).
T_o = standard temperature at sea level
= 288.16° K.; (see par. 2.8).

ρ_0 = standard density of dry air at sea level.
R = 2.8704×10^6 ergs gm.^{-1} $(°\text{K.})^{-1}$ (see par. 2.5).

Substituting these data in eq. (2) we obtain

$\rho_0 = \frac{1}{R}\frac{P_o}{T_o} = 0.0012250$ gm. cm.^{-3} which is the value of the standard density of dry air at sea level.

2.10 Standard Specific Weight of Dry Air

Specific weight is represented by the product of the acceleration of gravity and the density. For the computation of specific weight in the standard atmosphere the convention is adopted that gravitational acceleration has the constant value $g_s = 980.665$ cm.sec.^{-2}; hence if ρ denotes density, the standard specific weight is $g_s\rho$. It follows in accordance with par. 2.9, that the standard specific weight of dry air at sea level is given by

$$g_s\rho_0 = 1.20131 \text{ gm. cm.}^{-2} \text{ sec.}^{-2}.$$

2.11 Lapse Rate and Vertical Temperature Structure of the Standard Atmosphere

Lapse rate is defined as the rate of *decrease* of temperature with height; hence if a denotes lapse rate

$$a = \left(-\frac{dT}{dH}\right).$$

In the *troposphere* of the standard atmosphere, the adopted value of the lapse rate is given by

$a = 0.0065°$ C. per standard geopotential meter.

Expressing this in English unit equivalents, we get

$a = 0.00356616°$ F. per standard geopotential foot.

The foregoing value of the lapse rate is intended to apply up to the level of the tropopause (base of the isothermal stratosphere). In conformity with the foregoing assumption regarding the assumed lapse rate (a), the absolute temperature (T) at any point within the troposphere where the geopotential is H may be determined in accordance with the equation

$$T = T_o - aH \qquad (7)$$

where

T_o = standard absolute temperature at sea level (see eq. 6, par. 2.8).

Eq. (7) is assumed to apply *below* sea level in the standard atmosphere, as well as up to the tropopause.

In the isothermal stratosphere of the standard atmosphere, the temperature is assumed to take the constant value denoted by T^*. This value will be understood to apply from the tropopause to the top of the isothermal stratosphere. The value adopted is

$$T^* = 216.66° \text{ K.}$$

which is equivalent to −56.50° C.

The asterisk (*) is intended to denote that the quantity so marked refers to the *tropopause*. Thus, let H^* represent the geopotential at the level of the tropopause. Similarly let T^*, P^*, and ρ^* represent the absolute temperature, pressure and density respectively at the tropopause.

Thus, in eq. (7), when H becomes H^*, T must be replaced by T^*; hence

$$T^* = T_o - aH^*. \qquad (7a)$$

Since

$$T_o = 288.16° \text{ K.}$$

(see Par. 2.8), and

$$T^* = 216.66° \text{ K.}$$

(by adoption, see above), while

a = 0.0065° K. per standard geopotential meter (m′),

we may calculate H^* with the aid of equation (7a) for T^* given above. This yields the result

$$H^* = 11{,}000 \text{ m}'$$

which represents the value of the geopotential at the standard tropopause. NACA Report 1235 includes data covering the isothermal layer from 11,000 m′ to 20,000 m′ based on the assumed constant temperature 216.66° K. for the stratum.

Notes:

In the Introduction to the ICAO Standard Atmosphere (see NACA Report 1235), it is indicated that the standard atmosphere as defined in the foregoing may be regarded as a suitable reference basis for average values of certain elements in the free air up to 20,000 meters. This view is taken since Gregg in NACA Report 147 shows that such an artificial atmosphere based on simple assumptions gave results in fairly good agreement with average annual values in regard to pressure, temperature, and density as observed at about latitude 40° in North America for altitudes up to 20,000 meters. Further, the Introduction concludes with the following statement:

> “The extension of the standard atmosphere to above 20,000 meters (65,617 feet) as an approximation to the average conditions at those altitudes must still await the collection and analysis of a considerable number of reliable upper air soundings.”

Since 1952 many high level upper air soundings have been made.

In view of the need for an extension of the standard atmosphere to pressure altitudes above 20,000 m′, the Geophysics Research Directorate of the Air Force Cambridge Research Center and the United States Weather Bureau jointly sponsored in November, 1953, the organization of a Committee on Extension to the Standard Atmosphere. A Working Group was appointed to formulate a temperature-altitude profile and to recommend basic values and parameters. As a result of the considerations and recommendations of the Working Group and the Committee, a set of specifications pertaining to the U.S. Extension to the ICAO Standard Atmosphere was adopted in 1956 by a number of governmental and private organizations in the United States. The detailed data based on these specifications have been published.[1] See also reference 19, Chap. 8.

After additional upper-air data were obtained in connection with the International Geophysical Year from July 1, 1957, to December 31, 1958, it was concluded that the information compiled in the publication by Minzner, Ripley, and Condron, previously cited (Ref. 1), was not accurately representative of actual average conditions above an altitude of 20,000 m′ (where 1 m′ = 1 standard geopotential meter). By virtue of the requirements for more representative data pertaining to these high altitudes, the U.S. Weather Bureau, the Geophysics Research Directorate (U.S. Air Force Cambridge Research Laboratories), and the National Aeronautics and Space Administration in 1960 co-sponsored the U.S. Committee on Extension of the Standard Atmosphere (COESA). The table presented below indicates the revised values of altitude, temperature, and pressure for the range from 0 to 90,000 meters considered for adoption in 1962 by the above-mentioned U.S. Committee on Extension of the Standard Atmosphere.

TABLE

Vertical Distribution of Temperature and Pressure for the Altitude Range 0–90,000 Meters Recommended for the U. S. Standard Atmosphere (1962)

Altitude		Temperature	Pressure
m.	m′	°Kelvin	mb.
90,000	88,743	180.65	0.0016438
79,994	79,000	180.65	0.010377
61,591	61,000	252.65	0.182099
52,429	52,000	270.65	0.590005
47,350	47,000	270.65	1.10905
32,162	32,000	228.65	8.68014
20,063	20,000	216.65	54.7487
11,019	11,000	216.65	226.32
0	0	288.15	1013.250

The data in the table are derived on the basis of certain assumptions and conventions which differ in some respects from those on whose basis the previously adopted standard atmosphere was constructed as follows:

(a) The “ice point” or temperature of melting ice under a pressure of one atmosphere is defined as having a value of 273.15° Kelvin; while the standard temperature at sea level is assumed to be 15° Celsius as before, hence the equivalent value of the standard temperature at sea level in absolute units is taken as 288.15° K.

(b) We denote $P =$ pressure; $T =$ absolute temperature $\rho =$ density of dry air at pressure P and temperature T; $P_0 =$ standard pressure at sea level $= 1013250$ dynes/cm^2, that is, 1013.250 millibars; $T_0 =$ standard temperature at sea level in absolute units $=$ 288.15° K; $\rho_0 =$ standard density of dry air

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[1] R. A. Minzner, W. S. Ripley, and T. P. Condron, “U.S. Extension to the ICAO Standard Atmosphere. Tables and Data to 300 Standard Geopotential Kilometers,” Prepared under the direction of The Committee on Extension to the Standard Atmosphere, Geophysics Research Directorate and U.S. Weather Bureau, Co-sponsors, U.S. Government Printing Office, Washington, D.C., 1958.

at sea level at pressure P_o and temperature T_o; R^* = universal gas constant for 1 gram mole of ideal gas; and M = molecular weight of dry air where the composition is the same as the standard considered to exist at sea level; and R = gas constant for one gram of dry air $= R^*/M$. Under the assumption that dry air behaves as an ideal gas we may write $\rho_o = (M/R^*)\ (P_o/T_o) = (1/R)\ (P_o/T_o)$ and $\rho = (M/R^*)\ (P/T) = (1/R)\ (P/T)$. If the first equation is solved for (M/R^*) and (R^*/M), one obtains the results $(1/R) = (M/R^*) = (T_o\rho_o)/P_o$ and $R = (R^*/M) = P_o/(T_o\rho_o)$. The U.S. Committee on Extension of the Standard Atmosphere adopted the plan of considering that $P_o = 1013250$ dynes/cm², $T_o = 288.15°$ K., and $\rho_o = 0.0012250$ gram/cm³ *exactly*, by definition. (See par. 2.9.) When these values are substituted in the last two equations, it is possible to compute the corresponding effective values of M/R^* and $R^*/M = R$. After the quantity M/R^* is determined on this basis, the density of dry air at pressure P and temperature T can be computed by means of the equation $\rho = (M/R^*)\ (P/T)$. The value of the gas constant calculated by the foregoing procedure is $R = P_o/(T_o\rho_o) = 2.87053 \times 10^6$ cm.²/sec.² °K.

(c) The composition of dry air is assumed to be uniform from sea level to an altitude of 90,000 m. Under this assumption the value of M will remain constant throughout the same range of altitude and, for that reason, the value of R pertinent to this range will be a constant.

3. DERIVATION OF PRESSURE-ALTITUDE RELATIONSHIPS

In order to obtain an equation relating pressure (P) to geopotential (H), eq. (7), par. 2.11, is substituted in eq. (2), par. 2.4, and the resulting expression is substituted in eq. (3), par. 2.6. Then $g\ dZ$ is eliminated by means of eq. (4), par. 2.7. On this basis one obtains for the troposphere

$$\frac{dP}{P} = \frac{G}{R}\,\frac{(-dH)}{(T_o - aH)} = \frac{G}{aR}\,\frac{d(T_o - aH)}{(T_o - aH)} \tag{8}$$

When $H = 0$, the pressure is

$$P_o = 1013.250 \text{ mb.};$$

while corresponding to any value H in the troposphere the pressure is P in general.

Integrating eq. (8) between the limits of 0 and H in the right-hand member, but limits P_o and P in the left-hand member, we find

$$\log_e\left(\frac{P}{P_o}\right) = \frac{G}{aR}\log_e\left(\frac{T_o - aH}{T_o}\right) \tag{9}$$

where $\log_e$ refers to natural, or Napierian logarithms; that is, logarithms to the base e, which is given by $e = 2.718281828.......$ [Note: if N is a number, and $k = \log_{10} e$, then

$$\log_e N = (1/k)\log_{10} N,$$

where k called the modulus of common logarithms has the known value

$$k = 0.434294482........]$$

Let

$$n = \frac{G}{aR} \tag{10}$$

Since

$G = 9.80665$ m.² sec.⁻² $(m')^{-1}$,

$a = 0.0065°$ K. $(m')^{-1}$,

and

$R = 2.8704 \times 10^2$m.² sec.⁻² $(°K.)^{-1}$,

the numerical value of n is given by the expression

$$n = 5.2561 \text{ (dimensionless)}.$$

Substituting eq. (10) in eq. (9) we may rewrite the latter as

$$\frac{P}{P_o} = \left(\frac{T_o - aH}{T_o}\right)^n \tag{11}$$

This is the required equation pertaining to the troposphere, developed for the purpose of giving P as a function of H, where P_o, T_o, and a are known constants (see par. 2.3, 2.8, and 2.11).

Solving eq. (11) for H as a function of P, one obtains

$$H = \frac{T_o}{a}\left[1 - \left(\frac{P}{P_o}\right)^{1/n}\right] \tag{12}$$

This is the so-called "pressure-altitude equation" pertaining to the troposphere of the Standard Atmosphere. Eq. (12) simply signifies that for every given pressure (P) in the troposphere there is a corresponding geopotential (H). Table 8.1 may be regarded as an illustration of this relationship.

Note.—Referring to equations (11) and (12), (also eqs. (21) and (22), below) it is common practice in aeronautics to call H *"the pressure altitude"* corresponding to the pressure P. Since the numerical value of H, the geopotential in m′ (standard geopotential meter) is very nearly the same as the numerical value of Z, the geometric altitude in m. (meter), this common practice is understandably convenient to avoid the use of the less well-known term "geopotential" in aviation.

We will next derive equations applicable to the isothermal stratosphere which is characterized by the constant temperature denoted by T^*, where

$$T^* = 216.66^\circ \text{ K.}$$

Let P^* denote the pressure at the tropopause, H^* the geopotential at the tropopause, and T^* the temperature at the tropopause. The same value of temperature is assumed to hold up to 20,000 m′. See reference 2, next page, which gives data for range −5 to 700 Km.

Substituting T^* in eq. (2), par. 2.4, in order to make it appropriate for the portion of the stratosphere where the temperature is assumed to hold that constant value, we find for this portion that the density is given by

$$\rho = \frac{1}{R}\,\frac{P}{T^*} \tag{13}$$

Substituting eq. (13) in eq. (3), and eliminating $g\,dZ$ by means of eq. (4), par. 2.7, we obtain

$$-\frac{dP}{P} = \frac{G}{RT^*}\,dH \tag{14}$$

Integrating the right-hand member of eq. (14) between the limits H^* and H, and the left-hand member between the corresponding limits P^* and P, we secure the result

$$\log_e\left(\frac{P^*}{P}\right) = \frac{G}{RT^*}\,(H - H^*) \tag{15}$$

Using common logarithms in place of natural logarithms (see note following eq. (9)) this equation may be rewritten

$$\log_{10}\frac{P^*}{P} = \left(\frac{G}{RT^*}\log_{10} e\right)(H - H^*) \tag{16}$$

Let

$$B = \frac{G \log_{10} e}{RT^*} \tag{17}$$

Since

$$G = 9.80665 \text{ m.}^2 \text{ sec.}^{-2} \text{ (m}')^{-1}$$

$$\log_{10} e = 0.434294482 \ldots\ldots$$

$$R = 2.8704 \times 10^2 \text{ m.}^2 \text{ sec.}^{-2} \text{ (}^\circ\text{K.)}^{-1}$$

and

$$T^* = 216.66^\circ \text{ K.},$$

we obtain the result

$$B = 0.6848317 \times 10^{-4} \text{ (m}')^{-1}$$

Substitution of eq. (17) in eq. (16) yields

$$\log_{10}\frac{P^*}{P} = B(H - H^*) \tag{18}$$

Referring to eq. (11) we observe that when H becomes H^*, P assumes the value P^*, hence from eq. (11) we find

$$\frac{P^*}{P_o} = \left(\frac{T_o - aH^*}{T_o}\right)^n \tag{19}$$

From eq. (19) we obtain by calculation

$$P^* = 226.32 \text{ mb.}$$

Taking the common logarithm of eq. (19) we secure

$$\log_{10}\left(\frac{P^*}{P_o}\right) = n \log_{10}\left(\frac{T_o - aH^*}{T_o}\right) \tag{20}$$

Subtraction of eq. (18) from eq. (20) yields the result

$$\log_{10}\left(\frac{P}{P_o}\right) = n \log_{10}\left(\frac{T_o - aH^*}{T_o}\right) - B(H - H^*) \tag{21}$$

This equation may be rewritten, if desired, to represent P as a function of H in the isothermal stratosphere characterized by the constant temperature denoted by T^*.

Solving eq. (21) for H as a function of P we obtain the result *pertinent only to this portion of the stratosphere*

$$H = H^* + \frac{1}{B}\left[n \log_{10}\left(\frac{T^*}{T_o}\right)\right] - \frac{1}{B}\log_{10}\left(\frac{P}{P_o}\right) \tag{22}$$

Eqs. (21) and (22) represent the so-called "pressure-altitude relationships" valid only for the isothermal portion of the stratosphere where the temperature is

$$T^* = 216.66^\circ \text{ K.}$$

At altitudes where this condition does not hold, different equations apply.[2]

For convenience in reference eqs. (11), (12), (21) and (22) are summarized as eqs. (Ia), (Ib), (IIa), and (IIb), respectively, in sec. 1 of this Appendix. Data in Table 8.1 of this Manual were computed on the basis of eq. (12).

The following points indicate the features in the U.S. Standard Atmosphere, 1962,[2] which differ significantly from those employed in the ICAO Standard Atmosphere, 1952:

(1) A new unified scale of relative atomic weights was adopted in 1961 for the chemical elements, based on the assignment of the value 12 exactly to the atomic weight of the carbon—12 (^{12}C) isotope. Under the new scale the relative atomic weight of natural oxygen is taken as 15.9994, whereas it had been taken as 16 exactly under the old scale of chemical atomic weights. Data regarding the relative atomic weights of the chemical elements on the basis of the carbon–12 scale have been published.[3]

(2) The absolute temperature of the ice point (that is, the temperature corresponding to 0°C.) was adopted as 273.15° Kelvin (°K.) in harmony with the adoption of this value in 1954 by the Tenth General Conference on Weights and Measures. On this basis the standard temperature of 15°C., accepted for sea level in the standard atmosphere, is represented by $T_o = 288.15$°K., and the standard temperature at the tropopause is represented by $T^* = 216.65$°K. which refers to an altitude of 11,000 m′.

(3) Owing to the above-mentioned revisions in the scale of relative atomic weights and in the scale of absolute temperatures it was necessary to make consistent revisions in the values of other related physical constants. Thus, in the 1962 Standard Atmosphere the following values were adopted: the universal gas constant $R^* = 8.31432 \times 10^7$ ergs (gram-mole)$^{-1}$ (°K.)$^{-1}$; Avogadro's number $N = 6.02257 \times 10^{23}$ molecules per gram-mole.

(4) The assumed composition of the atmosphere up to an altitude of 90 kilometers was revised, with the most significant changes being the adoption of the following percentages by volume: oxygen, 20.9476%; argon, 0.934%; and carbon dioxide, 0.0314%. For additional information regarding atmospheric composition, reference should be made to other authorities.[4,5,6,7,8,9,10]

(5) The density of dry air at sea level under the conditions assumed for standard was adopted as $\rho_o = 0.0012250$ gram per cubic centimeter (1.2250 kg.m.$^{-3}$), which relates to a pressure of $P_o = 1013.250$ mb., and a temperature of $T_o = 288.15$°K. When one uses these data, together with the value of R^* cited in paragraph (3) above, the corresponding value of the apparent molecular weight M of dry air can be computed by the relationship $M = \rho_o R^* T_o / P_o$ (see sec. 2.9 of this appendix, where $R = R^*/M$). Such a computation yields $M = 28.9644$ grams per gram-mole on the basis of the ^{12}C-scale of relative atomic weights.

(6) The vertical distribution of temperature assumed in the U.S. Standard Atmosphere, 1962 for altitudes up to 90 kilometers is indicated in the table in sec. 2.11 of this appendix. It should be understood that the vertical gradient of temperature is assumed to be uniform in each layer between the adjacent levels listed.

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[2] U.S. Committee on Extension to the Standard Atmosphere, "U.S. Standard Atmosphere, 1962" (ICAO Standard Atmosphere to 20 Kilometers; Proposed ICAO Extension to 32 Kilometers; and Tables and Data to 700 Kilometers) Prepared under the sponsorship of National Aeronautics and Space Administration, United States Air Force, United States Weather Bureau. Published by U.S. Government Printing Office, Washington 25, D.C. (1962), 278 pp.

[3] Cameron, A. E. and Wichers, E., "Report of the International Commission on Atomic Weights (1961)," Jour. Am. Chem. Soc., *84*, 4175 (1962).

[4] Glueckauf, E., "The Composition of Atmospheric Air," Chapter 1, pp. 3–10, in *Compendium of Meteorology*, edited by Malone, T. F.: Boston: American Meteorological Society, pp. 1334 (1951).

[5] Hutchinson, G. E., "The Biochemistry of the Terrestrial Atmosphere," Chapter 8, pp. 371–433, in ***The Earth as a Planet***, edited by Kuiper, G. P.: Chicago: Univ. of Chicago Press, pp. 751 (1954).

[6] Kuiper, G. P. (Editor), "The Atmospheres of the Earth and Planets," Chicago: Univ. of Chicago Press, 2nd ed., pp. 434 (1952).

[7] Junge, C. E., "Air Chemistry and Radioactivity," New York: Academic Press, pp. 382 (1963).

[8] Callendar, G. S., "On the Amount of Carbon Dioxide in the Atmosphere," Tellus, *10*, 243 (1958).

[9] Keeling, C. D., "The Concentration and Isotopic Abundances of Carbon Dioxide in the Atmosphere," Tellus, *12*, 200 (1960).

[10] Bischof, W., "Variations in Concentration of Carbon Dioxide in the Free Atmosphere," Tellus, *14*, 87 (1962).

APPENDIX 8.2.1

INFORMATION REGARDING ALTITUDE CONTROL UNDER CIVIL AIR REGULATIONS AS OF JANUARY 15, 1959

Below there are presented some extracts from Civil Air Regulations with a view to providing background information and illustrative data relevant to the considerations discussed in Chapter 8 on "Altimetry." This material was obtained from publications of the Civil Aeronautics Board and of the Civil Aeronautics Administration (now superseded by the Federal Aviation Agency effective December 31, 1958). Since the latest of these publications available at time of writing was effective January 15, 1959, it is probable that amendments to the Civil Air Regulations will render obsolete in the future the information given herein. Therefore, the reader is urged to consult and make use of the latest effective Civil Air Regulations pertinent to the present subject rather than to accept as strictly valid the information given in this appendix.

Abbreviation CAR will be understood to signify "Civil Air Regulation." The symbols VFR and IFR signify "Visual Flight Rules" and "Instrument Flight Rules," respectively. It is conventional that the abbreviation "MSL" represent "Mean Sea Level," with the objective of indicating that the altitude referred to is measured with respect to the datum at mean sea level. According to CAR 60.25 and 60.60, it is clear that the intent is to convey the notion that when an altimeter in an aircraft is set in accordance with the current altimeter setting reported by a station in close proximity, the altitudes indicated by the instrument will be regarded as measured vertically with respect to mean sea level.

It is important to distinguish between the terms "cruising altitude" and "flight level." Thus, "cruising altitude" will be understood to refer to an indicated altitude measured with respect to mean sea level and determined from an altimeter whose pressure scale has been set in accordance with the current altimeter setting reported by a station in close proximity to the aircraft; while "flight level" will be understood to refer to a level of indicated altitude determined from an aircraft altimeter whose pressure scale has been set to the standard constant setting of 29.92 inches of mercury (QNE).

The specific language of the Civil Air Regulations regarding "cruising altitude," "flight level," and "altimeter setting" is as follows:[1]

CAR 60.60 Definitions

Cruising altitude.—Cruising altitude is a level determined by vertical measurement from mean sea level.

Flight level.—Flight level is a level of constant atmospheric pressure related to a reference datum of 29.92″ Hg. For example, flight level 250 is equivalent to an altimeter indication of 25,000 feet, and flight level 265 to 26,500 feet.

CAR 60.25 Altimeter setting.—The cruising altitude or flight level of aircraft shall be maintained by reference to an altimeter which shall be set:

(a) At or below 23,500 feet MSL, to the current reported altimeter setting of a station along the route of flight within 100 nautical miles: *Provided*, That where there is no such station, the current reported altimeter setting of an appropriate available station shall be used: *And provided further*, That in aircraft having no radio the altimeter shall be set to the elevation of the airport of departure or appropriate altimeter settings available prior to departure shall be used.

(b) At or above 24,000 feet MSL, to

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[1] Extract from Civil Air Regulations Amendment 60-13. Effective January 15, 1959. Adopted December 4, 1958. Civil Aeronautics Board, Washington, D.C.

29.92″ Hg. The use of flight levels below this altitude is not permissible.

(c) For overseas operations, in ICAO Flight Information Regions, in accordance with ICAO Regional Supplementary Procedures.

NOTE—Flight levels appropriate to normally encountered atmospheric pressure are shown in the table following:

Table

Atmospheric pressure in inches of mercury	Lowest usable flight level
29.92	240
29.91 to 29.42	245
29.41 to 28.92	250
28.91 to 28.42	255
28.41 to 27.92	260

Effective January 15, 1959, cruising altitudes and flight levels under visual flight rules (VFR) and instrument flight rules (IFR) were governed by the following regulations:[2]

Visual Flight Rules

CAR 60.32 VFR cruising altitudes and flight levels.[3]—When an aircraft is operated in level cruising flight at 3,000 feet or more above the surface, the following cruising altitudes, or the equivalent flight levels, whichever is appropriate, shall be observed:

(a) *Below 29,000 feet.* At a cruising altitude or flight level[3] appropriate to the magnetic course being flown as follows:

(1) 0° to 179° inclusive, at odd thousands plus 500 (3,500; 5,500; etc.).

(2) 180° to 359° inclusive, at even thousands plus 500 (4,500; 6,500; etc.).

(b) *Above 29,000 feet.* At a flight level[3] appropriate to the magnetic course being flown as follows:

(1) 0° to 179° inclusive, at 4,000-foot intervals beginning at 30,000 (30,000; 34,000; etc.).

(2) 180° to 359° inclusive, at 4,000-foot intervals beginning at 32,000 (32,000; 36,000; etc.).

Instrument Flight Rules

CAR 60.44 IFR cruising altitudes and flight levels.[3]—When an aircraft is operated in level cruising flight, it shall be operated in accordance with the following cruising altitudes, or the equivalent flight levels, whichever is appropriate, except that, in the absence of a specific altitude authorized by air traffic control, aircraft operating "on top" shall be flown at altitudes specified in paragraph 60.32:

(a) *Within controlled airspace.*—At altitudes authorized by air traffic control.

(b) *Outside controlled airspace—below 29,000 feet.*—At a cruising altitude or flight level[3] appropriate to the magnetic course being flown as follows:

(1) 0° to 179° inclusive, at odd thousands (1,000; 3,000; etc.).

(2) 180° to 359° inclusive, at even thousands (2,000; 4,000; etc.).

(c) *Outside controlled airspace at and above 29,000 feet in Alaska and the territorial possessions of the United States.*—At a flight level[3] appropriate to the magnetic courses being flown as follows:

(1) 0° to 179° inclusive, at 4,000-foot intervals beginning at 29,000 (29,000; 33,000; etc.).

(2) 180° to 359° inclusive, at 4,000-foot intervals beginning at 31,000 (31,000; 35,000; etc.).

The reader is cautioned to consult the latest effective Civil Air Regulations, and Amendments thereto, since the foregoing may become more or less obsolete in the course of time after January 15, 1959; while the reader should also note that many provisions of the Civil Air Regulations in effect on that date are not cited here. Important examples of Civil Air Regulations relevant to altitude control, yet not extracted herein, relate to those regulations which concern basic VFR Weather Minimums (see for example, CAR 60.30 and CAR 60.31).

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[2] Extracts compiled from the following Civil Air Regulations Amendments: No. 60-10, Effective August 15, 1958; Adopted June 6, 1958. No. 60-12, Effective August 15, 1958; Adopted August 14, 1958. No. 60-13, Effective January 15, 1959; Adopted December 4, 1958.

NOTE.—Some of the language in the regulations was changed slightly for presentation here to make the terminology regarding cruising altitude and flight level consistent with that specified in CAR 60.25 and CAR 60.60.

[3] See CAR 60.25 and CAR 60.60.

APPENDIX 8.2.2

DEVELOPMENT OF CRITERION FOR TERRAIN CLEARANCE

The objective is to derive a criterion by which one may determine the minimum indicated altitude that should provide a prescribed vertical clearance relative to the point of maximum height above sea level on the highest mountainous obstacle on or near the flight path of an aircraft.

Before actually embarking on the development of a criterion, it is necessary to classify various sources of error in the altimetry system and to introduce suitable notation. We shall be concerned with the maximum altitude (A_x) of the highest obstacle under consideration; the minimum indicated altitude (I_n) which can be selected under existing Civil Air Regulations to give safe vertical clearance for the route over which the operation is to be conducted; the clearance (C_v) vertically with respect to the maximum altitude of the highest obstacle; and the sum of the errors (e_s) due to all possible relevant causes not already compensated, or the sum of the corrections (k_s) to overcome these errors and effects.

First of all, the error is defined as the negative of the correction. Therefore, the following relationship is an identity by definition

$$(I_n - e_s) = (I_n + k_s) = \text{true minimum altitude.} \quad (1)$$

The *criterion* to be satisfied is that the true minimum altitude selected for the flight operation must be greater than or equal to ($\geqq$) the sum of the maximum altitude of the highest obstacle (A_x) and the desired clearance (C_v). Therefore, the criterion expressed mathematically is

$$(I_n + k_s) \geqq (A_x + C_v), \quad (2)$$

where I_n is the minimum value of the indicated altitude satisfying this relationship, selected in conformity with existing relevant Civil Air Regulations governing cruising altitudes and flight levels.

According to Air Traffic Control Procedures, in those areas designated as mountainous a clearance of 2000 feet must be maintained; hence in this case $C_v = 2000$ feet. Under these same procedures the maximum altitudes (A_x) of the highest obstacle within a horizontal distance of five miles from the center of the course intended to be flown can be ascertained from topographic charts.

Thus, before it is possible to compute the value of I_n which satisfies the criterion it is necessary to determine the pertinent value of the sum of the corrections (k_s) to overcome the errors and effects influencing the altimetry system. The sum k_s will vary with a number of factors. An estimate of the value of k_s can be made on the basis of the various component corrections of which the sum is composed. The following list is therefore presented to show the categories of component corrections whose algebraic sum constitutes k_s:

(a) k_i = correction for instrumental errors combined. (See sec. 8.2.2, which itemizes these errors individually under the headings—diaphragm, hysteresis, drift, friction, instrument temperature, backlash, balance, coordination, instability, zero setting, and readability.)

(b) k_p = correction for error due to the static pressure system in excess of any portion of the error from this cause already compensated or corrected. (See sec. 8.2.2 for further information and sources of data.)

(c) k_f = correction for flight technical error; that is, correction for departure of the aircraft from its assigned cruising altitude or flight level, depending upon the performance of the auto-pilot and pilot combination with regard to maintenance of the assigned height, the effects of downdrafts, gusts, or other turbulent phenomena in causing a vertical deviation, etc.

(d) k_r = correction for residual errors or factors not otherwise taken into account, such as size of aircraft, etc.

(e) k_t = correction for departure of atmosphere temperature (see sec. 8.3).

(f) k_a = correction for departure of the altimeter setting actually used for setting the pressure scale of the aircraft altimeter from the current altimeter setting reported by the station nearest to and generally within 100 nautical miles of the highest obstacle for which adequate vertical clearance is being sought in the given case of flight operation under existing air traffic control procedures. Note: The departure referred to represents: (the altimeter setting used on aircraft *minus* the current, reported altimeter setting).

(g) k_w = correction for influence of wind which, by virtue of the Bernoulli or Venturi effect, causes the local altimeter setting on or near the peak of the highest obstacle to become lower than it would be in the free air away from the obstacle, where the effect is such that the departure of the local altimeter setting from the smooth free-air value varies approximately as the square of the wind speed across the obstacle.

The algebraic sum of the foregoing list of corrections is equal to k_s; that is,

$$k_s = (k_i + k_p + k_f + k_r + k_t + k_a + k_w). \quad (3)$$

For present purposes one may assume that in the case of flight operations of a given aircraft over the specified obstacle, the factors or parameters which control the appropriate corrections k_i, k_p, k_f, and k_r will normally lie within a limited range. Under normal operating conditions such a restricted range is likely to apply to such parameters as indicated altitude, air speed, Mach number, angle of attack, auto-pilot performance, size of aircraft, etc. Therefore, for the present one may assume that in considering the flight operation plans for a particular aircraft involving passage over a specified obstacle of known elevation the algebraic sum of the first four corrections listed above can be regarded as a constant pertinent to the given aircraft, obstacle, and flight operation. If deemed desirable, a safety factor could be included in the term k_r to cover the probable effects of any possible adverse situations that might cause any of the first three factors to become greater than would be the case under normal operating conditions. On this basis, it will be assumed that the sum of the first four corrections is a known constant, denoted by k_c, where

$$k_c = (k_i + k_p + k_f + k_r), \quad (4)$$

pertinent to the given aircraft, obstacle, flight operation, and other relevant factors which might control the correction terms involved.

It will be noted that the last three corrections listed in equation (3) relate to meteorological conditions, namely, temperature, altimeter setting (or atmospheric pressure), and wind. Therefore, these three corrections are correlated and none of these three can be considered singly without proper regard for the remaining ones. For some purposes it may be convenient to deal with their algebraic sum, denoted by k_m, where the subscript m is used to suggest that one is concerned with a correction for the effects of variable meteorological factors together with topographic factors. On this basis

$$k_m = (k_t + k_a + k_w) \quad (5)$$

From equations (3), (4), and (5) it follows that

$$k_s = (k_c + k_m). \quad (6)$$

It is possible to make some calculations which will yield to a fairly close degree of approximation the values of the terms k_t, k_a, and k_w that appear in equation (5). Before attempting to make such calculations it is necessary to derive the pertinent relationships, and this is the task to which our attention is next directed. For the sake of consistency use is made here of the notation employed in Appendixes 7.1 and 8.0.1, insofar as practicable except that the symbol A will be employed instead of H. Thus, consider two levels in the atmosphere at actual geopotentials A_1 and A_2, with corresponding atmospheric pressures P_1 and P_2, respectively. Let T_v denote absolute virtual temperature (°K.) in the atmosphere at a pressure P and geopotential A, in general; and let T_{mv} denote the absolute mean virtual temperature (°K.) of the layer between the geopotentials A_1 and A_2. Suppose that the geopotentials are expressed in units of standard geopotential meters as defined in Appendix 8.0.1. Then let $G = 9.80665$ m.^{2} sec.$^{-2}$ per standard geopotential meter (a constant which determines the size of the standard geopotential meter). Also let $R =$ gas constant for one gram of dry air, whose value in the centimeter-gram-second system of units is equal to 2.8704×10^6 ergs gm.$^{-1}$ °K.$^{-1}$ All logarithms employed in the following derivations are Napierian logarithms (to the base $e = 2.7182818\ldots$).

According to equations (17) and (18) of Appendix 7.1, it is found that

$$(R/G)\log(P_1/P_2) = \frac{(A_2 - A_1)}{T_{mv}} = \int_{A_1}^{A_2} \frac{dA}{T_v} \qquad (7)$$

The left-hand member of equation (7) may be written

$$(R/G)\log(P_1/P_2) = (R/G)\log(P_o/P_2) - (R/G)\log(P_o/P_1), \qquad (8)$$

where

P_o = assumed pressure in the standard atmosphere at sea level;

P_o = 29.92 inches of mercury (approximately).

Let the symbols below be defined:

I_{p2} = pressure altitude in the standard atmosphere corresponding to pressure P_2;

I_{p1} = pressure altitude in the standard atmosphere corresponding to pressure P_1;

T_{mp2} = mean temperature in the standard atmosphere column for the range of pressure altitude from zero (0) to I_{p2};

T_{mp1} = mean temperature in the standard atmosphere column for the range of pressure altitude from zero (0) to I_{p1};

I = pressure altitude regarded as a variable in general;

and

T = temperature in the standard atmosphere, regarded as a function of I.

On the basis of the specifications of the standard atmosphere (see National Advisory Committee for Aeronautics, Report 1235, Washington, D.C., 1955), one has

$$\frac{I_{p2}}{T_{mp2}} = \int_0^{I_{p2}} \frac{dI}{T} = (R/G)\log(P_o/P_2) \qquad (9)$$

and

$$\frac{I_{p1}}{T_{mp1}} = \int_0^{I_{p1}} \frac{dI}{T} = (R/G)\log(P_o/P_1) \qquad (10)$$

It follows from equations (7), (8), (9), and (10) that

$$(A_2 - A_1) = T_{mv}\left(\frac{I_{p2}}{T_{mp2}} - \frac{I_{p1}}{T_{mp1}}\right). \qquad (11)$$

The left-hand member of equation (11) represents the true difference of geopotential in the actual atmosphere between the two levels at which the pressures are P_2 and P_1, respectively. For present purposes one may regard A_1 and A_2 as representing actual altitudes above mean sea level, that is, true elevations as might be measured by means of a tapeline, although expressed in terms of standard geopotential units which differ slightly from geometric units near sea level (see Appendix 1.3.1). On these grounds the distinction between geopotential and geometric altitude is ignored for the present applications.

Consider an aircraft flying over the point of maximum elevation on the highest mountain ridge or peak which is to be passed en route. The problem is to determine the corrections which should be applied to the indicated altitude reading shown on the aircraft altimeter in order to ascertain the true altitude (actual elevation) measured with reference to mean sea level and to secure a certain desired vertical clearance between the aircraft and the top of the highest obstacle. In general, the altimeter setting employed on the aircraft to set the pressure scale of the altimeter will have been obtained more or less currently from a meteorological reporting station usually located away from the mountain crest, perhaps in a nearby valley or on the slope. Sometimes occasions arise in which the altimeter setting employed on the aircraft differs considerably from that issued currently by the specified reporting station.

Consideration will also be given to the special case in which the reporting station that issues the altimeter setting is located at the very crest of the mountain where in general the minimum pressure on the obstacle prevails. Such minimum pressure may be a result of the joint influences of relatively low temperature in the ambient atmospheric air column and of relatively high winds crossing the mountain which cause the pressure to decrease by virtue of the Bernoulli effect.

The following notation is employed:

A_x = actual elevation of the point of maximum height above sea level on the highest obstacle to be flown over or to be passed within a horizontal distance of five (5) nautical miles by the aircraft while en route.

A_a = actual altitude (true elevation) of the aircraft above mean sea level when passing over or near the highest obstacle.

C_v = clearance in the vertical which is desired between the aircraft and the point of maximum height on the highest obstacle (usually C_v should be at least 2,000 feet according to FAA air traffic control procedures).

T_{mvxa} = mean virtual *absolute* temperature in the actual column of atmosphere extending vertically from the point of maximum height on the highest obstacle to the level of the aircraft (that is, in the range of altitude from A_x to A_a).

I_{pa} = pressure altitude at the level of the aircraft while flying en route at actual altitude A_a, as previously defined.

T_{mpa} = mean absolute temperature in the standard atmosphere column for the range of pressure altitude from zero (0) to I_{pa}. (T_{mpa} is a function of I_{pa}, a fact which may be verified by means of equation (9) or (10) and the data supplied in Appendix 8.0.1.)

I_{px} = pressure altitude existing at the point of maximum height above sea level on the highest obstacle at the instant the aircraft flies over it. Note: One may assume that the most critical values of I_{px} will be governed by relatively low atmospheric pressure and temperature accompanied by strong winds.

T_{mpx} = mean absolute temperature in the standard atmosphere column for the range of pressure altitude from zero (0) to I_{px}. (T_{mpx} is a function of I_{px} as follows from equations (9) and (10), together with the specifications of Appendix 8.0.1.)

E_s = elevation (height) above mean sea level of the reporting station which is nearest to the point of maximum height on the highest obstacle and which reports altimeter settings (where in the majority of cases the station lies in a nearby valley or is on the mountain slope, but in a special case it may be installed at the mountain top itself).

I_{ps} = pressure altitude existing at the reporting station (see E_s) at the instant the aircraft flies over the highest obstacle.

T_{mps} = mean absolute temperature in the standard atmosphere column for the range of pressure altitude from zero (0) to I_{ps}. (T_{mps} is a function of I_{ps} as may be seen on the basis of equations (9) and (10), together with the information in Appendix 8.0.1.)

T_{mvsx} = mean virtual absolute temperature in the actual column of atmosphere extending vertically from the reporting station at elevation E_s to the level of the point of maximum height on the highest obstacle (that is, in the range of altitude from E_s to A_x).

I_{pxw} = value of pressure altitude at the point of maximum height above sea level on the highest obstacle, *calculated* on the basis of equation (11), in which the following substitutions are made: $A_2 = A_x$; $A_1 = E_s$; $T_{mv} = T_{mvsx}$; $I_{p1} = I_{ps}$; $T_{mp1} = T_{mps}$; $I_{p2} = I_{pxw}$; and $T_{mp2} = T_{mpxw}$. (Note: On this basis, I_{pxw} is more or less *independent* of any influence of winds on I_{px}, since the reporting station is generally not subject to the Bernoulli effect when in a valley. Under this assumption the letter w in the subscript of I_{pxw} is intended to connote that I_{pxw} is *free* from such a wind effect whereas I_{px} is generally higher than I_{pxw} owing to the decrease in pressure at the mountain top brought about by the Bernoulli phenomenon.)

T_{mpxw} = mean absolute temperature in the standard atmosphere column for the range of pressure altitude from zero (0) to I_{pxw}. (T_{mpxw} is a function of I_{pxw}.)

$A.S._u$ = altimeter setting which is actually being used in the pressure scale of the altimeter as the aircraft flies over or nearest to the highest obstacle.

$A.S._s$ = altimeter setting which is being currently observed at the reporting station at the instant the aircraft is nearest to the crest of the highest obstacle. (Note: $A.S._s$ is determined by E_s and I_{ps}; see equation (12) and definition of H_{As}.)

$A.S._x$ = altimeter setting which would be currently observed at the point of maximum height on the highest obstacle at the instant the aircraft is nearest to the point, under the assumption that a suitable automatic instrument could yield an observation of the altimeter setting if it were located at the point of maximum height. (Note: $A.S._x$ is determined by A_x and I_{px}; see equation (13) and definition of H_{Ax}.)

$A.S._{xw}$ = altimeter setting which would correspond to actual elevation A_x and pressure altitude I_{pxw}. (Note: $A.S._{xw}$ is determined by A_x and I_{pxw}; see equation (14) and the definition of H_{Axw}.)

H_{Au} = pressure altitude corresponding to pressure $A.S._u$.

H_{As} = pressure altitude corresponding to pressure $A.S._s$.

H_{Ax} = pressure altitude corresponding to pressure $A.S._x$.

H_{Axw} = pressure altitude corresponding to pressure $A.S._{xw}$.

P_a = atmospheric pressure to which altimeter of aircraft is subjected when in flight. (Note: The pressure altitude corresponding to P_a is represented by I_{pa}.)

I_u = indicated altitude yielded by aircraft altimeter when at a pressure altitude I_{pa} while its altimeter setting is $A.S._u$.

I_s = indicated altitude yielded by aircraft altimeter when at a pressure altitude I_{pa} while its altimeter setting is $A.S._s$.

I_{xw} = indicated altitude yielded by aircraft altimeter when at a pressure altitude I_{pa} while its altimeter setting is $A.S._{xw}$.

I_x = indicated altitude yielded by aircraft altimeter when at a pressure altitude I_{pa} while its altimeter setting is $A.S._x$.

The following points should be noted with regard to the foregoing definitions: (a) The aircraft altimeter under consideration is assumed to be perfectly free of all mechanical instrumental errors, and it is further assumed that there is no static pressure error. (b) By virtue of the specifications of the standard atmosphere (see Appendix 8.0.1), pressure altitude is a function of pressure, and vice versa; for example, H_{Au} is a function of $A.S._u$; etc. (c) On similar grounds, mean temperatures in the standard atmosphere columns extending from zero (0) to I_p pressure altitude are functions of I_p; hence the ratio of I_p to the thus-defined mean temperature is also a function of I_p (see for example equations (9) and (10)).

According to the definition of altimeter setting the following three equations are valid:

$$H_{As} = (I_{ps} - E_s), \qquad (12)$$

$$H_{Ax} = (I_{px} - A_x), \qquad (13)$$

and

$$H_{Axw} = (I_{pxw} - A_x). \qquad (14)$$

At this stage it is the purpose to investigate the correction k_a necessary owing to use of an incorrect or improper altimeter setting. With this object in view, consider an aircraft whose altimeter is subjected to an atmospheric pressure P_a while in flight, and let the corresponding pressure altitude be denoted by I_{pa}. Suppose that the altimeter setting in actual use for the aircraft instrument is $A.S._u$; and let this be a pressure whose corresponding pressure altitude in the standard atmosphere is H_{Au}, while the apparent indicated altitude yielded by the instrument under these conditions is I_u. However, suppose that in this case the proper altimeter setting which should be in use is $A.S._s$; and let the latter be a pressure whose corresponding pressure altitude is represented by H_{As}, while the indicated altitude which would have been given by the instrument on this basis is I_s. Thus, I_u is in error relative to I_s owing to the discrepancy of H_{Au} compared with H_{As}.

On the basis of the method of operation of the altimeter, one has

$$I_u = (I_{pa} - H_{Au}) \qquad (15)$$

and

$$I_s = (I_{pa} - H_{As}) \qquad (16)$$

Therefore, from equations (15) and (16) one finds

$$(I_s - I_u) = [(I_{pa} - H_{As}) - (I_{pa} - H_{Au})] \qquad (17)$$

This relationship represents the correction that would have to be applied to the indicated altitude I_u in order to overcome the error resulting from the use of improper altimeter setting $A.S._u$ when $A.S._s$ would have been the proper one to employ.

By virtue of equation (17) and the explanation just given we shall *define* the correction k_a by the expression

$$k_a = [(I_{pa} - H_{As}) - (I_{pa} - H_{Au})], \qquad (18)$$

whence

$$k_a = (H_{Au} - H_{As}). \qquad (19)$$

This expression for k_a may be regarded as the correction for the use of an erroneous or improper altimeter setting.

Now, it is desired to investigate the correction k_w necessary as a result of the effect of wind. To this end, once more consider an aircraft whose altimeter is subjected to an atmospheric pressure P_a while in flight, and let the corresponding pressure altitude be I_{pa}, as before. Suppose that in this case the altimeter setting in actual use for the aircraft instrument is $A.S._{xw}$. Let the latter be a pressure whose corresponding pressure altitude is denoted by H_{Axw}, and let the apparent indicated altitude yielded by instrument be I_{xw} under these conditions. On the other hand suppose that the proper altimeter setting which should be in use is $A.S._x$. The latter is a pressure whose pressure altitude shall be denoted by H_{Ax}, while the indicated altitude which would have been given by the instrument in this situation shall be represented by I_x. Here, I_{xw} is in error relative to I_x, owing to the discrepancy of H_{Axw} compared with H_{Ax}.

Then, in accordance with the operation of the altimeter

$$I_{xw} = (I_{pa} - H_{Axw}), \qquad (20)$$

and

$$I_x = (I_{pa} - H_{Ax}). \qquad (21)$$

Subtracting equation (20) from (21), one finds

$$(I_x - I_{xw}) = [(I_{pa} - H_{Ax}) - (I_{pa} - H_{Axw})] \qquad (22)$$

This expression represents the correction that would have to be applied to the indicated altitude I_{xw} in order to overcome the error resulting from the use of improper altimeter setting $A.S._{xw}$ when $A.S._x$ would have been the proper one to use.

As previously explained, the value of H_{Ax} is affected by strong winds blowing across the obstacle, where H_{Axw} is calculated from data based on altimeter settings observed at the reporting station; hence in general the computed value H_{Axw} is not affected by strong winds in the same manner as H_{Ax} if the station is not at the top of the obstacle. Therefore, it is reasonable to consider equation (22) to represent largely a correction for the effect of winds on the top of the obstacle acting in a more adverse manner in that location than at the reporting station, due to the greater lowering of pressure at the crest by virtue of the Bernoulli phenomenon.

Consequently, by virtue of equation (22) and the explanation which follows it, we shall *define* the correction k_w by the expression

$$k_w = [(I_{pa} - H_{Ax}) - (I_{pa} - H_{Axw})], \quad (23)$$

whence on the basis of equations (13), (14) and (23)

$$k_w = (H_{Axw} - H_{Ax}) = (I_{pxw} - I_{px}). \quad (24)$$

This expression for k_w may be considered as the correction to overcome the Bernoulli effect of strong winds blowing over the crest of the highest obstacle.

Thus far in the present treatment definitions for the terms k_a and k_w have been provided (see equations (19) and (24)). It, therefore, remains to develop an expression for k_t, the correction for departure of atmospheric temperature from standard (see equation (5)). Such an expression for k_t must be compatible with the definitions for k_a and k_w. At the same time the relationships between all three of these terms must be in harmony with the specifications of the standard atmosphere, with the method of operation of the altimeter, and with equation (11) which may be regarded as an expression of the fundamental hypsometric formula (see Appendix 7.1).

Now, attention is directed to the problem of deriving an equation of k_t.

The desired vertical clearance between the aircraft at cruising altitude (or flight level) and the crest of the highest obstacle is C_v, by definition. When this vertical clearance exists, one has

$$(A_a - A_x) = C_v \quad (25)$$

Consider the aircraft in flight over the point of maximum elevation on the highest obstacle with vertical clearance C_v. Then, one may apply equation (11) to this case, by means of the following substitutions: $A_2 = A_a$; $A_1 = A_x$; $T_{mv} = T_{mvxa}$; $I_{p2} = I_{pa}$; $T_{mp2} = T_{mpa}$; $I_{p1} = I_{px}$; and $T_{mp1} = T_{mpx}$. Thus, by virtue of equations (25) and (11), one obtains

$$(A_a - A_x) = C_v = T_{mvxa}\left[\frac{I_{pa}}{T_{mpa}} - \frac{I_{px}}{T_{mpx}}\right]; \quad (26)$$

therefore

$$I_{pa} = T_{mpa}\left[\frac{C_v}{T_{mvxa}} + \frac{I_{px}}{T_{mpx}}\right] \quad (27)$$

According to equation (15), one finds

$$I_{pa} = (I_u + H_{Au}). \quad (28)$$

Substituting equation (28) in equation (27), there results

$$I_u = T_{mpa}\left[\frac{C_v}{T_{mvxa}} + \frac{I_{px}}{T_{mpx}}\right] - H_{Au} \quad (29)$$

Consider an altimeter system free from all mechanical errors so that then $k_c = 0$; and we may replace k_s in equation (2) by k_m as defined by equation (5).

If I_u in equation (29) is regarded as the minimum indicated altitude which would give a vertical clearance C_v while the aircraft is flying over the highest obstacle, then in accordance with equation (2)

$$I_u + k_m = A_x + C_v \quad (30)$$

Substituting equation (29) in equation (30) and solving for k_m, one obtains

$$k_m = (A_x + C_v) - T_{mpa}\left[\frac{C_v}{T_{mvxa}} + \frac{I_{px}}{T_{mpx}}\right] + (H_{Au} - H_{As}) + (H_{As}). \quad (31)$$

Substituting equations (19) and (24) in equation (5), there results

$$k_m = k_t + (H_{Au} - H_{As}) + (H_{Axw} - H_{Ax}). \quad (32)$$

On the basis of equation (12)

$$H_{As} = (I_{ps} - E_s) \quad (33)$$

Subtracting equation (13) from equation (14) one finds

$$(H_{Axw} - H_{Ax}) = (I_{pxw} - I_{px}). \quad (34)$$

Substituting equations (33) and (34) in equation (32) one obtains

$$k_m = k_t + H_{Au} - (I_{ps} - E_s) + (I_{pxw} - I_{px}). \quad (35)$$

By substituting equation (35) in (31) the resultant expression for k_t becomes

$$k_t = (A_x + C_v) - T_{mpa}\left[\frac{C_v}{T_{mvxa}} + \frac{I_{px}}{T_{mpx}}\right] + (I_{ps} - E_s) + (I_{px} - I_{pxw}). \quad (36)$$

According to the definition of I_{pxw}, one finds on the basis of equation (11)

$$(A_x - E_s) = T_{mvsx}\left[\frac{I_{pxw}}{T_{mpxw}} - \frac{I_{ps}}{T_{mps}}\right]. \quad (37)$$

Equation (37) yields

$$I_{pxw} = T_{mpxw}\left[\frac{(A_x - E_s)}{T_{mvsx}} + \frac{I_{ps}}{T_{mps}}\right]. \quad (38)$$

Substitution of equation (38) in (36) gives the result

$$k_t = (A_x + C_v) - T_{mpa}\left[\frac{C_v}{T_{mvxa}} + \frac{I_{px}}{T_{mpx}}\right] + I_{px} + (I_{ps} - E_s) - T_{mpxw}\left[\frac{(A_x - E_s)}{T_{mvsx}} + \frac{I_{ps}}{T_{mps}}\right] \quad (39)$$

Equation (39) therefore reduces to

$$k_t = (A_x - E_s)\left[1 - \frac{T_{mpxw}}{T_{mvsx}}\right] + C_v\left[1 - \frac{T_{mpa}}{T_{mvxa}}\right] + I_{px}\left[1 - \frac{T_{mpa}}{T_{mpx}}\right] + I_{ps}\left[1 - \frac{T_{mpxw}}{T_{mps}}\right] \quad (40)$$

This is the desired expression for k_t.

It may be shown by making use of equations (27) and (38) that equation (39) may also be written

$$k_t = [(A_x - E_s) - (I_{pxw} - I_{ps})] + [C_v - (I_{pa} - I_{px})]. \quad (41)$$

Substituting equation (25) in equation (41), the last expression gives the result

$$k_t = (A_a - E_s) - [I_{pa} + (I_{pxw} - I_{px}) - I_{ps}]. \quad (42)$$

By virtue of equation (5) one may add equations (19), (24) and (42) in order to obtain an expression for k_m, which yields

$$k_m = (A_a - E_s) - (I_{pa} - I_{ps}) + (H_{Au} - H_{As}). \quad (43)$$

Equation (43) can be rewritten in the form

$$k_m = (A_a - E_s) + (H_{Au} - H_{As}) - [(I_{pa} - I_{px}) - (I_{pxw} - I_{px}) + (I_{pxw} - I_{ps})]. \quad (44)$$

In order to determine k_m with the aid of equation (44) the term $(I_{pxw} - I_{ps})$ should be first evaluated by means of equation (37), thus obtaining I_{pxw}; the term $(I_{pxw} - I_{px})$ can be estimated largely on the basis of wind data as explained later in this appendix; the quantity I_{px} can then be easily computed on the basis of the results derived from the first two steps; the term $(I_{pa} - I_{px})$ can be calculated with the aid of equation (27); and finally the quantity $(H_{Au} - H_{As})$ is to be estimated on the basis of the meteorological situation regarding pressure and temperature, the intended flight route, the probabilities that the proper altimeter setting will not be used in setting the pressure scale of the altimeter during the contemplated flight, the difference in elevation between altimeter reporting stations on approaching the highest obstacles (see sec. 8.1.6), etc.

Reverting to equation (42), the term in parentheses in the bracket expression of the equation can be interpreted as a correction which when applied to I_{pa} eliminates the effect of the wind. That is, if the Bernoulli effect causes I_{px} to be relatively low, then I_{pa} will also be correspondingly low owing to reduction of pressure (see equation (11) and Appendix 7.1); hence equations (13), (14), and (24), combined, reveal that by applying the term in parentheses to I_{pa} the effect of the wind in lowering the pressure is compensated.

A study of equations (41) and (42) in the light of the foregoing remarks enables one to better visualize the physical significance of k_t, the correction for departure of atmospheric temperature from standard. It should be noted that effect of the wind is already taken into account in the correction term k_w; while the effect of using an improper altimeter setting is corrected by application of the term k_a.

For the proper employment of the correction terms, as previously stated, one requires the sum $k_m = (k_a + k_w + k_t)$, as may be obtained by adding together equations (19), (24), and (40). (See also alternative forms of expression for k_m, such as equations (31), (32), (35), (43), and (44).)

By substituting appropriate representative values of the variables in equations (19), (24), and (40), one can compute the corresponding values of the terms k_a, k_w, and k_t. This enables one to determine the corresponding quantity $k_m = (k_a + k_w + k_t)$, which is required for use in conjunction with equations (4) and (6), in order to permit one to evaluate the criterion, equation (2). See sec. 8.2.1 regarding the application of the criterion.

In the last two paragraphs it was pointed out that one could determine the value of k_m by combining equations (19), (24), and (40) in accordance with equation (5). Other methods which are capable of yielding the appropriate value of k_m stem from the use of equation (31) or (44). In each of these cases it is necessary to ascertain I_{pxw} and T_{mpxw} by means of equation (37), since the required value of I_{px} will be unknown if E_s is unequal to A_x. However, the difference $(I_{pxw} - I_{px})$ will, in general, be a function of one-half the product of the air density and the square of the wind velocity immediately above the mountain crest.[1] Other parameters are also involved in the function, such as height and shape of the mountain; vertical temperature, humidity and wind distributions; topography; etc.

Thus, if one determines this function for a particular mountain, it would be possible to estimate the pertinent value of $(I_{pxw} - I_{px})$ corresponding to the existing meteorological and topographic conditions. For example, in the case of Mt. Washington, New Hampshire,[1] it was found that the pressure deficiency due to the wind is approximately proportional to one-half the product of the air density and the square of the wind velocity as measured a short distance above the mountain crest, while the proportionality factor was determined to be very nearly equal to unity (1), provided that the pressure deficiency is measured in terms of dynes per cm.[2] On this basis it was observed that with a wind velocity of 100 miles per hour the pressure deficiency attained a maximum value of about 0.33 inch of mercury, which corresponds to a difference of 370 feet in terms of $(I_{pxw} - I_{px})$. It should be noted that the effect varies very nearly in proportion to the square of the wind velocity, hence with a velocity of 150 miles per hour, the pressure deficiency would be about 2.25 times greater, or approximately 0.74 inch of mercury.

The following procedure might therefore be employed to estimate k_m:

(a) Determine the proper pressure deficiency function for the mountain.

(b) Apply this function to compute the pressure deficiency at the mountain crest, and then calculate the corresponding value of $(I_{pxw} - I_{px})$ in accordance with the standard atmosphere tables.

(c) Compute I_{pxw} on the basis of equation (37), making use of available aerological data for the determination of atmospheric temperature parameters involved in the solution of this equation. The value of T_{mpxw} is correlated with I_{pxw} through the medium of the standard atmosphere tables (see NACA Report 1235).

(d) On the basis of the results of steps (b) and (c), use is made of the identity $I_{px} = I_{pxw} - (I_{pxw} - I_{px})$ in order to compute I_{px}.

(e) By applying available aerological data, equation (27) is employed to calculate I_{pa}; and the standard atmosphere table will yield the corresponding value of T_{mpa}.

(f) Finally, equation (31) or (44) can serve to permit computation of k_m, provided that available aerological data are used as a basis for estimating T_{mvxa}, and a reasonable assumption is made regarding the value of $(H_{Au} - H_{As})$. The values of $(A_x + C_v)$ or $(A_a - E_s)$ are presumed to be known.

Now we leave the subject of determining k_m, k_t, k_a, and k_w; but turn to the matter of some important conclusions that can be reached on the basis of the equations developed in the foregoing. In the following, consideration will be given primarily to the consequences of having the aircraft use the proper altimeter setting, and of establishing the station which reports altimeter setting at the crest of the highest obstacle. It is presumed that under the most adverse conditions the minimum surface barometric pressure in the area of flight will occur at this crest owing to the joint effects of strong cross

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[1] R. E. Falconer, "Use of Pitot Tube to Compensate for Pressure Deficiency Due to Wind on Mt. Washington, N. H.," Trans. Amer. Geophys. Union, vol 28, pp. 385–397, (1947).

winds, low atmospheric temperatures relative to the standard atmosphere values, and other possible factors. Some attention will also be devoted to the relative importance of certain terms which appear in equation (40) giving an expression for the correction k_t, designed to overcome the effects of departure of atmospheric temperature from standard.

First of all, suppose that the altimeter setting which is actually being used to set the pressure scale of the aircraft instrument is equal to the current altimeter setting observed at the reporting station. On this basis $A.S._u = A.S._s$. The pressure altitudes which correspond to these pressures are functions of these specified values, respectively; hence it follows that $H_{Au} = H_{As}$. It may be seen immediately from equation (19) that a consequence of this deduction is that $k_a = 0$.

Secondly, suppose that the elevation of the reporting station, E_s, is equal to that of the point of greatest height on the highest obstacle, A_x; and suppose also concurrently that the altimeter setting which is being used for the aircraft instrument is equal to the altimeter setting currently observed at the reporting station located at the elevation A_x. Then, on the basis of these conditions one has the following relationships: $E_s = A_x$; and $A.S._u = A.S._s = A.S._x$. Therefore, the pressure altitudes which correspond to these altimeter settings are also equal; hence $H_{Au} = H_{As} = H_{Ax}$. See the definitions of the latter quantities. As in the preceding paragraph, the immediate consequence of this deduction is that $k_a = 0$, according to equation (19).

Thirdly, again consider the conditions stipulated in the preceding paragraph. From these conditions it is clear that the station pressure at the reporting station is equal to the atmospheric pressure existing at the point of maximum elevation on the highest obstacle. Therefore, the pressure altitudes which correspond to these pressures are also equal; that is, $I_{ps} = I_{px}$. An inspection of equation (37) yields the result that if the condition $E_s = A_x$ is maintained in effect, then $I_{pxw} = I_{ps}$. From a consideration of equations (12), (13), (14), and (24), it can be concluded on this basis that $k_w = 0$; that is, the correction for the Bernoulli effect of the wind acting at the crest of the obstacle is zero, *provided* that $E_s = A_x$.

Fourthly, as outlined in the preceding paragraph, when the specified condition $E_s = A_x$ applies to the given situation, the definitions of the relevant terms together with a consideration of equation (37) yield the results $I_{pxw} = I_{ps} = I_{px}$; while on a similar basis it is found that $T_{mpxw} = T_{mps} = T_{mpx}$. By virtue of the specified condition taken in conjunction with this latter finding it will be observed that the first and the fourth terms in the right-hand member of equation (40) reduce to zero (0), provided that the station is located at the crest of the obstacle.

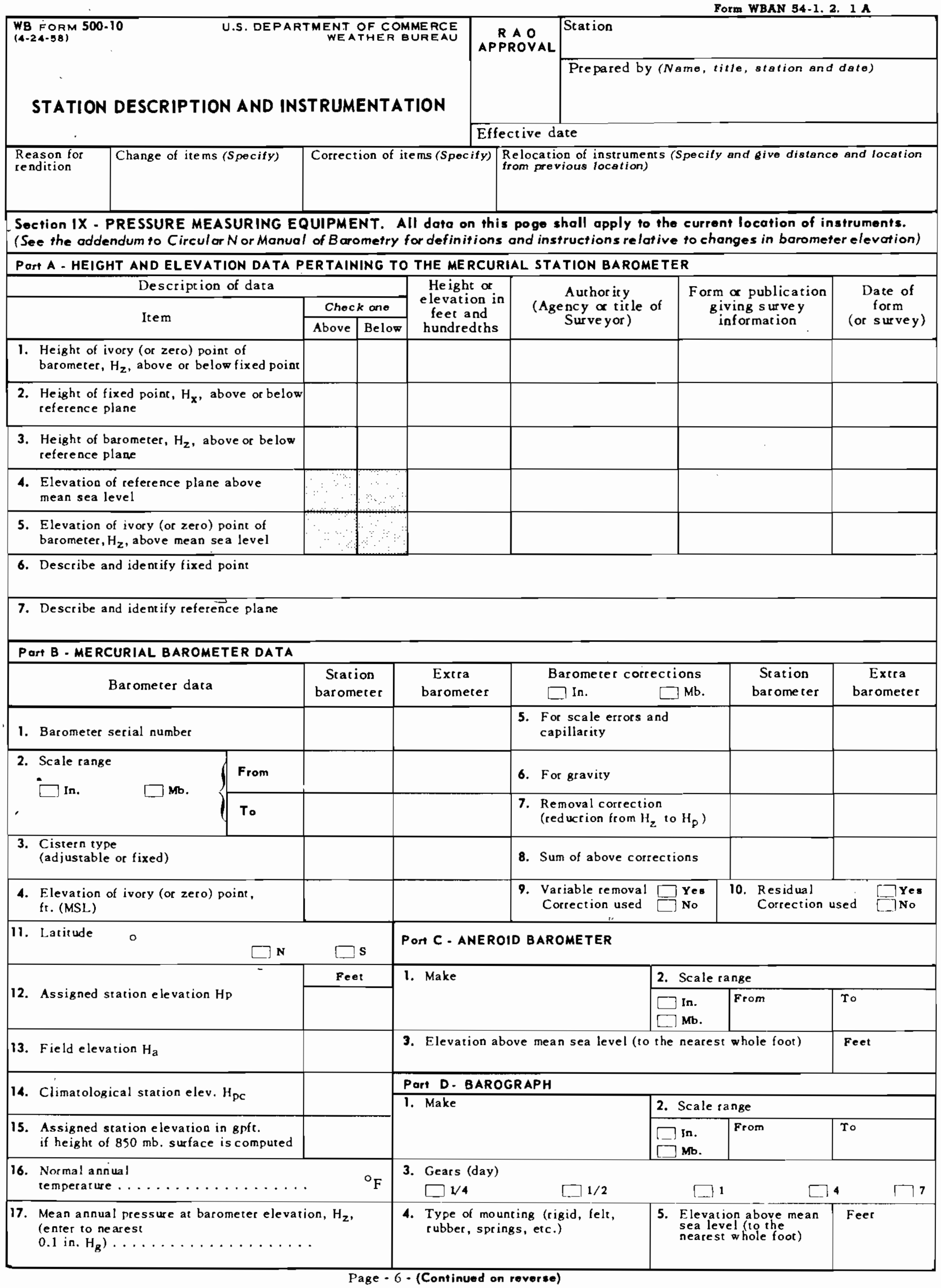
To summarize: From an investigation of the pertinent relationships (19), (24), and (40), the following *important conclusion* stands revealed: if the reporting station were located at the point of minimum pressure on or near the crest of the highest obstacle, and if the aircraft instrument were set so that its altimeter setting agrees with that being currently observed by a reporting station located at such a point, then both $k_a = 0$ and $k_w = 0$, while k_t becomes a minimum.

It may be concluded also that, in general, if the reporting station is located on or near the mountain, but is not necessarily at its crest, then the sum $k_m = (k_t + k_a + k_w)$ tends to approach a minimum as the station elevation, E_s, approaches the elevation A_x of the point of maximum height on the mountain, provided that the aircraft instrument is adjusted in accordance with the current altimeter setting observed at the reporting station, and assuming that the degree of lowering of pressure due to the wind (Bernoulli effect) increases with increasing elevation along the mountain surface, and reaches a maximum at the top.

Referring to equation (40) it may be seen that when E_s differs considerably from A_x and the ambient atmosphere is very cold compared to standard, the first term in the right-hand member of the expression is likely to be the dominant one in the equation from a numerical standpoint, depending upon the product of the departure of elevation and temperature, namely $(A_x - E_s)$ $(T_{mcsx} - T_{mpxw})$. Extreme departures of temperature as specified in the last expression in parentheses can occur in the winter in the case of regions subject to very cold climates. Some idea regarding the order of magnitude of k_t under various regimes of temperature may be gained from a study of the tabular data contained in sec. 8.3. It should be noted that when the atmospheric temperatures in the air column are much below standard the algebraic sign of k_t is of such character as to indicate that the error due to this effect of air temperature is on the dangerous side, while at the same time the magnitude of the error is likely to be most serious during the occurrence of relatively large differences in $(A_x - E_s)$, $(T_{mvsx} - T_{mpxw})$, and $(T_{mvxa} - T_{mpa})$, under these conditions.

CHAPTER 13

FORMS



Form WBAN 54-1. 2. 1 A

WB FORM 500-10 (4-24-58)	U.S. DEPARTMENT OF COMMERCE WEATHER BUREAU	R A O APPROVAL	Station
STATION DESCRIPTION AND INSTRUMENTATION			Prepared by *(Name, title, station and date)*
		Effective date	

Reason for rendition	Change of items *(Specify)*	Correction of items *(Specify)*	Relocation of instruments *(Specify and give distance and location from previous location)*

Section IX - PRESSURE MEASURING EQUIPMENT. All data on this page shall apply to the current location of instruments. *(See the addendum to Circular N or Manual of Barometry for definitions and instructions relative to changes in barometer elevation)*

Part A - HEIGHT AND ELEVATION DATA PERTAINING TO THE MERCURIAL STATION BAROMETER

Description of data			Height or elevation in feet and hundredths	Authority (Agency or title of Surveyor)	Form or publication giving survey information	Date of form (or survey)
Item	*Check one*					
	Above	Below				
1. Height of ivory (or zero) point of barometer, H_z, above or below fixed point						
2. Height of fixed point, H_x, above or below reference plane						
3. Height of barometer, H_z, above or below reference plane						
4. Elevation of reference plane above mean sea level						
5. Elevation of ivory (or zero) point of barometer, H_z, above mean sea level						

6. Describe and identify fixed point

7. Describe and identify reference plane

Part B - MERCURIAL BAROMETER DATA

Barometer data		Station barometer	Extra barometer	Barometer corrections ☐ In. ☐ Mb.	Station barometer	Extra barometer
1. Barometer serial number				5. For scale errors and capillarity		
2. Scale range ☐ In. ☐ Mb.	From			6. For gravity		
	To			7. Removal correction (reduction from H_z to H_p)		
3. Cistern type (adjustable or fixed)				8. Sum of above corrections		
4. Elevation of ivory (or zero) point, ft. (MSL)				9. Variable removal Correction used ☐ Yes ☐ No	10. Residual Correction used ☐ Yes ☐ No	

11. Latitude ° ☐ N ☐ S	
12. Assigned station elevation Hp	Feet
13. Field elevation H_a	
14. Climatological station elev. H_{pc}	
15. Assigned station elevation in gpft. if height of 850 mb. surface is computed	
16. Normal annual temperature . . . . °F	
17. Mean annual pressure at barometer elevation, H_z, (enter to nearest 0.1 in. H_g)	

Part C - ANEROID BAROMETER

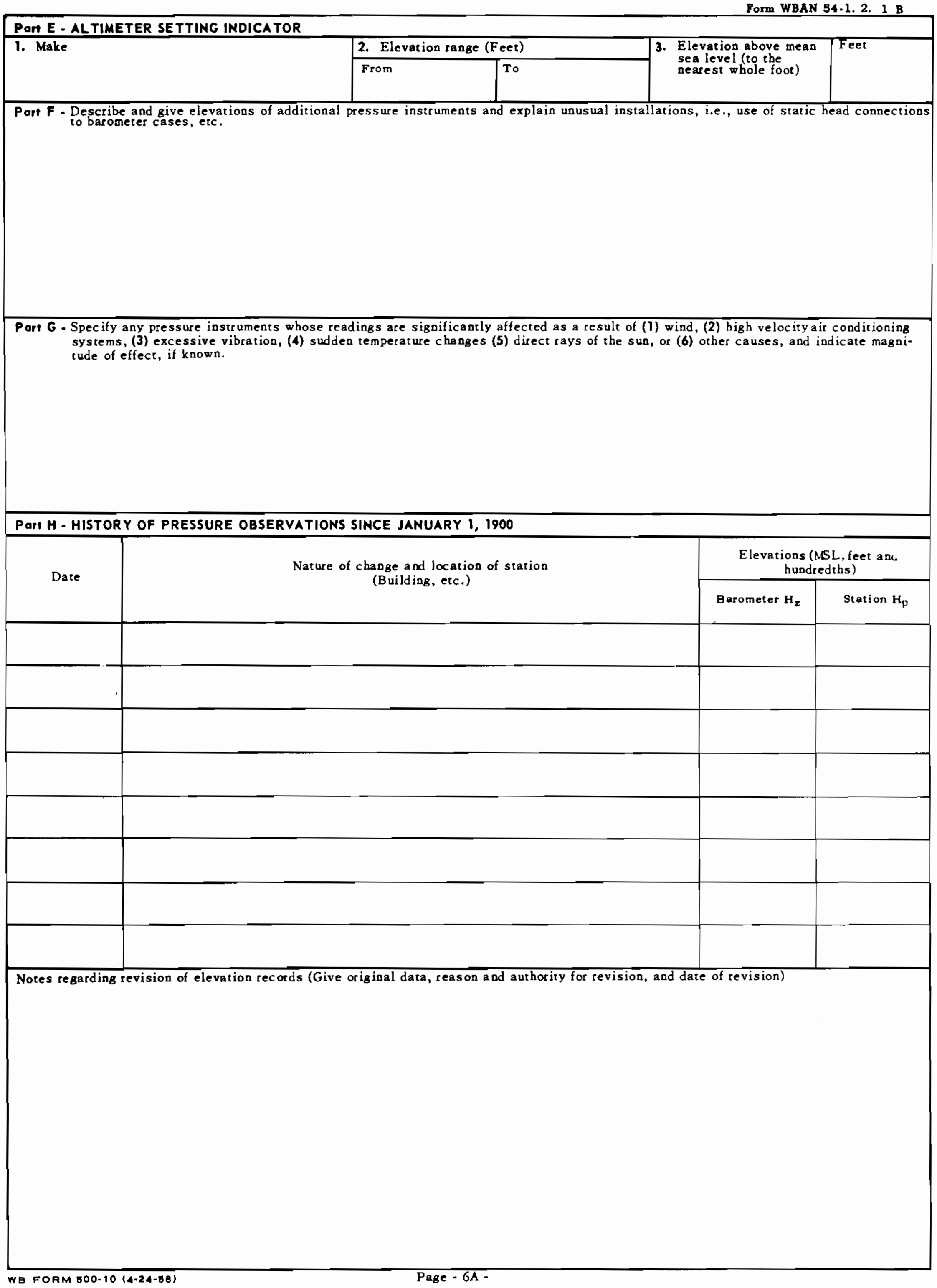
1. Make	2. Scale range		
	☐ In. ☐ Mb.	From	To
3. Elevation above mean sea level (to the nearest whole foot)			Feet

Part D - BAROGRAPH

1. Make	2. Scale range		
	☐ In. ☐ Mb.	From	To
3. Gears (day) ☐ 1/4 ☐ 1/2 ☐ 1 ☐ 4 ☐ 7			
4. Type of mounting (rigid, felt, rubber, springs, etc.)	5. Elevation above mean sea level (to the nearest whole foot)		Feet

Page - 6 - **(Continued on reverse)**

FIGURE 13.1.1. Form WBAN 54–1.2.1 A, "Station Description and Instrumentation; Section IX—Pressure Measuring Equipment." (Reduced to 80% of original dimensions.)



Form WBAN 54-1. 2. 1 B

Part E - ALTIMETER SETTING INDICATOR

1. Make	2. Elevation range (Feet)		3. Elevation above mean sea level (to the nearest whole foot)	Feet
	From	To		

Part F - Describe and give elevations of additional pressure instruments and explain unusual installations, i.e., use of static head connections to barometer cases, etc.

Part G - Specify any pressure instruments whose readings are significantly affected as a result of (1) wind, (2) high velocity air conditioning systems, (3) excessive vibration, (4) sudden temperature changes (5) direct rays of the sun, or (6) other causes, and indicate magnitude of effect, if known.

Part H - HISTORY OF PRESSURE OBSERVATIONS SINCE JANUARY 1, 1900

Date	Nature of change and location of station (Building, etc.)	Elevations (MSL, feet and hundredths)	
		Barometer H_z	Station H_p

Notes regarding revision of elevation records (Give original data, reason and authority for revision, and date of revision)

WB FORM 500-10 (4-24-58)

Page - 6A -

FIGURE 13.1.2. Form WBAN 54–1.2.1 B, "Station Description and Instrumentation: Section IX—Pressure Measuring Equipment," (continued). (This is the reverse of the form shown in fig. 13.1.1.) (Reduced to 80% of original dimensions.)

WB Form 500-9
(6-58)

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

Form WBAN 54-1.2.2

RECORD OF LEVELING AND OTHER MEASUREMENTS

STATION	DISTRICT
BY WHOM DONE	DATE
CHARACTER OF INSTRUMENT	

COPY OF LEVEL NOTES AND OF OTHER MEASUREMENTS MADE

Station	B. S. (+)	H. I.	F. S. (−)	Elevation	Remarks

542

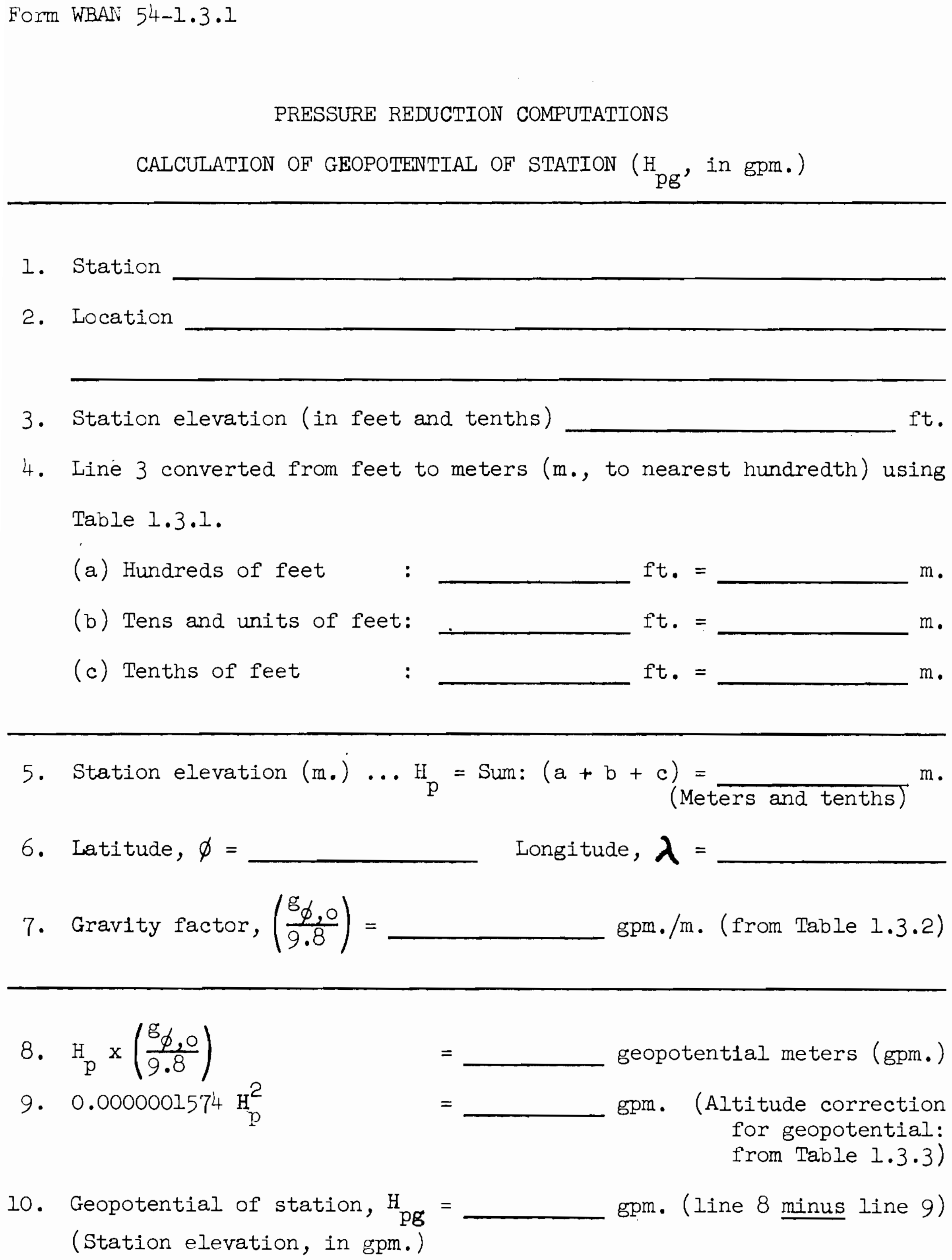
FIGURE 13.1.3. Face of Form WBAN 54–1.2.2, "Record of Leveling and Other Measurements." (Reduced to 80% of original dimensions.)

COPY OF LEVEL NOTES AND OF OTHER MEASUREMENTS MADE.—Continued

Station	B. S. (+)	H. I.	F. S. (−)	Elevation	Remarks

209

FIGURE 13.1.4. Reverse of Form WBAN 54–1.2.2, "Record of Leveling and Other Measurements." (Reduced to 80% of original dimensions.)



Form WBAN 54-1.3.1

PRESSURE REDUCTION COMPUTATIONS

CALCULATION OF GEOPOTENTIAL OF STATION (H_{pg}, in gpm.)

---

1. Station ________________________________

2. Location ________________________________

____

3. Station elevation (in feet and tenths) ____________ ft.

4. Line 3 converted from feet to meters (m., to nearest hundredth) using Table 1.3.1.

(a) Hundreds of feet : ____________ ft. = ____________ m.

(b) Tens and units of feet: ____________ ft. = ____________ m.

(c) Tenths of feet : ____________ ft. = ____________ m.

---

5. Station elevation (m.) ... H_p = Sum: (a + b + c) = ____________ m.
(Meters and tenths)

6. Latitude, ϕ = ____________ Longitude, λ = ____________

7. Gravity factor, $\left(\frac{g_{\phi,o}}{9.8}\right)$ = ____________ gpm./m. (from Table 1.3.2)

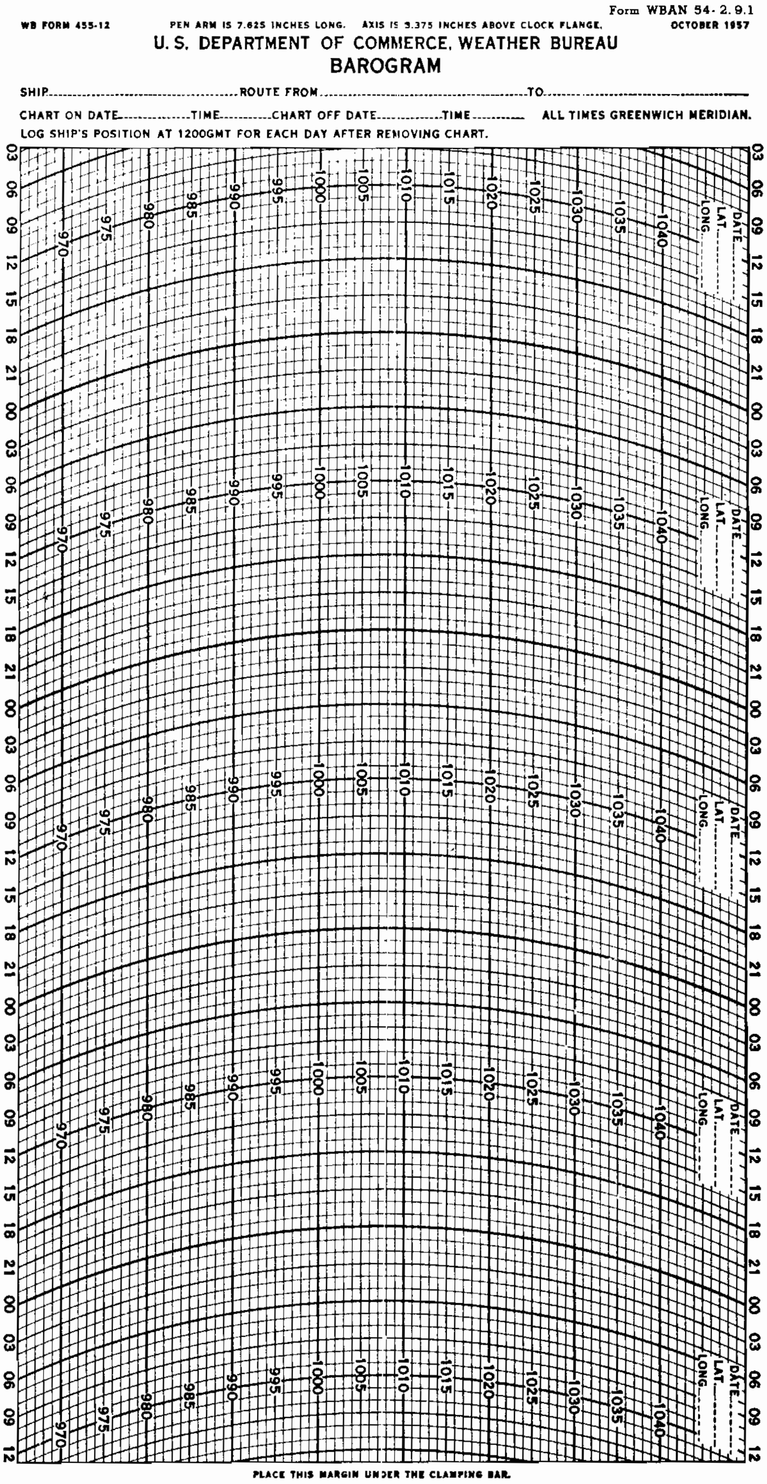
---

8. $H_p \times \left(\frac{g_{\phi,o}}{9.8}\right)$ = ____________ geopotential meters (gpm.)

9. $0.0000001574 \; H_p^2$ = ____________ gpm. (Altitude correction for geopotential: from Table 1.3.3)

10. Geopotential of station, H_{pg} = ____________ gpm. (line 8 minus line 9)
(Station elevation, in gpm.)

FIGURE 13.1.5. Form WBAN 54-1.3.1, "Pressure Reduction Computations; Calculation of Geopotential of Station (H_{pg}, in gpm.)." (Full size.)



Form WBAN 54-2.9.1

WB FORM 455-12 PEN ARM IS 7.625 INCHES LONG. AXIS IS 3.375 INCHES ABOVE CLOCK FLANGE. OCTOBER 1957

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

BAROGRAM

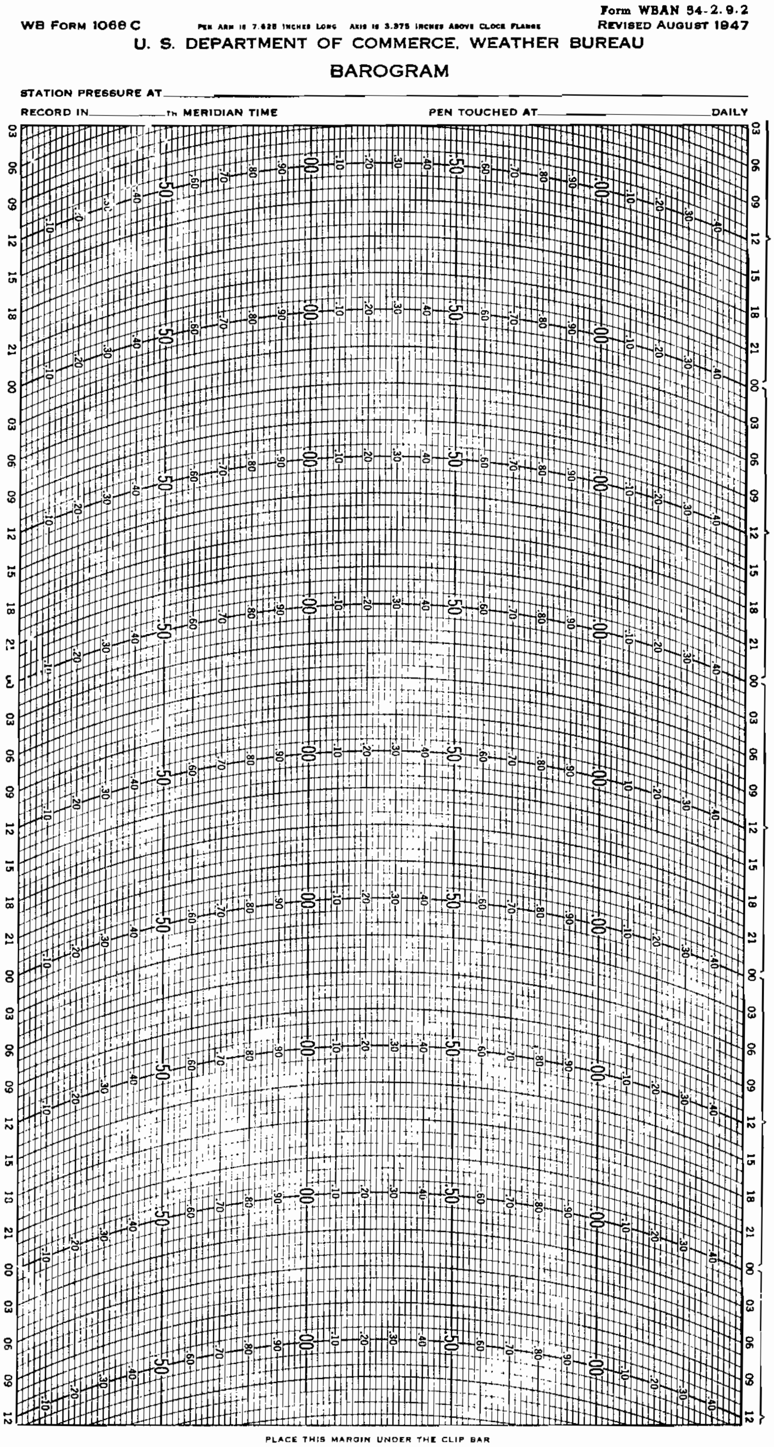
SHIP.................................ROUTE FROM.................................TO.................................

CHART ON DATE..............TIME..........CHART OFF DATE..............TIME.......... ALL TIMES GREENWICH MERIDIAN.

LOG SHIP'S POSITION AT 1200GMT FOR EACH DAY AFTER REMOVING CHART.

PLACE THIS MARGIN UNDER THE CLAMPING BAR.

FIGURE 13.2.1 Form WBAN 54–2.9.1, U.S. Weather Bureau "Barogram." (WB Form 455–12). (Reduced to 60% of original dimensions.)



Form WBAN 54-2.9.2
WB Form 1068 C
Pen Arm is 7.625 Inches Long   Axis is 3.375 Inches Above Clock Flange
Revised August 1947

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

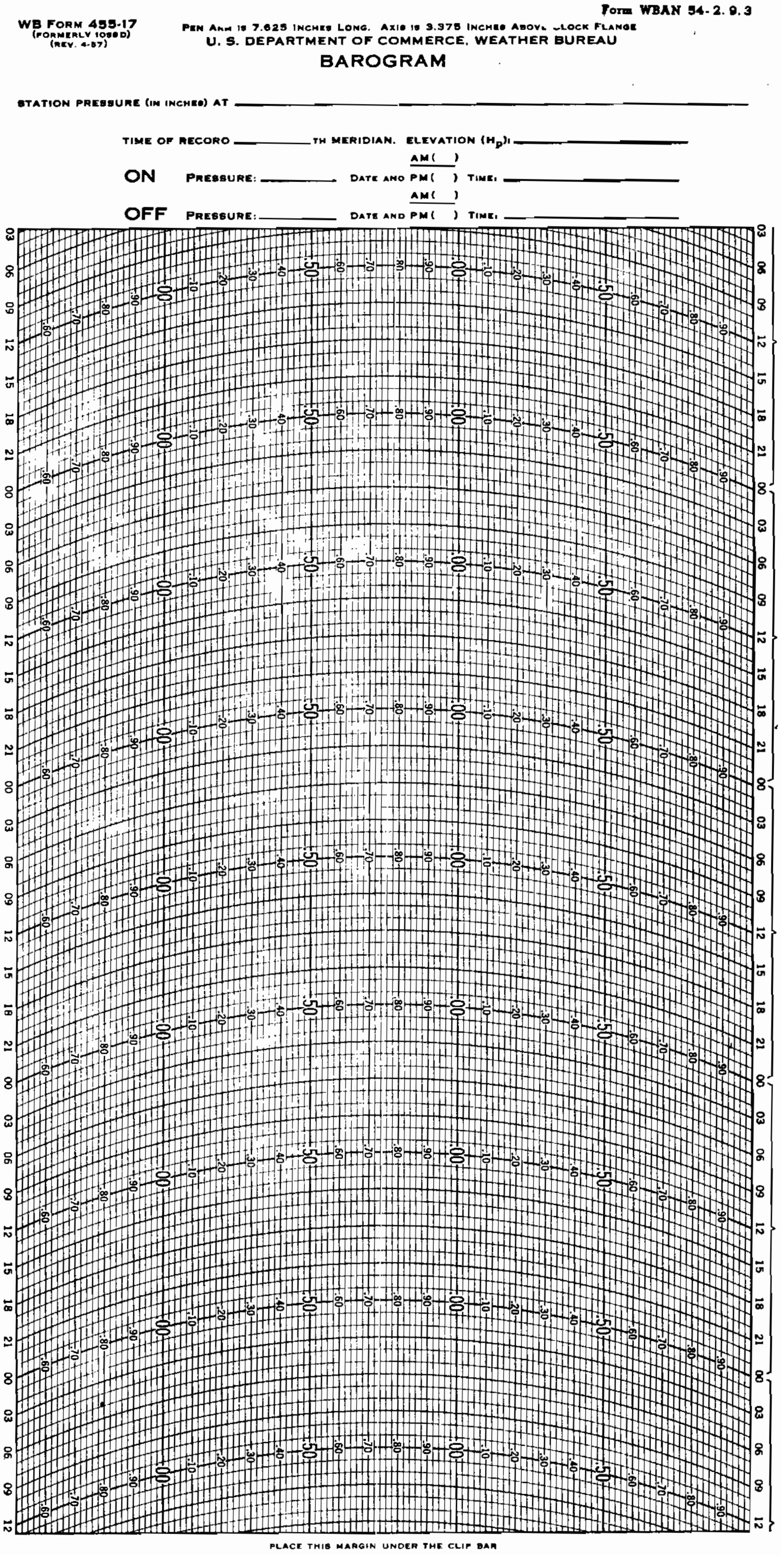
BAROGRAM

STATION PRESSURE AT____________________________________

RECORD IN____________TH MERIDIAN TIME   PEN TOUCHED AT__________________DAILY

PLACE THIS MARGIN UNDER THE CLIP BAR

FIGURE 13.2.2. Form WBAN 54–2.9.2, U.S. Weather Bureau "Barogram." (WB Form 1068 C). (Reduced to 60% of original dimensions.)



Form WBAN 54-2.9.3

WB Form 455-17
(Formerly 1098D)
(Rev. 4-57)

Pen Arm is 7.625 Inches Long. Axis is 3.375 Inches Above Clock Flange

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

BAROGRAM

STATION PRESSURE (IN INCHES) AT ____

TIME OF RECORD ____TH MERIDIAN. ELEVATION (H_p): ____

ON Pressure: ____ Date and AM( ) PM( ) Time: ____

OFF Pressure: ____ Date and AM( ) PM( ) Time: ____

PLACE THIS MARGIN UNDER THE CLIP BAR

FIGURE 13.2.3. Form WBAN 54–2.9.3, U.S. Weather Bureau "Barogram." (WB Form 455–17). (Reduced to 60% of original dimensions.)

Form WBAN 54-2.9.4

WB FORM 455-18
(FORMERLY 1068E)
(REV 4-57)

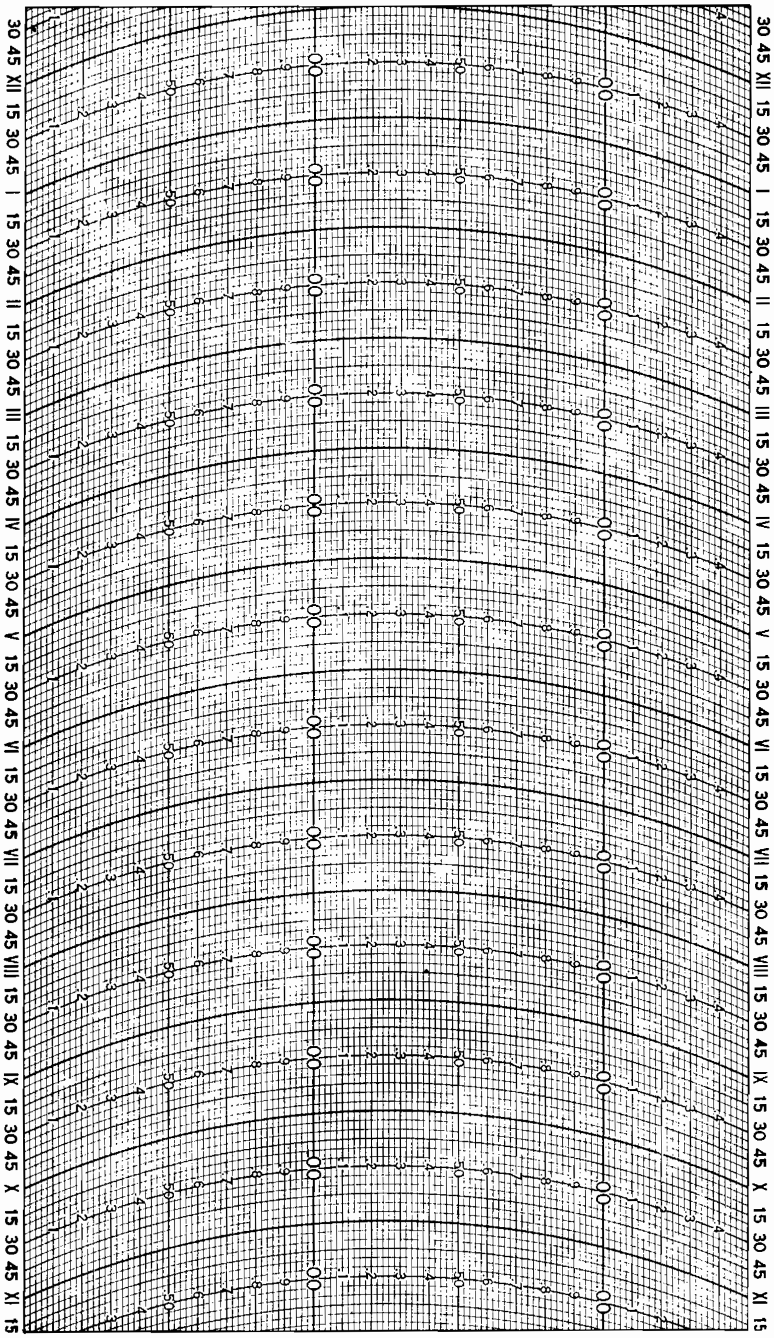
PEN ARM IS 7.625 INCHES LONG AXIS IS 3.375 INCHES ABOVE CLOCK FLANGE
U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
12–HOUR BAROGRAM

STATION PRESSURE (IN INCHES) AT ______________________________

TIME OF RECORD ________ TH MERIDIAN. ELEVATION (H_p): ______________

ON PRESSURE: ________ DATE AND AM ( ) PM ( ) TIME: ______________

OFF PRESSURE: ________ DATE AND AM ( ) PM ( ) TIME: ______________



REMARKS ______________________________

FIGURE 13.2.4. Form WBAN 54–2.9.4, U.S. Weather Bureau "12-Hour Barogram." (WB Form 455-18). (Reduced to 60% of original dimensions.)

FORM 1068-G. MET'L. (W.B.)
FRIEZ PART No. 503230-1
PRINTED IN U. S. A.

BAROGRAPH

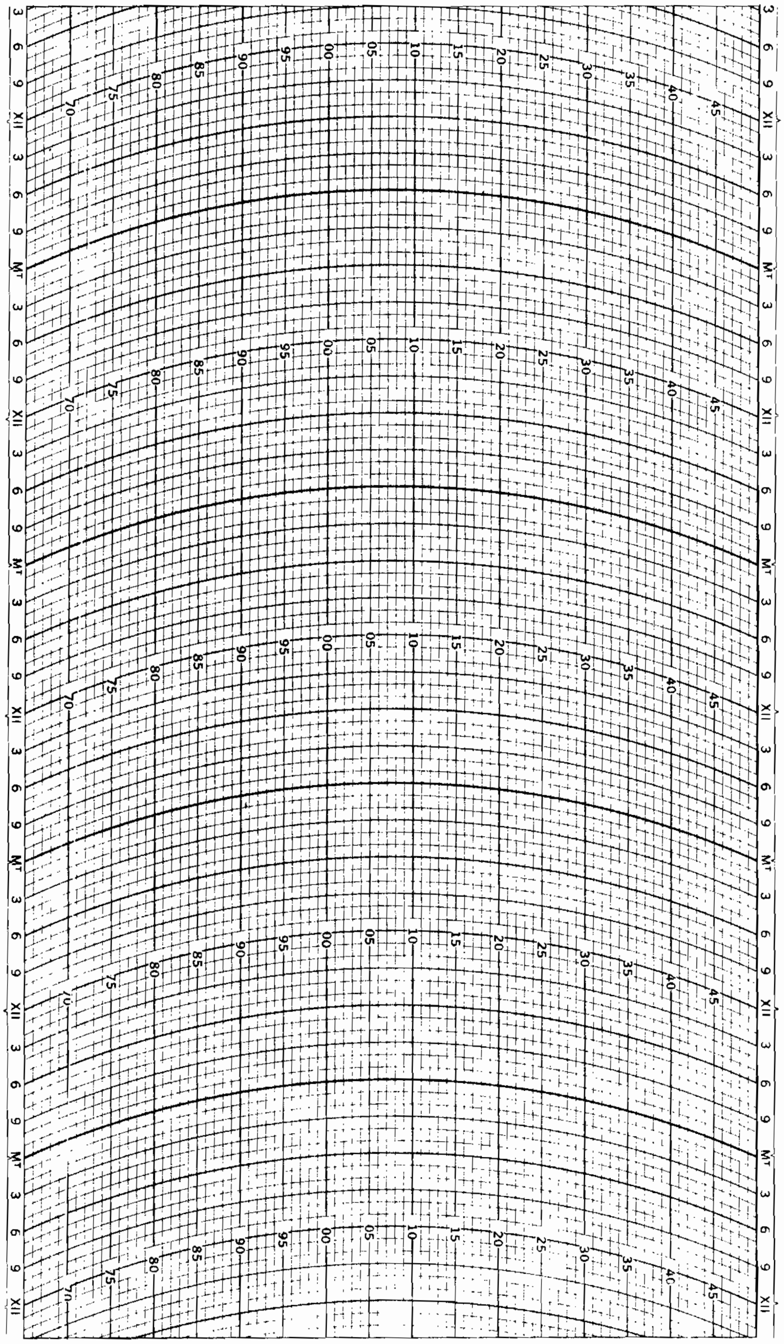
BENDIX AVIATION CORPORATION
FRIEZ INSTRUMENT DIVISION
BALTIMORE 4, MD., U. S. A.

OPEN SCALE, 4-DAY; PRESSURE IN MILLIBARS

Form WBAN 54-2.9.6

PEN ARM IS 7.625 INCHES LONG; AXIS 3.375 INCHES ABOVE CLOCK FLANGE

(MAKE NO NOTATIONS ON THIS MARGIN WHICH IS RESERVED FOR BINDING)



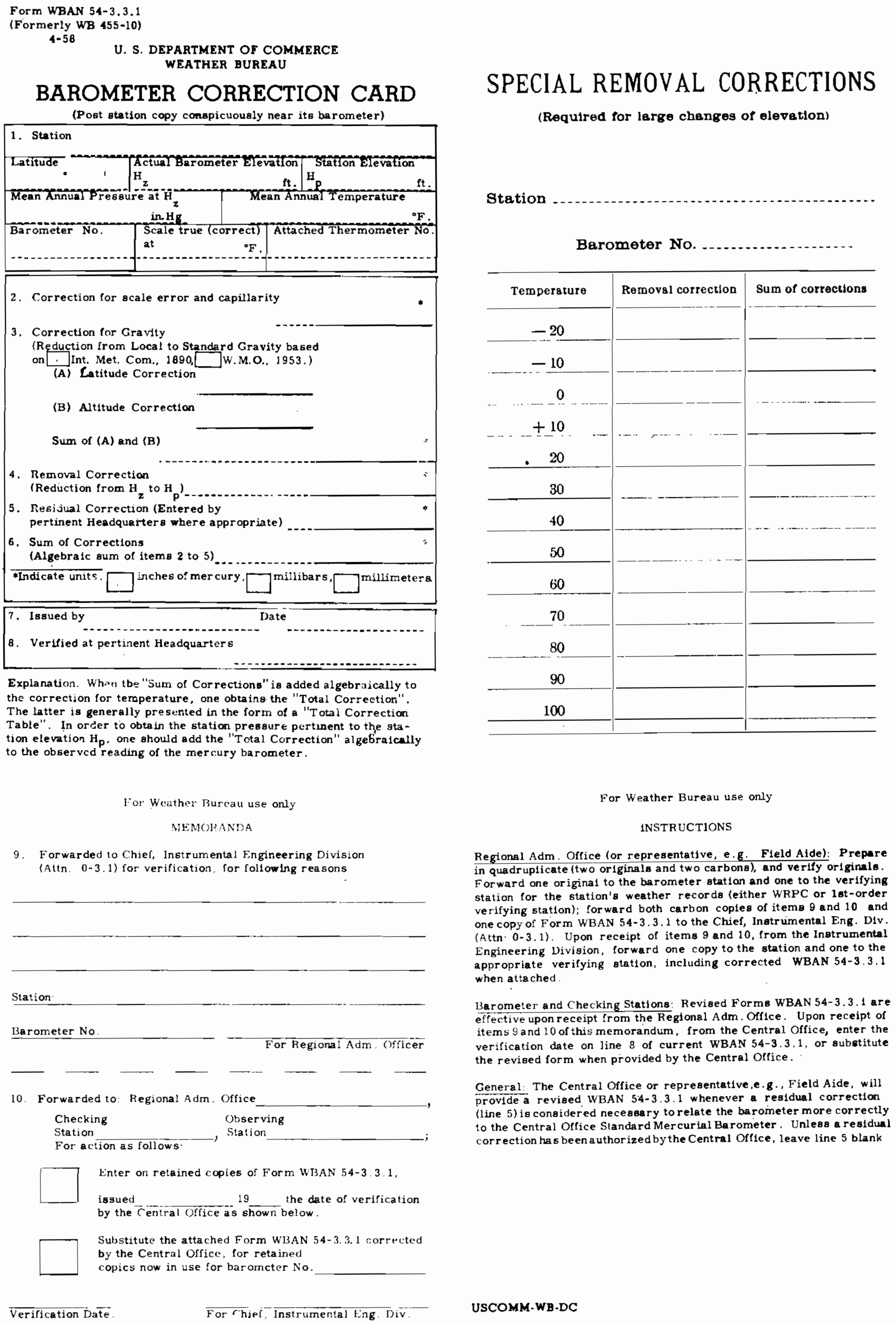
STATION ....

DATE PUT ON ....

DATE TAKEN OFF ....

REMARKS ....

FIGURE 13.2.5. Form WBAN 54–2.9.6, "Barogram" for Open Scale, 4-Day Barograph. (Form 1068–G. Met'l (W.B.)). (Reduced to 60% of original dimensions.)



Form WBAN 54-3.3.1
(Formerly WB 455-10)
4-58

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU

BAROMETER CORRECTION CARD

(Post station copy conspicuously near its barometer)

1. Station		
Latitude ° '	Actual Barometer Elevation H_z ft.	Station Elevation H_p ft.
Mean Annual Pressure at H_z in. Hg	Mean Annual Temperature °F.	
Barometer No.	Scale true (correct) at °F.	Attached Thermometer No.

2. Correction for scale error and capillarity *

3. Correction for Gravity
(Reduction from Local to Standard Gravity based on ☐ Int. Met. Com., 1890, ☐ W.M.O., 1953.)
(A) Latitude Correction
(B) Altitude Correction
Sum of (A) and (B) *

4. Removal Correction
(Reduction from H_z to H_p) *

5. Residual Correction (Entered by pertinent Headquarters where appropriate) *

6. Sum of Corrections
(Algebraic sum of items 2 to 5) *

*Indicate units. ☐ inches of mercury, ☐ millibars, ☐ millimeters

7. Issued by ______ Date ______

8. Verified at pertinent Headquarters ______

Explanation. When the "Sum of Corrections" is added algebraically to the correction for temperature, one obtains the "Total Correction". The latter is generally presented in the form of a "Total Correction Table". In order to obtain the station pressure pertinent to the station elevation H_p, one should add the "Total Correction" algebraically to the observed reading of the mercury barometer.

SPECIAL REMOVAL CORRECTIONS

(Required for large changes of elevation)

Station ______

Barometer No. ______

Temperature	Removal correction	Sum of corrections
−20		
−10		
0		
+10		
20		
30		
40		
50		
60		
70		
80		
90		
100		

For Weather Bureau use only

MEMORANDA

9. Forwarded to Chief, Instrumental Engineering Division (Attn. 0-3.1) for verification, for following reasons

Station ______

Barometer No. ______ ______
For Regional Adm. Officer

10. Forwarded to: Regional Adm. Office ______,
Checking Station ______, Observing Station ______;
For action as follows:

☐ Enter on retained copies of Form WBAN 54-3.3.1, issued ______ 19____ the date of verification by the Central Office as shown below.

☐ Substitute the attached Form WBAN 54-3.3.1 corrected by the Central Office, for retained copies now in use for barometer No. ______

Verification Date ______ For Chief, Instrumental Eng. Div. ______

For Weather Bureau use only

INSTRUCTIONS

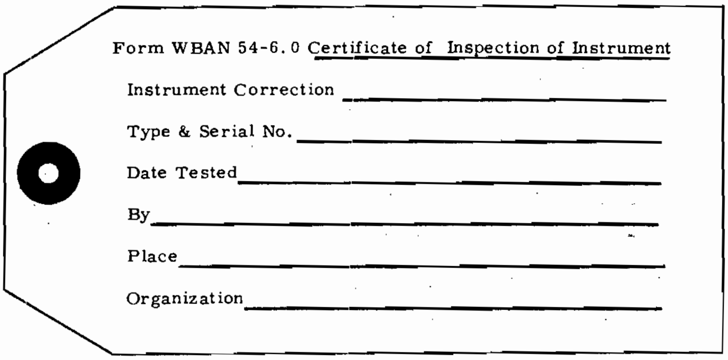
Regional Adm. Office (or representative, e.g. Field Aide): Prepare in quadruplicate (two originals and two carbons), and verify originals. Forward one original to the barometer station and one to the verifying station for the station's weather records (either WRPC or 1st-order verifying station); forward both carbon copies of items 9 and 10 and one copy of Form WBAN 54-3.3.1 to the Chief, Instrumental Eng. Div. (Attn: 0-3.1). Upon receipt of items 9 and 10, from the Instrumental Engineering Division, forward one copy to the station and one to the appropriate verifying station, including corrected WBAN 54-3.3.1 when attached.

Barometer and Checking Stations: Revised Forms WBAN 54-3.3.1 are effective upon receipt from the Regional Adm. Office. Upon receipt of items 9 and 10 of this memorandum, from the Central Office, enter the verification date on line 8 of current WBAN 54-3.3.1, or substitute the revised form when provided by the Central Office.

General: The Central Office or representative, e.g., Field Aide, will provide a revised WBAN 54-3.3.1 whenever a residual correction (line 5) is considered necessary to relate the barometer more correctly to the Central Office Standard Mercurial Barometer. Unless a residual correction has been authorized by the Central Office, leave line 5 blank

USCOMM-WB-DC

FIGURE 13.3.1. Face and reverse of Form WBAN 54-3.3.1, "Barometer Correction Card." (Reduced to 80% original dimensions.)



Form WBAN 54-6.0 Certificate of Inspection of Instrument

Instrument Correction ____________________

Type & Serial No. ____________________

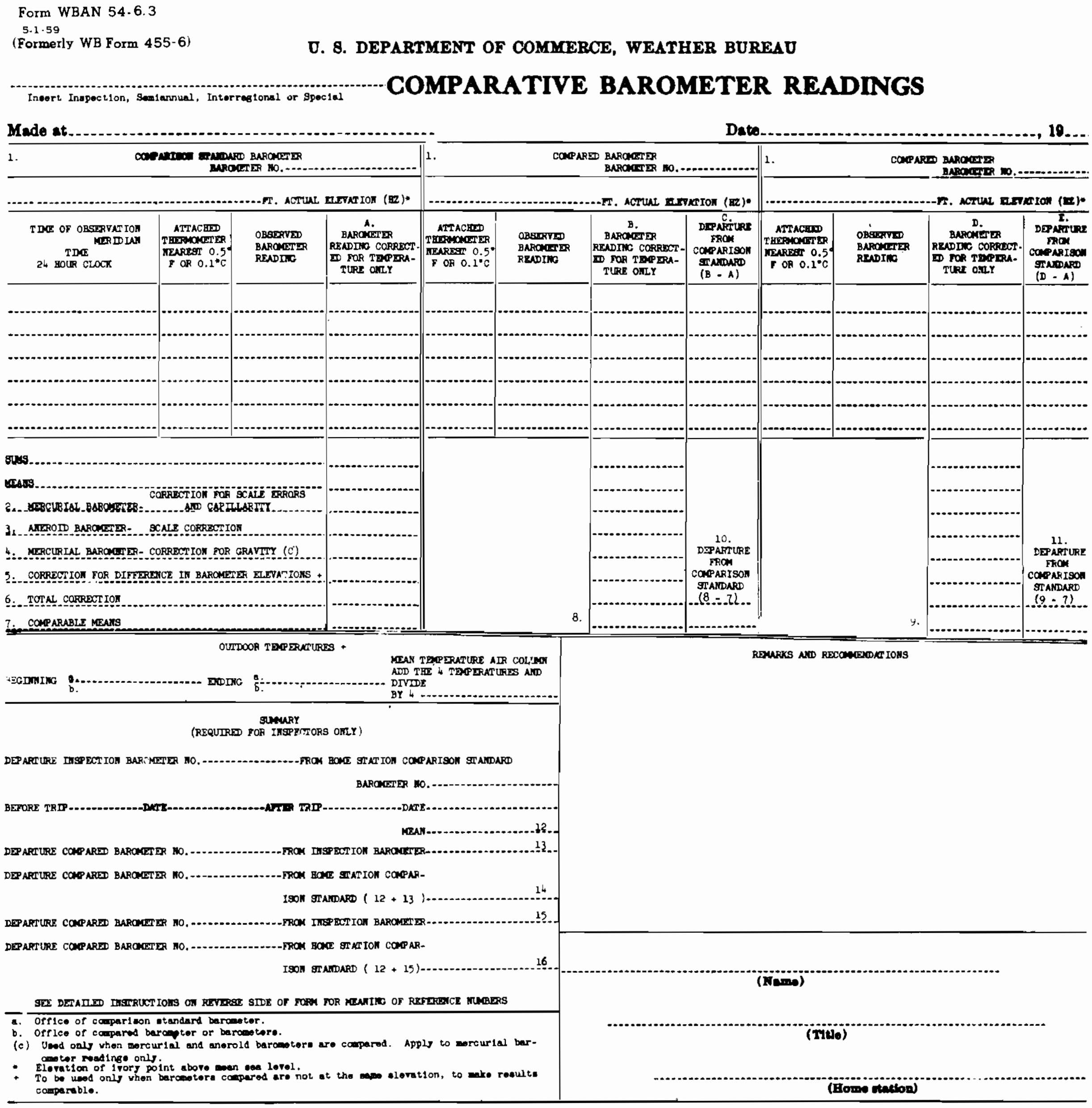
Date Tested ____________________

By ____________________

Place ____________________

Organization ____________________

FIGURE 13.6.1. Form WBAN 54-6.0, "Certificate of Inspection of Instrument." (Approximate size.)



Form WBAN 54-6.3
5-1-59
(Formerly WB Form 455-6)

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

------------ **COMPARATIVE BAROMETER READINGS**
Insert Inspection, Semiannual, Interregional or Special

Made at------------ **Date**------------, **19**---

1. COMPARISON STANDARD BAROMETER BAROMETER NO.------				1. COMPARED BAROMETER BAROMETER NO.------				1. COMPARED BAROMETER BAROMETER NO.------			
------FT. ACTUAL ELEVATION (HZ)*				------FT. ACTUAL ELEVATION (HZ)*				------FT. ACTUAL ELEVATION (HZ)*			
TIME OF OBSERVATION MERIDIAN TIME 24 HOUR CLOCK	ATTACHED THERMOMETER NEAREST 0.5° F OR 0.1°C	OBSERVED BAROMETER READING	A. BAROMETER READING CORRECTED FOR TEMPERATURE ONLY	ATTACHED THERMOMETER NEAREST 0.5° F OR 0.1°C	OBSERVED BAROMETER READING	B. BAROMETER READING CORRECTED FOR TEMPERATURE ONLY	C. DEPARTURE FROM COMPARISON STANDARD (B - A)	ATTACHED THERMOMETER NEAREST 0.5° F OR 0.1°C	OBSERVED BAROMETER READING	D. BAROMETER READING CORRECTED FOR TEMPERATURE ONLY	E. DEPARTURE FROM COMPARISON STANDARD (D - A)
SUMS											
MEANS											
2. MERCURIAL BAROMETER- CORRECTION FOR SCALE ERRORS AND CAPILLARITY											
3. ANEROID BAROMETER- SCALE CORRECTION											
4. MERCURIAL BAROMETER- CORRECTION FOR GRAVITY (C)											
5. CORRECTION FOR DIFFERENCE IN BAROMETER ELEVATIONS +											
6. TOTAL CORRECTION							10. DEPARTURE FROM COMPARISON STANDARD (8 - 7)				11. DEPARTURE FROM COMPARISON STANDARD (9 - 7)
7. COMPARABLE MEANS					8.				9.		

OUTDOOR TEMPERATURES +

BEGINNING a.------ b. ENDING a.------ b.

MEAN TEMPERATURE AIR COLUMN ADD THE 4 TEMPERATURES AND DIVIDE BY 4 ------

REMARKS AND RECOMMENDATIONS

SUMMARY
(REQUIRED FOR INSPECTORS ONLY)

DEPARTURE INSPECTION BAROMETER NO.------FROM HOME STATION COMPARISON STANDARD BAROMETER NO.------

BEFORE TRIP------DATE------AFTER TRIP------DATE------

MEAN------12.

DEPARTURE COMPARED BAROMETER NO.------FROM INSPECTION BAROMETER------13.

DEPARTURE COMPARED BAROMETER NO.------FROM HOME STATION COMPARISON STANDARD (12 + 13)------14

DEPARTURE COMPARED BAROMETER NO.------FROM INSPECTION BAROMETER------15

DEPARTURE COMPARED BAROMETER NO.------FROM HOME STATION COMPARISON STANDARD (12 + 15)------16

SEE DETAILED INSTRUCTIONS ON REVERSE SIDE OF FORM FOR MEANING OF REFERENCE NUMBERS

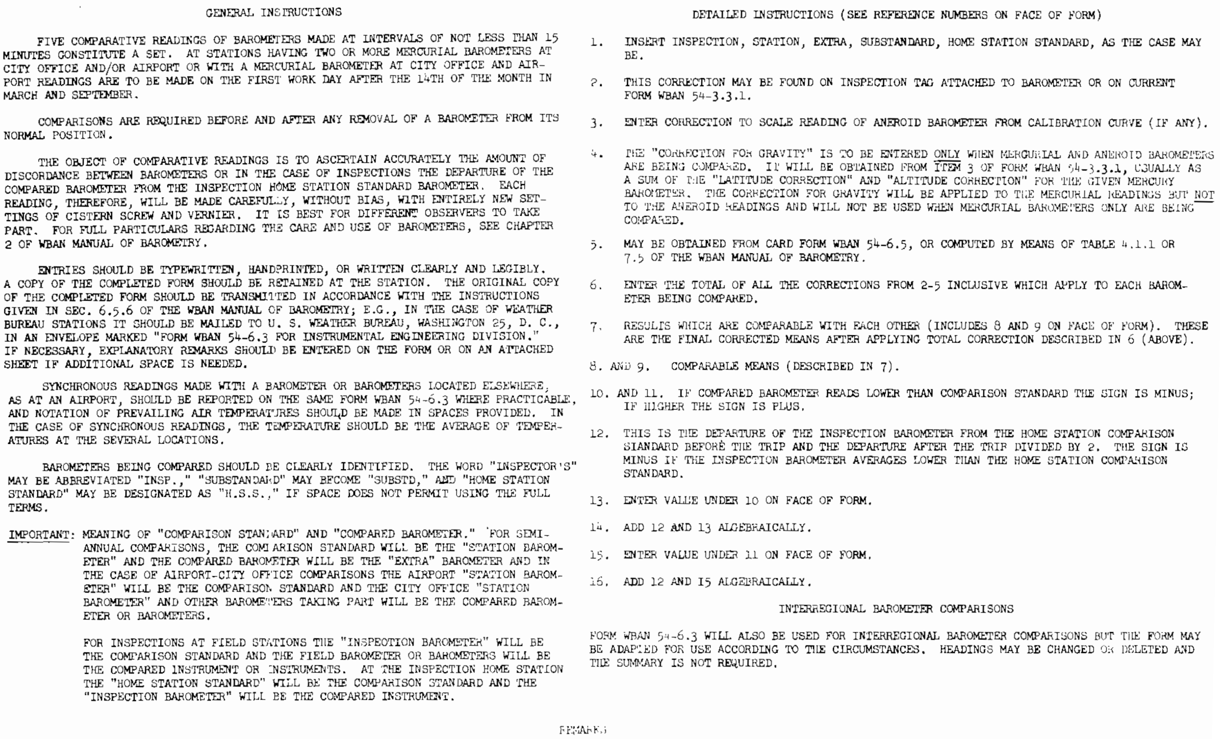
(Name)

(Title)

(Home station)

a. Office of comparison standard barometer.
b. Office of compared barometer or barometers.
(c) Used only when mercurial and aneroid barometers are compared. Apply to mercurial barometer readings only.
* Elevation of ivory point above mean sea level.
\+ To be used only when barometers compared are not at the same elevation, to make results comparable.

FIGURE 13.6.2. Form WBAN 54–6.3, "Comparative Barometer Readings." (Reduced to 80% of original dimensions.)



GENERAL INSTRUCTIONS

FIVE COMPARATIVE READINGS OF BAROMETERS MADE AT INTERVALS OF NOT LESS THAN 15 MINUTES CONSTITUTE A SET. AT STATIONS HAVING TWO OR MORE MERCURIAL BAROMETERS AT CITY OFFICE AND/OR AIRPORT OR WITH A MERCURIAL BAROMETER AT CITY OFFICE AND AIRPORT READINGS ARE TO BE MADE ON THE FIRST WORK DAY AFTER THE 14TH OF THE MONTH IN MARCH AND SEPTEMBER.

COMPARISONS ARE REQUIRED BEFORE AND AFTER ANY REMOVAL OF A BAROMETER FROM ITS NORMAL POSITION.

THE OBJECT OF COMPARATIVE READINGS IS TO ASCERTAIN ACCURATELY THE AMOUNT OF DISCORDANCE BETWEEN BAROMETERS OR IN THE CASE OF INSPECTIONS THE DEPARTURE OF THE COMPARED BAROMETER FROM THE INSPECTION HOME STATION STANDARD BAROMETER. EACH READING, THEREFORE, WILL BE MADE CAREFULLY, WITHOUT BIAS, WITH ENTIRELY NEW SETTINGS OF CISTERN SCREW AND VERNIER. IT IS BEST FOR DIFFERENT OBSERVERS TO TAKE PART. FOR FULL PARTICULARS REGARDING THE CARE AND USE OF BAROMETERS, SEE CHAPTER 2 OF WBAN MANUAL OF BAROMETRY.

ENTRIES SHOULD BE TYPEWRITTEN, HANDPRINTED, OR WRITTEN CLEARLY AND LEGIBLY. A COPY OF THE COMPLETED FORM SHOULD BE RETAINED AT THE STATION. THE ORIGINAL COPY OF THE COMPLETED FORM SHOULD BE TRANSMITTED IN ACCORDANCE WITH THE INSTRUCTIONS GIVEN IN SEC. 6.5.6 OF THE WBAN MANUAL OF BAROMETRY; E.G., IN THE CASE OF WEATHER BUREAU STATIONS IT SHOULD BE MAILED TO U. S. WEATHER BUREAU, WASHINGTON 25, D. C., IN AN ENVELOPE MARKED "FORM WBAN 54-6.3 FOR INSTRUMENTAL ENGINEERING DIVISION." IF NECESSARY, EXPLANATORY REMARKS SHOULD BE ENTERED ON THE FORM OR ON AN ATTACHED SHEET IF ADDITIONAL SPACE IS NEEDED.

SYNCHRONOUS READINGS MADE WITH A BAROMETER OR BAROMETERS LOCATED ELSEWHERE, AS AT AN AIRPORT, SHOULD BE REPORTED ON THE SAME FORM WBAN 54-6.3 WHERE PRACTICABLE, AND NOTATION OF PREVAILING AIR TEMPERATURES SHOULD BE MADE IN SPACES PROVIDED. IN THE CASE OF SYNCHRONOUS READINGS, THE TEMPERATURE SHOULD BE THE AVERAGE OF TEMPERATURES AT THE SEVERAL LOCATIONS.

BAROMETERS BEING COMPARED SHOULD BE CLEARLY IDENTIFIED. THE WORD "INSPECTOR'S" MAY BE ABBREVIATED "INSP.," "SUBSTANDARD" MAY BECOME "SUBSTD," AND "HOME STATION STANDARD" MAY BE DESIGNATED AS "H.S.S.," IF SPACE DOES NOT PERMIT USING THE FULL TERMS.

IMPORTANT: MEANING OF "COMPARISON STANDARD" AND "COMPARED BAROMETER." FOR SEMI-ANNUAL COMPARISONS, THE COMPARISON STANDARD WILL BE THE "STATION BAROMETER" AND THE COMPARED BAROMETER WILL BE THE "EXTRA" BAROMETER AND IN THE CASE OF AIRPORT-CITY OFFICE COMPARISONS THE AIRPORT "STATION BAROMETER" WILL BE THE COMPARISON STANDARD AND THE CITY OFFICE "STATION BAROMETER" AND OTHER BAROMETERS TAKING PART WILL BE THE COMPARED BAROMETER OR BAROMETERS.

FOR INSPECTIONS AT FIELD STATIONS THE "INSPEOTION BAROMETER" WILL BE THE COMPARISON STANDARD AND THE FIELD BAROMETER OR BAROMETERS WILL BE THE COMPARED INSTRUMENT OR INSTRUMENTS. AT THE INSPECTION HOME STATION THE "HOME STATION STANDARD" WILL BE THE COMPARISON STANDARD AND THE "INSPECTION BAROMETER" WILL BE THE COMPARED INSTRUMENT.

DETAILED INSTRUCTIONS (SEE REFERENCE NUMBERS ON FACE OF FORM)

1. INSERT INSPECTION, STATION, EXTRA, SUBSTANDARD, HOME STATION STANDARD, AS THE CASE MAY BE.

2. THIS CORRECTION MAY BE FOUND ON INSPECTION TAG ATTACHED TO BAROMETER OR ON CURRENT FORM WBAN 54-3.3.1.

3. ENTER CORRECTION TO SCALE READING OF ANEROID BAROMETER FROM CALIBRATION CURVE (IF ANY).

4. THE "CORRECTION FOR GRAVITY" IS TO BE ENTERED ONLY WHEN MERCURIAL AND ANEROID BAROMETERS ARE BEING COMPARED. IT WILL BE OBTAINED FROM ITEM 3 OF FORM WBAN 54-3.3.1, USUALLY AS A SUM OF THE "LATITUDE CORRECTION" AND "ALTITUDE CORRECTION" FOR THE GIVEN MERCURY BAROMETER. THE CORRECTION FOR GRAVITY WILL BE APPLIED TO THE MERCURIAL READINGS BUT NOT TO THE ANEROID READINGS AND WILL NOT BE USED WHEN MERCURIAL BAROMETERS ONLY ARE BEING COMPARED.

5. MAY BE OBTAINED FROM CARD FORM WBAN 54-6.5, OR COMPUTED BY MEANS OF TABLE 4.1.1 OR 7.5 OF THE WBAN MANUAL OF BAROMETRY.

6. ENTER THE TOTAL OF ALL THE CORRECTIONS FROM 2-5 INCLUSIVE WHICH APPLY TO EACH BAROMETER BEING COMPARED.

7. RESULTS WHICH ARE COMPARABLE WITH EACH OTHER (INCLUDES 8 AND 9 ON FACE OF FORM). THESE ARE THE FINAL CORRECTED MEANS AFTER APPLYING TOTAL CORRECTION DESCRIBED IN 6 (ABOVE).

8. AND 9. COMPARABLE MEANS (DESCRIBED IN 7).

10. AND 11. IF COMPARED BAROMETER READS LOWER THAN COMPARISON STANDARD THE SIGN IS MINUS; IF HIGHER THE SIGN IS PLUS.

12. THIS IS THE DEPARTURE OF THE INSPECTION BAROMETER FROM THE HOME STATION COMPARISON STANDARD BEFORE THE TRIP AND THE DEPARTURE AFTER THE TRIP DIVIDED BY 2. THE SIGN IS MINUS IF THE INSPECTION BAROMETER AVERAGES LOWER THAN THE HOME STATION COMPARISON STANDARD.

13. ENTER VALUE UNDER 10 ON FACE OF FORM.

14. ADD 12 AND 13 ALGEBRAICALLY.

15. ENTER VALUE UNDER 11 ON FACE OF FORM.

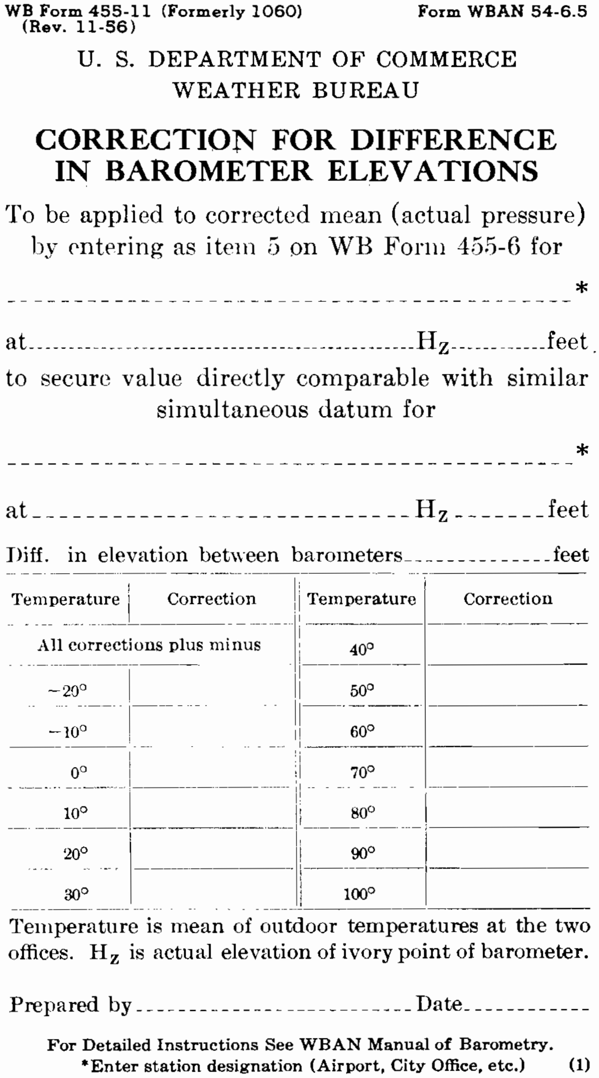
16. ADD 12 AND 15 ALGEBRAICALLY.

INTERREGIONAL BAROMETER COMPARISONS

FORM WBAN 54-6.3 WILL ALSO BE USED FOR INTERREGIONAL BAROMETER COMPARISONS BUT THE FORM MAY BE ADAPTED FOR USE ACCORDING TO THE CIRCUMSTANCES. HEADINGS MAY BE CHANGED OR DELETED AND THE SUMMARY IS NOT REQUIRED.

REMARKS

FIGURE 13.6.3. Reverse of Form WBAN 54-6.3, "Comparative Barometer Readings." (Reduced to 80% of original dimensions.)



WB Form 455-11 (Formerly 1060) (Rev. 11-56)

Form WBAN 54-6.5

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU

CORRECTION FOR DIFFERENCE IN BAROMETER ELEVATIONS

To be applied to corrected mean (actual pressure) by entering as item 5 on WB Form 455-6 for

--*

at--H_Z------------feet.

to secure value directly comparable with similar simultaneous datum for

--*

at----------------------------H_Z-------feet

Diff. in elevation between barometers--------------feet

Temperature	Correction	Temperature	Correction
All corrections plus minus		40°	
−20°		50°	
−10°		60°	
0°		70°	
10°		80°	
20°		90°	
30°		100°	

Temperature is mean of outdoor temperatures at the two offices. H_Z is actual elevation of ivory point of barometer.

Prepared by-------------------------Date------------

For Detailed Instructions See WBAN Manual of Barometry.
*Enter station designation (Airport, City Office, etc.) (1)

FIGURE 13.6.4. Form WBAN 54–6.5, "Correction for Difference in Barometer Elevations." (Full size.)

Form WBAN 54- 6. 6

BAROMETER COMPARISONS

Comparison of altimeter setting indicator ( ) or aneroid barometer ( ) Type and Serial No. ____________ with Mercurial Barometer Type & Serial No. ____________

Station: ____________ Location: ____________ Year: ______ See detailed instructions for preparation of form on reverse side.

Mercurial barometer data: Sum of corr. ____________

Removal corr. ____________ Residual corr. ____________

Actual elev. merc. bar., H_z = ____________ ft. Station elevation, H_p = ____________ ft.

Actual elev. aneroid bar., = ____________ ft. Actual elev. alt. setting ind. = ____________ ft.

Comparison No.	Month and Day	Time (LST)	Data Based on Mercurial Barometer					Observed Reading (Aneroid or A. S. Ind.)	Correction (C_a)	Sum of C_a for Group; & Comp. Nos.	Mean C_a for Group	Difference Between Successive Means	Alt. Setting Indicator Elevation Scale Reading & Remarks
			Temp. Attach. Therm.	Observed Barometer Reading	Station Pressure	Station Pressure	Altimeter Setting						
1	2	3	4	5	6	7	8	9	10	11	12	13	14
					(in. Hg.)$_n$	mb.	in.						ft.

FIGURE 13.6.5. Form WBAN 54–6.6, "Barometer Comparisons." (Full size.)

Reverse side of Form WBAN 54-6.6

Instructions for Preparing Form*

Headings Fill in all blank lines with data required according to the legends, and enter appropriate units above columns. (As a good source of data for the legends, such as "Sum of corrections," H_z, H_p, etc., refer to Form WBAN 54-3.3.1; formerly WB Form 455-10 and Form 1059.)

Data should be entered in the columns, in accord with the following instructions:*

Col. 1 Enter comparison numbers in consecutive order. Use appended letters (a, b, ...) to designate special comparisons following a regular one on same day.

Col. 2 Enter month and day of comparison (as 2/5 for February 5).

Col. 3 Indicate Standard Meridian in heading, and local standard time on 24-hour clock to nearest minute, in column (as 1912 for 7:12 P.M.).**

Col. 4 Enter temperature of attached thermometer.

Col. 5 Enter reading of the mercury barometer.

Col. 6 Enter station pressure if "removal correction" is constant; but "pressure at H_z" if "removal correction" is variable. That is, in the latter case do not apply the variable "removal correction," and relabel the heading to read "Pressure at H_z." Omit entry if barometer is graduated in mb.

Col. 7 Depending on the nature of the removal correction, make the heading read the same as that of Col. 6; and if data are given under Col. 6, convert them to mb. and enter results under Col. 7.

Col. 8 If an aneroid barometer is being compared, leave Col. 8 blank. However, if an altimeter setting indicator is being compared, enter in Col. 8 the value of altimeter setting corresponding to the entry in Col. 6 or 7. Use the "Altimeter Setting Table" or the altimeter-setting side of the Pressure Reduction Computer to determine the altimeter setting. If the "removal correction" is constant, the altimeter setting is computed on the basis of the station elevation H_p and the station pressure as entered in Col. 6; but if the "removal correction" is variable, the altimeter setting is computed on the basis of the actual barometer elevation H_z and the pressure at H_z as entered in Col. 6.

Col. 9 Enter observed reading of the aneroid barometer or altimeter setting indicator.

Col. 10 If an aneroid barometer is being compared, enter the difference (Col. 6 minus Col. 9) when aneroid is graduated in $(\text{in. Hg})_n$, or the difference (Col. 7 minus Col. 9) when aneroid is graduated in mb. If an altimeter setting indicator is being compared, enter the difference (Col. 8 minus Col. 9).

Col. 11 Enter sum of ten values of C_a obtained on five days spaced at weekly intervals.** When any regular comparison is found to be in error as indicated by two or more special comparisons, the mean C_a based on the specials may be used in lieu of the regular value, in forming the sum. Enter in small numbers the first and last comparison numbers included in the sum.

Col. 12 Enter mean C_a based on sum given under Col. 11.

Col. 13 Enter the difference (previous mean C_a for group minus current mean C_a for group), based on Col. 12.

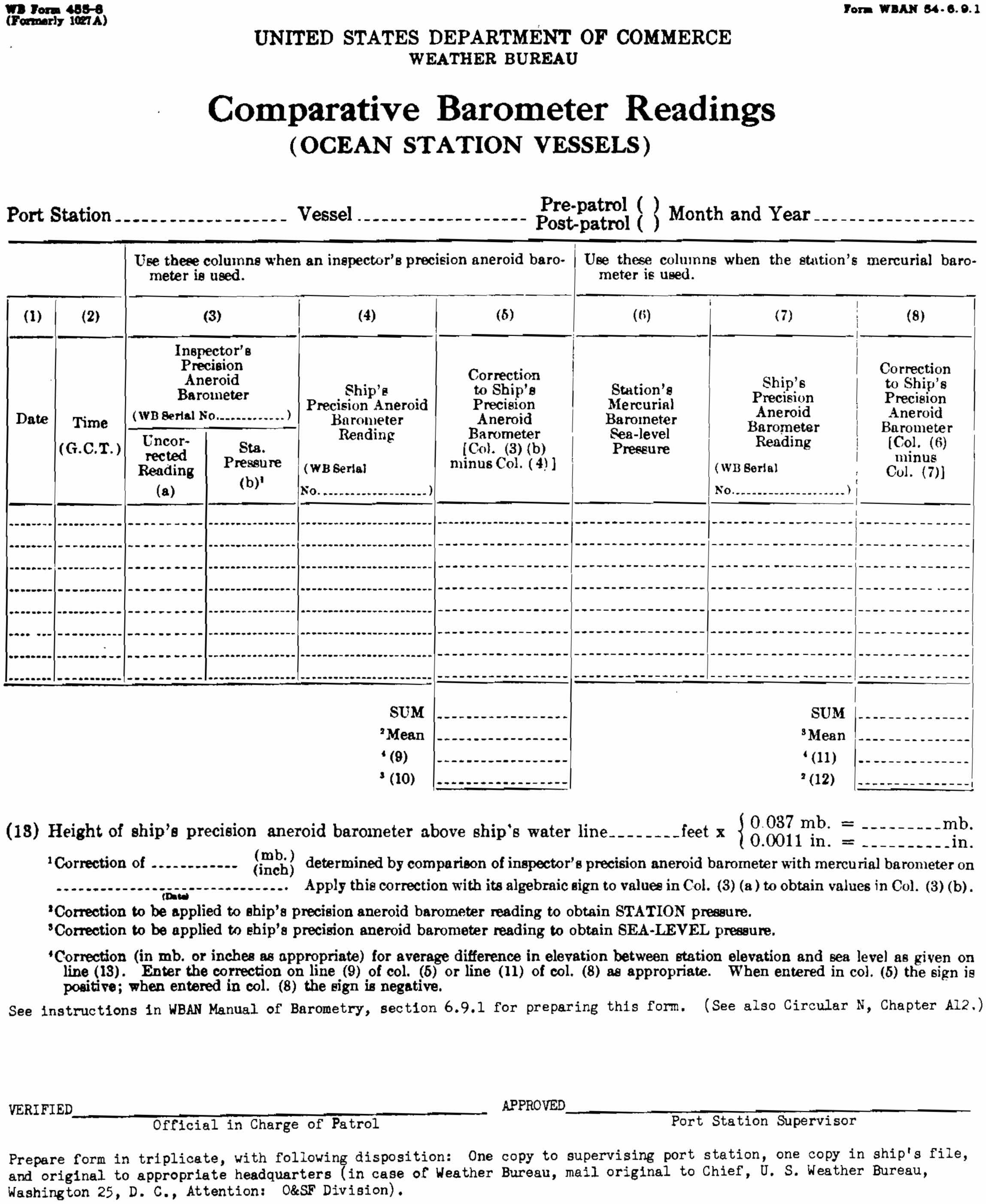
Col. 14 If an altimeter setting indicator is being compared, enter the elevation scale reading of the instrument. Should there be failure of the aneroid instruments to satisfy the established criteria of quality control for this type, enter appropriate notes under "Remarks" and take corrective action as required under the instructions referred to below.* The criteria are specified in the pertinent manuals. Enter any sums and differences used in connection with study of drift.

---

*See the latest edition of the WBAN Manual of Surface Observations, Circular N, and its Addendum. Refer to WBAN Manual of Barometry, secs. 6.7 and 6.8 for further information; specifically secs. 6.7.3 and 6.8.2.2 for detailed instructions.

**The frequency of comparative readings will normally be two observations at 6-hour intervals on one day of every successive week. When the comparative data are obtained on this basis, the mean value of C_a for Col. 12 (denoted C_{am}) will be computed from the average of the last ten such individually determined values of C_a.

FIGURE 13.6.6. Reverse of Form WBAN 54-6.6, "Barometer Comparisons," "Instructions for preparing form." (Full size.)



WB Form 455-8
(Formerly 1027A)

Form WBAN 54-6.9.1

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

Comparative Barometer Readings
(OCEAN STATION VESSELS)

Port Station .... Vessel .... Pre-patrol ( ) Post-patrol ( ) Month and Year ....

		Use these columns when an inspector's precision aneroid barometer is used.				Use these columns when the station's mercurial barometer is used.		
(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)
Date	Time (G.C.T.)	Inspector's Precision Aneroid Barometer (WB Serial No..........)		Ship's Precision Aneroid Barometer Reading (WB Serial No..........)	Correction to Ship's Precision Aneroid Barometer [Col. (3) (b) minus Col. (4)]	Station's Mercurial Barometer Sea-level Pressure	Ship's Precision Aneroid Barometer Reading (WB Serial No..........)	Correction to Ship's Precision Aneroid Barometer [Col. (6) minus Col. (7)]
		Uncorrected Reading (a)	Sta. Pressure (b)[1]					
				SUM			SUM	
				[2]Mean			[3]Mean	
				[4](9)			[4](11)	
				[3](10)			[2](12)	

(13) Height of ship's precision aneroid barometer above ship's water line........feet x { 0.037 mb. = ...mb. / 0.0011 in. = ...in. }

[1] Correction of .... (mb.) (inch) determined by comparison of inspector's precision aneroid barometer with mercurial barometer on .... (Date) Apply this correction with its algebraic sign to values in Col. (3) (a) to obtain values in Col. (3) (b).

[2] Correction to be applied to ship's precision aneroid barometer reading to obtain STATION pressure.

[3] Correction to be applied to ship's precision aneroid barometer reading to obtain SEA-LEVEL pressure.

[4] Correction (in mb. or inches as appropriate) for average difference in elevation between station elevation and sea level as given on line (13). Enter the correction on line (9) of col. (5) or line (11) of col. (8) as appropriate. When entered in col. (5) the sign is positive; when entered in col. (8) the sign is negative.

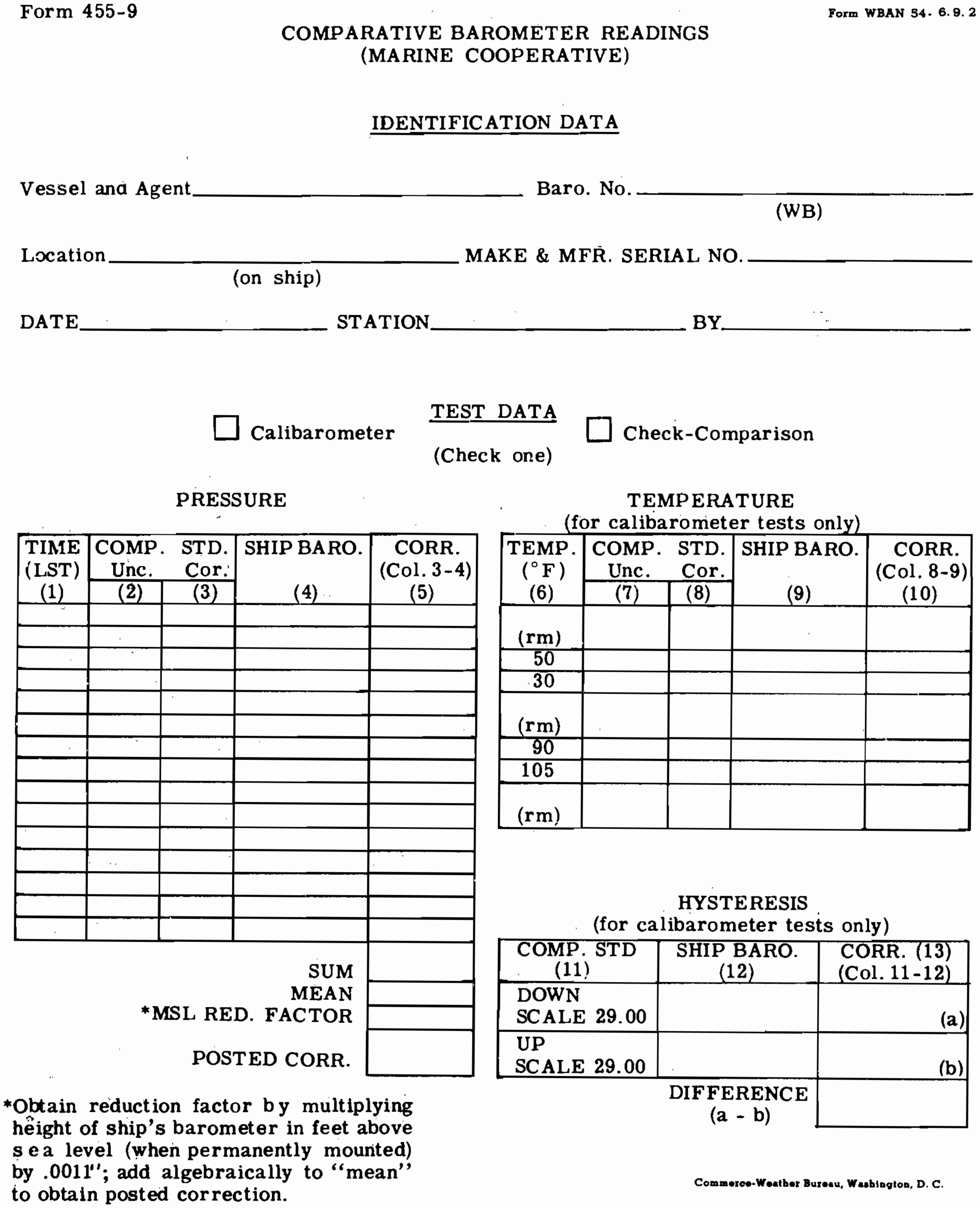
See instructions in WBAN Manual of Barometry, section 6.9.1 for preparing this form. (See also Circular N, Chapter A12.)

VERIFIED____________________ Official in Charge of Patrol

APPROVED____________________ Port Station Supervisor

Prepare form in triplicate, with following disposition: One copy to supervising port station, one copy in ship's file, and original to appropriate headquarters (in case of Weather Bureau, mail original to Chief, U. S. Weather Bureau, Washington 25, D. C., Attention: O&SF Division).

FIGURE 13.6.7. Form WBAN 54-6.9.1, "Comparative Barometer Readings (Ocean Station Vessels)." (Reduced to 80% of original dimensions.)



Form 455-9

Form WBAN 54- 6.9.2

COMPARATIVE BAROMETER READINGS
(MARINE COOPERATIVE)

IDENTIFICATION DATA

Vessel and Agent ________ Baro. No. ________ (WB)

Location ________ (on ship) MAKE & MFR. SERIAL NO. ________

DATE ________ STATION ________ BY ________

TEST DATA

☐ Calibarometer ☐ Check-Comparison

(Check one)

PRESSURE

TIME (LST) (1)	COMP. Unc. (2)	STD. Cor. (3)	SHIP BARO. (4)	CORR. (Col. 3-4) (5)
			SUM	
			MEAN	
			*MSL RED. FACTOR	
			POSTED CORR.	

*Obtain reduction factor by multiplying height of ship's barometer in feet above sea level (when permanently mounted) by .0011"; add algebraically to "mean" to obtain posted correction.

TEMPERATURE
(for calibarometer tests only)

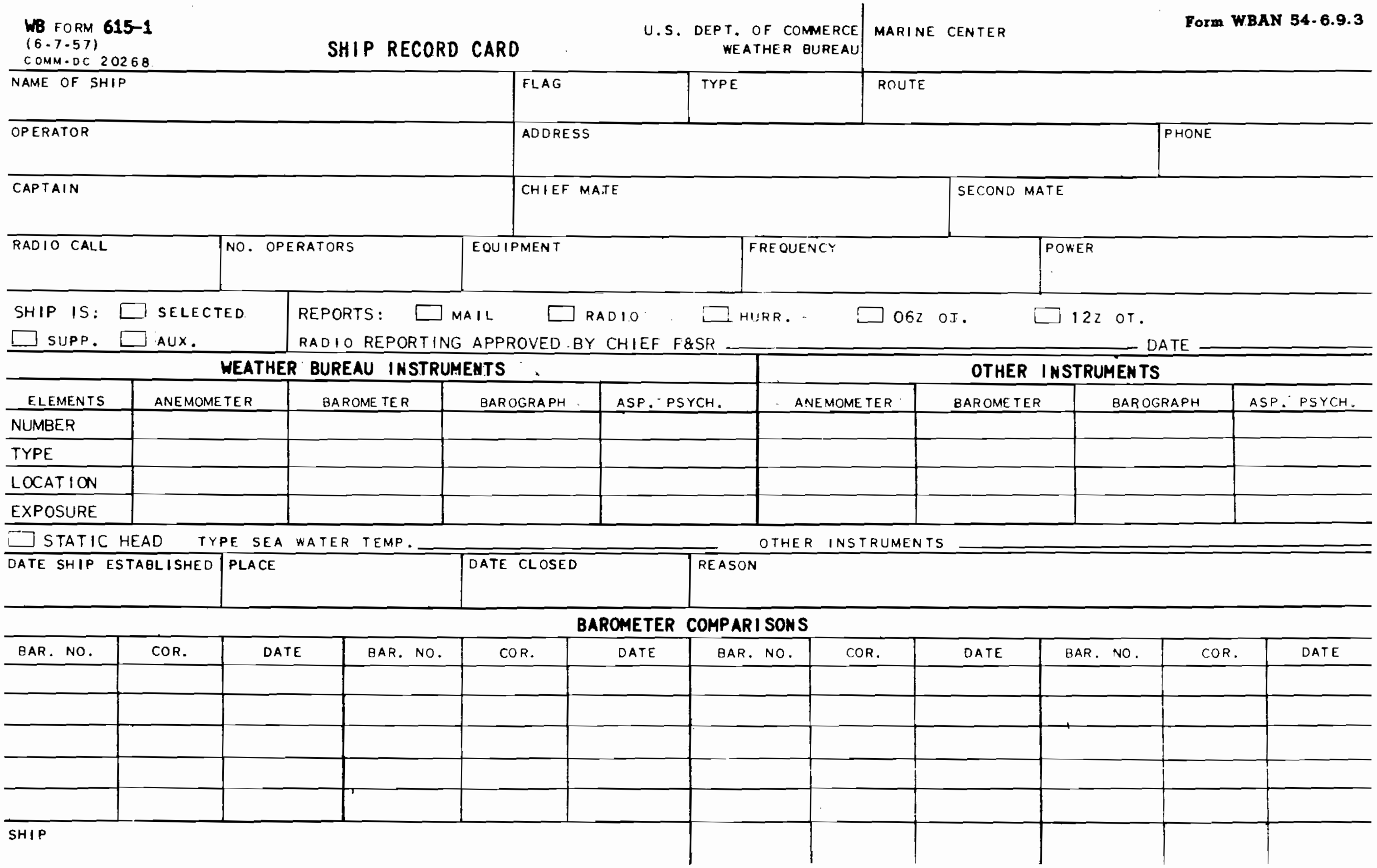
TEMP. (°F) (6)	COMP. Unc. (7)	STD. Cor. (8)	SHIP BARO. (9)	CORR. (Col. 8-9) (10)
(rm)				
50				
30				
(rm)				
90				
105				
(rm)				

HYSTERESIS
(for calibarometer tests only)

COMP. STD (11)	SHIP BARO. (12)	CORR. (13) (Col. 11-12)
DOWN SCALE 29.00		(a)
UP SCALE 29.00		(b)
	DIFFERENCE (a - b)	

Commerce-Weather Bureau, Washington, D. C.

FIGURE 13.6.8. Form WBAN 54–6.9.2, "Comparative Barometer Readings (Marine Cooperative)." (Reduced to 90% of original dimensions.)



WB FORM 615-1
(6-7-57)
COMM-DC 20268

SHIP RECORD CARD

U.S. DEPT. OF COMMERCE
WEATHER BUREAU

MARINE CENTER

Form WBAN 54-6.9.3

NAME OF SHIP	FLAG	TYPE	ROUTE

OPERATOR	ADDRESS	PHONE
CAPTAIN	CHIEF MATE	SECOND MATE

RADIO CALL	NO. OPERATORS	EQUIPMENT	FREQUENCY	POWER

SHIP IS: ☐ SELECTED ☐ SUPP. ☐ AUX.

REPORTS: ☐ MAIL ☐ RADIO ☐ HURR. ☐ 06Z OT. ☐ 12Z OT.

RADIO REPORTING APPROVED BY CHIEF F&SR ________ DATE ________

	WEATHER BUREAU INSTRUMENTS				OTHER INSTRUMENTS			
ELEMENTS	ANEMOMETER	BAROMETER	BAROGRAPH	ASP. PSYCH.	ANEMOMETER	BAROMETER	BAROGRAPH	ASP. PSYCH.
NUMBER								
TYPE								
LOCATION								
EXPOSURE								

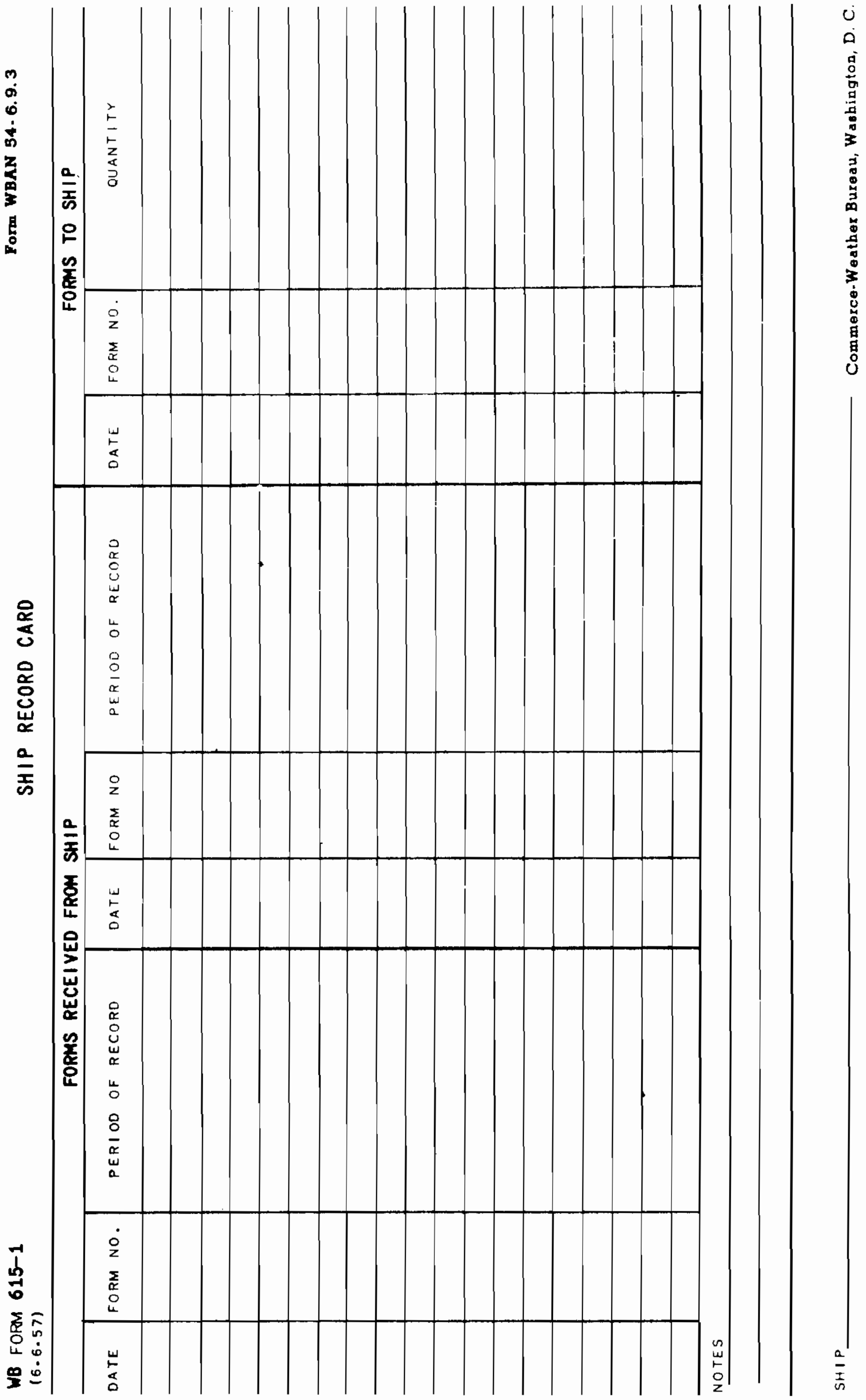
☐ STATIC HEAD TYPE SEA WATER TEMP. ________ OTHER INSTRUMENTS ________

DATE SHIP ESTABLISHED	PLACE	DATE CLOSED	REASON

BAROMETER COMPARISONS

BAR. NO.	COR.	DATE	BAR. NO.	COR.	DATE	BAR. NO.	COR.	DATE	BAR. NO.	COR.	DATE
SHIP											

FIGURE 13.6.9. Face of Form WBAN 54-6.9.3, "Ship Record Card." (Full size.)



WB FORM 615-1
(6-6-57)

Form WBAN 54-6.9.3

SHIP RECORD CARD

FORMS RECEIVED FROM SHIP						FORMS TO SHIP		
DATE	FORM NO.	PERIOD OF RECORD	DATE	FORM NO	PERIOD OF RECORD	DATE	FORM NO.	QUANTITY

NOTES

SHIP ______________________

Commerce-Weather Bureau, Washington, D. C.

FIGURE 13.6.10. Reverse of Form WBAN 54-6.9.3, "Ship Record Card." (Full size.)

Form WBAN 54-7.1

7.1, p. 1 of 2

PRESSURE REDUCTION COMPUTATIONS

Computation of (A) vapor pressure (e_s); (B) correction for plateau effect and local lapse rate anomaly, $F(t_s)$; and (C) mean virtual temperature (T_{mv}); as functions of station temperature argument, t_s.

1. Name of station ______________ 2. Latitude, ϕ = ________ Longitude, λ = ________

3. Geopotential of station, H_{pg} = ______________ gpm.

4. Annual normal temperature of station, t_{sn} = ________ °F. **(See Table 7.1.2 or 7.1.3 and Figure 7.2.0).**

(A) Tabular values represent vapor pressure, e_s (in mb.) as functions of t_s.

No.	Name of Humidity Point-of-Departure Station	Station temperature argument, t_s, °Fahrenheit								
		-60°	-50°	-40°	-30°	-20°	-10°	0°	+10°	+20°
(1)		mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
(2)										
(3)										
(4)	Sum									
(5)	Mean e_s									

Use data from line (5) in obtaining line (b) of (C) below.

(B) Tabular values represent $F(t_s)$, the correction for plateau effect and local lapse rate anomaly, as a function of t_s. (See Instructions, section 7.2 of Manual.)

	Names of "point-of-departure stations" for $F(t_s)$	Station temperature argument, t_s, °Fahrenheit								
		-60°	-50°	-40°	-30°	-20°	-10°	0°	+10°	+20°
(a)										
(b)										
(c)										
(d)										
(e)	Algebraic sum									
(f)	Mean = $F(t_s)$ for station									

Transfer data from line (f) to line (d) of (C) below.

(C) Computation of T_{mv} = mean virtual temperature (°Rankine).

Obtain data for line (b) from Table 7.3 as a function of H_{pg} and e_s (see line 5 of A above).

Line	Description	Station temperature argument, t_s, °Fahrenheit								
		-60°	-50°	-40°	-30°	-20°	-10°	0°	+10°	+20°
(a)	$459.7 + t_s$	399.7	409.7	419.7	429.7	439.7	449.7	459.7	469.7	479.7
(b)	$aH_{pg}/2 + e_sC_h$									
(c)	Algebraic sum of (a) and (b)									
(d)	$F(t_s)$									
(e)	T_{mv} = algebraic sum of (c) and (d)									

FIGURE 13.7.1. Form WBAN 54–7.1 (p. 1 of 2), "Pressure Reduction Computations. Computation of (A) vapor pressure (e_s); (B) correction for plateau effect and local lapse rate anomaly, $F(t_s)$; and (C) mean virtual temperature (T_{mv}); as functions of station temperature argument, t_s." (Full size.)

Form WBAN 54-7.1

7.1, p. 2 of 2

PRESSURE REDUCTION COMPUTATIONS

Computation of (A) vapor pressure (e_s); (B) correction for plateau effect and local lapse rate anomaly, $F(t_s)$; and (C) mean virtual temperature (T_{mv}); as functions of station temperature argument, t_s.

1. **Name** of station ______________________ 2. Latitude, ϕ = __________ Longitude, λ = __________

3. Geopotential of station, H_{pg} = ______________ gpm.

4. Annual normal temperature of station, t_{sn} = ________ °F. (See Table 7.1.2 or 7.1.3 and Figure 7.2.0).

(A) Tabular values represent vapor pressure, e_s (in mb.) as functions of t_s.

No.	Name of Humidity Point-of-Departure Station	Station temperature argument, t_s, °Fahrenheit								
		+30°	+40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°
(1)		mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
(2)										
(3)										
(4)	Sum									
(5)	Mean e_s									

Use data from line (5) in obtaining line (b) of (C) below.

(B) Tabular values represent $F(t_s)$, the correction for plateau effect and local lapse rate anomaly, as a function of t_s. (See Instructions, section 7.2 of Manual.)

	Names of "point-of-departure stations" for $F(t_s)$	Station temperature argument, t_s, °Fahrenheit								
		+30°	+40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°
(a)										
(b)										
(c)										
(d)										
(e)	Algebraic sum									
(f)	Mean = $F(t_s)$ for station									

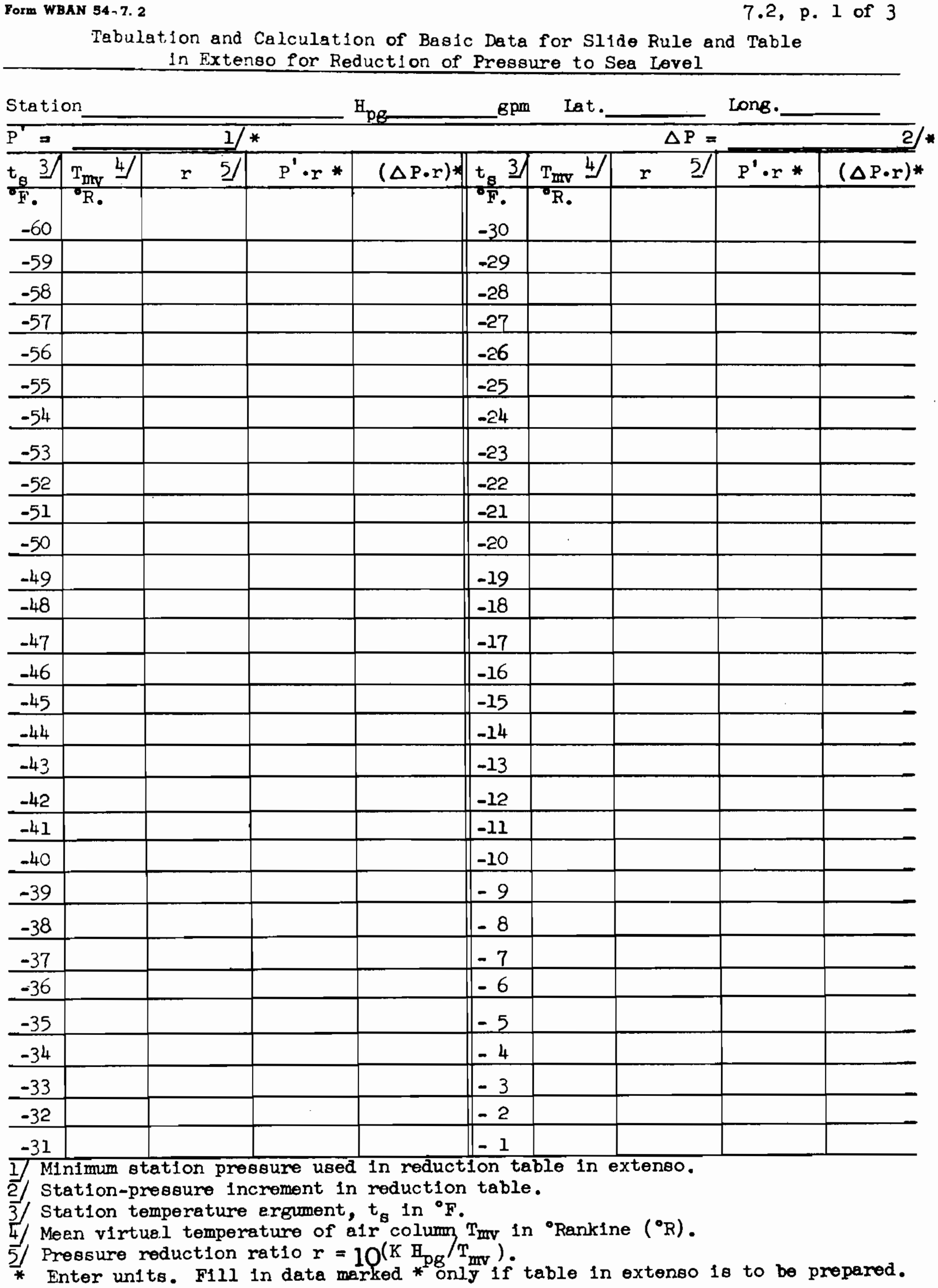
Transfer data from line (f) to line (d) of (C) below.

(C) Computation of T_{mv} = mean virtual temperature (°Rankine).

Obtain data for line (b) from Table 7.3 as a function of H_{pg} and e_s (see line 5 of A above).

Line	Description	Station temperature argument, t_s, °Fahrenheit								
		+30°	+40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°
(a)	$459.7 + t_s$	489.7	499.7	509.7	519.7	529.7	539.7	549.7	559.7	569.7
(b)	$aH_{pg}/2 + e_s C_h$									
(c)	Algebraic sum of (a) and (b)									
(d)	$F(t_s)$									
(e)	T_{mv} = algebraic sum of (c) and (d)									

FIGURE 13.7.2. Form WBAN 54–7.1 (p. 2 of 2), "Pressure Reduction Computations. Computation of (A) vapor pressure (e_s); (B) correction for plateau effect and local lapse rate anomaly, $F(t_s)$; and (C) mean virtual temperature (T_{mv}); as functions of station temperature argument, t_s." (Full size.)



Form WBAN 54-7. 2

7.2, p. 1 of 3

Tabulation and Calculation of Basic Data for Slide Rule and Table in Extenso for Reduction of Pressure to Sea Level

Station____________ H_{pg}________gpm Lat._______ Long._______

P' = ____________ 1/* ΔP = ____________ 2/*

t_s 3/ °F.	T_{mv} 4/ °R.	r 5/	P'·r *	(ΔP·r)*	t_s 3/ °F.	T_{mv} 4/ °R.	r 5/	P'·r *	(ΔP·r)*
-60					-30				
-59					-29				
-58					-28				
-57					-27				
-56					-26				
-55					-25				
-54					-24				
-53					-23				
-52					-22				
-51					-21				
-50					-20				
-49					-19				
-48					-18				
-47					-17				
-46					-16				
-45					-15				
-44					-14				
-43					-13				
-42					-12				
-41					-11				
-40					-10				
-39					- 9				
-38					- 8				
-37					- 7				
-36					- 6				
-35					- 5				
-34					- 4				
-33					- 3				
-32					- 2				
-31					- 1				

1/ Minimum station pressure used in reduction table in extenso.

2/ Station-pressure increment in reduction table.

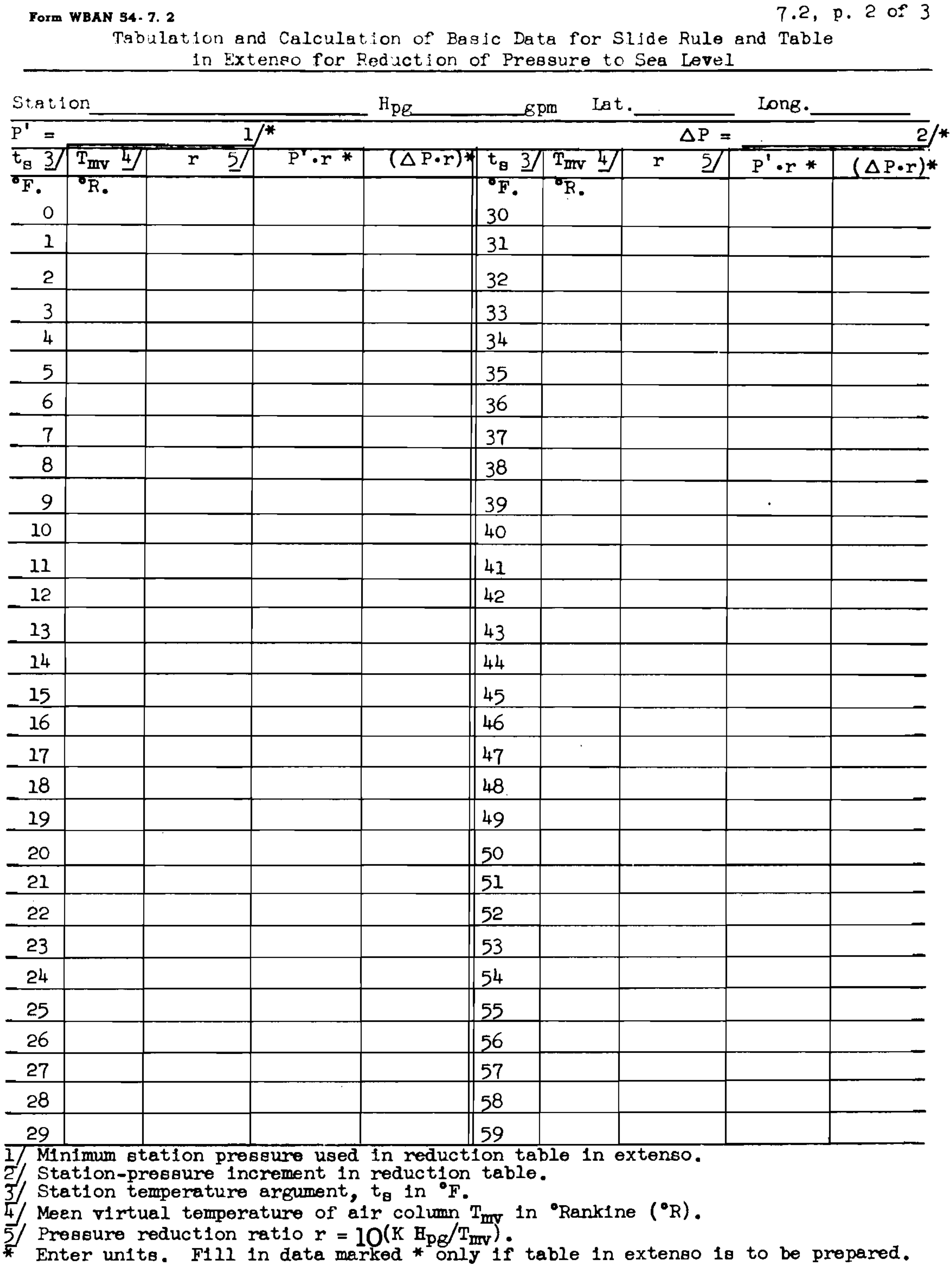
3/ Station temperature argument, t_s in °F.

4/ Mean virtual temperature of air column T_{mv} in °Rankine (°R).

5/ Pressure reduction ratio $r = 10^{(K\,H_{pg}/T_{mv})}$.

* Enter units. Fill in data marked * only if table in extenso is to be prepared.

FIGURE 13.7.3. Form WBAN 54–7.2 (p. 1 of 3), "Tabulation and Calculation of Basic Data for Slide Rule and Table in Extenso for Reduction of Pressure to Sea Level." (Reduced to 90% of original dimensions.)



Form WBAN 54-7. 2

7.2, p. 2 of 3

Tabulation and Calculation of Basic Data for Slide Rule and Table in Extenso for Reduction of Pressure to Sea Level

Station__________ H_{pg}________gpm Lat.________ Long.________

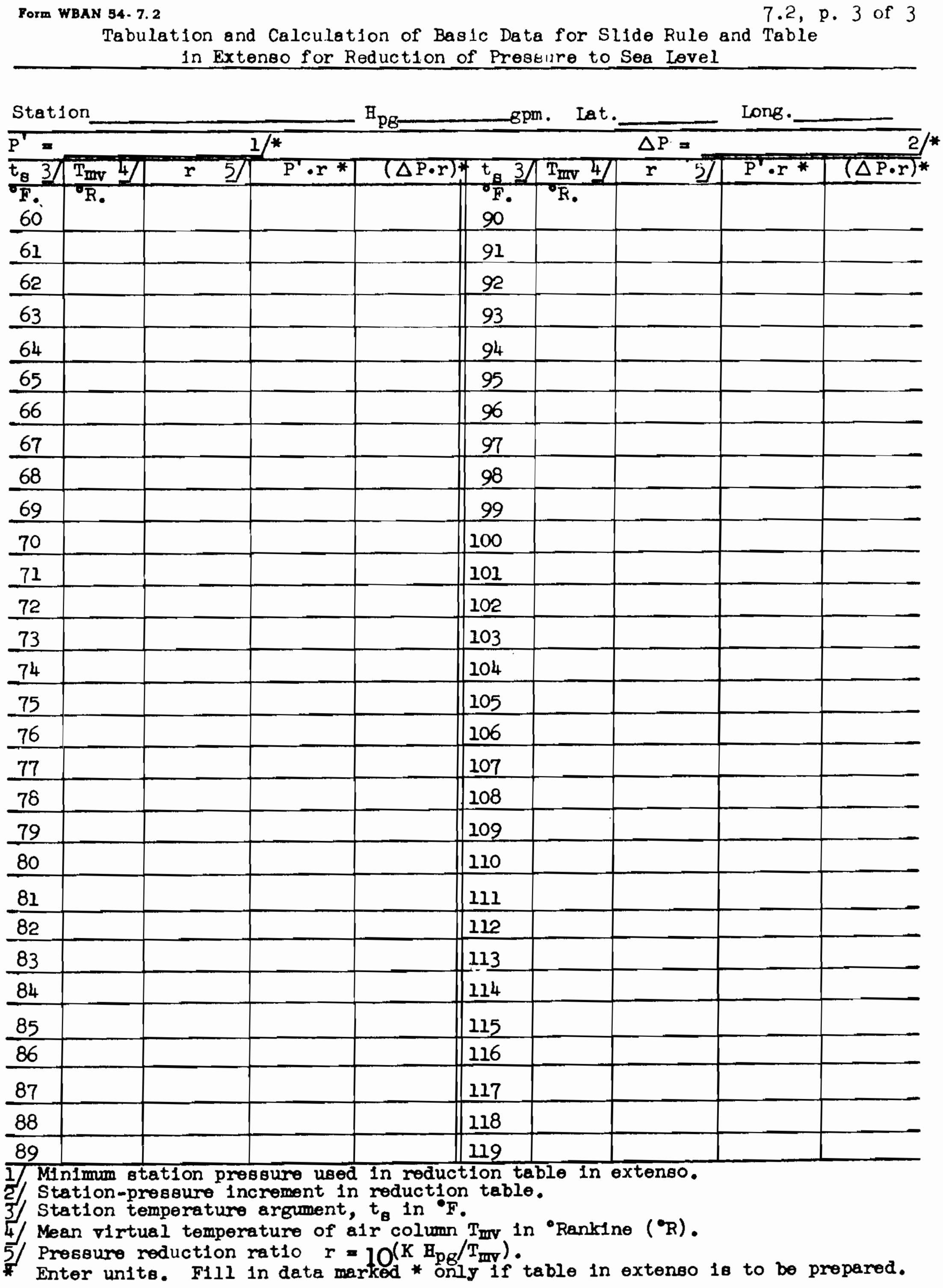
P' = ________ 1/*

ΔP = ________ 2/*

t_s 3/	T_{mv} 4/	r 5/	P'·r *	(ΔP·r)*	t_s 3/	T_{mv} 4/	r 5/	P'·r *	(ΔP·r)*
°F.	°R.				°F.	°R.			
0					30				
1					31				
2					32				
3					33				
4					34				
5					35				
6					36				
7					37				
8					38				
9					39				
10					40				
11					41				
12					42				
13					43				
14					44				
15					45				
16					46				
17					47				
18					48				
19					49				
20					50				
21					51				
22					52				
23					53				
24					54				
25					55				
26					56				
27					57				
28					58				
29					59				

1/ Minimum station pressure used in reduction table in extenso.
2/ Station-pressure increment in reduction table.
3/ Station temperature argument, t_s in °F.
4/ Mean virtual temperature of air column T_{mv} in °Rankine (°R).
5/ Pressure reduction ratio $r = 10^{(K\, H_{pg}/T_{mv})}$.
* Enter units. Fill in data marked * only if table in extenso is to be prepared.

FIGURE 13.7.4. Form WBAN 54–7.2 (p. 2 of 3), "Tabulation and Calculation of Basic Data for Slide Rule and Table in Extenso for Reduction of Pressure to Sea Level." (Reduced to 90% of original dimensions.)



Form WBAN 54-7.2

7.2, p. 3 of 3

Tabulation and Calculation of Basic Data for Slide Rule and Table in Extenso for Reduction of Pressure to Sea Level

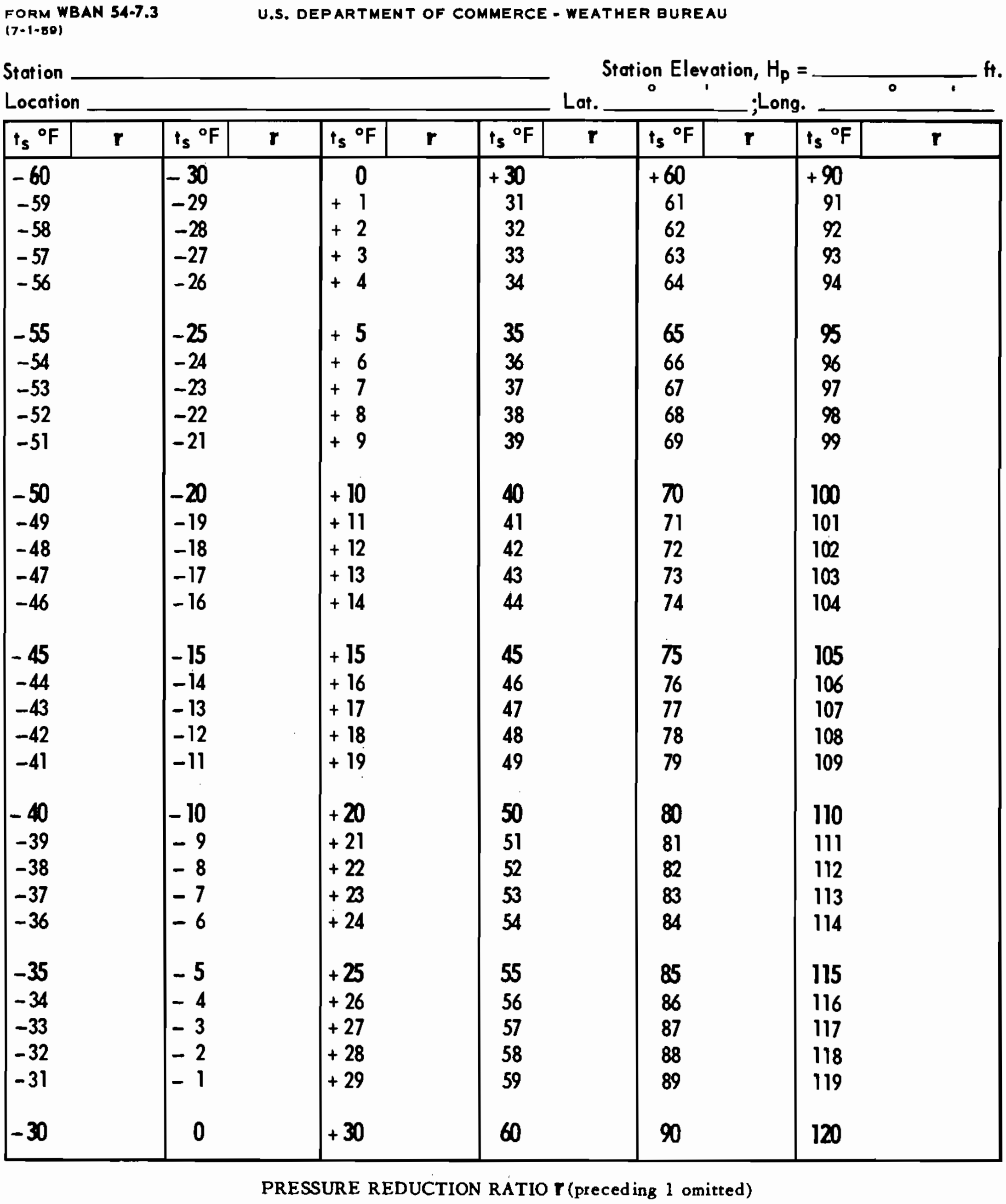
Station__________ H_{pg}______gpm. Lat.______ Long.______

P' = ______ 1/* ΔP = ______ 2/*

t_s 3/ °F.	T_{mv} 4/ °R.	r 5/	P'.r *	(ΔP.r)*	t_s 3/ °F.	T_{mv} 4/ °R.	r 5/	P'.r *	(ΔP.r)*
60					90				
61					91				
62					92				
63					93				
64					94				
65					95				
66					96				
67					97				
68					98				
69					99				
70					100				
71					101				
72					102				
73					103				
74					104				
75					105				
76					106				
77					107				
78					108				
79					109				
80					110				
81					111				
82					112				
83					113				
84					114				
85					115				
86					116				
87					117				
88					118				
89					119				

1/ Minimum station pressure used in reduction table in extenso.
2/ Station-pressure increment in reduction table.
3/ Station temperature argument, t_s in °F.
4/ Mean virtual temperature of air column T_{mv} in °Rankine (°R).
5/ Pressure reduction ratio $r = 10^{(K\,H_{pg}/T_{mv})}$.
* Enter units. Fill in data marked * only if table in extenso is to be prepared.

FIGURE 13.7.5. Form WBAN 54–7.2 (p. 3 of 3), "Tabulation and Calculation of Basic Data for Slide Rule and Table in Extenso for Reduction of Pressure to Sea Level." (Reduced to 90% of original dimensions.)



FORM WBAN 54-7.3
(7-1-59)

U.S. DEPARTMENT OF COMMERCE - WEATHER BUREAU

Station ______________________ Station Elevation, H_p = ____________ ft.

Location ______________________ Lat. ______ ° ' ;Long. ______ ° '

t_s °F	r	t_s °F	r	t_s °F	r	t_s °F	r	t_s °F	r	t_s °F	r
-60		-30		0		+30		+60		+90	
-59		-29		+ 1		31		61		91	
-58		-28		+ 2		32		62		92	
-57		-27		+ 3		33		63		93	
-56		-26		+ 4		34		64		94	
-55		-25		+ 5		35		65		95	
-54		-24		+ 6		36		66		96	
-53		-23		+ 7		37		67		97	
-52		-22		+ 8		38		68		98	
-51		-21		+ 9		39		69		99	
-50		-20		+10		40		70		100	
-49		-19		+11		41		71		101	
-48		-18		+12		42		72		102	
-47		-17		+13		43		73		103	
-46		-16		+14		44		74		104	
-45		-15		+15		45		75		105	
-44		-14		+16		46		76		106	
-43		-13		+17		47		77		107	
-42		-12		+18		48		78		108	
-41		-11		+19		49		79		109	
-40		-10		+20		50		80		110	
-39		- 9		+21		51		81		111	
-38		- 8		+22		52		82		112	
-37		- 7		+23		53		83		113	
-36		- 6		+24		54		84		114	
-35		- 5		+25		55		85		115	
-34		- 4		+26		56		86		116	
-33		- 3		+27		57		87		117	
-32		- 2		+28		58		88		118	
-31		- 1		+29		59		89		119	
-30		0		+30		60		90		120	

PRESSURE REDUCTION RATIO **r** (preceding 1 omitted)

FIGURE 13.7.6. Form WBAN 54–7.3, "Pressure Reduction Ratio (*r*)." (Reduced to 90% of original dimensions.)

Form WBAN 54-7.4

PRESSURE REDUCTION COMPUTATIONS

Calculation, by Successive Additions, of Pressure Reduced to Sea Level (P_o) for Reduction Table in Extenso, giving P_o as a Function of Station Temperature Argument (t_s) and Station Pressure (P).

(1) Name of Station ______________________ (2) Geopotential of station, H_{pg} = ______________ gpm.

(3) t_s = __________ °F.; (4) P′r = __________ (   ) Unit; (5) (ΔP·r) = __________ (   ) Unit

Definitions: P′ = minimum station pressure in table. ΔP = station-pressure increment in table. r = pressure reduction ratio, $10^{(K H_{pg}/T_{mv})}$, corresponding to H_{pg} and t_s.

No. of increment n	Station Pressure P=P′+ΔP·n	Calculation of sea-level pressure P_o=P·r=(P′r)+(ΔP·r)·n	No. of increment n	Station Pressure P=P′+ΔP·n	Calculation of sea-level pressure P_o=P·r=(P′r)+(ΔP·r)·n	No. of increment n	Station Pressure P=P′+ΔP·n	Calculation of sea-level pressure P_o=P·r=(P′r)+(ΔP·r)·n
0	P′ =	P′r =	15		Previous sub-total	30		Previous sub-total
1		ΔP·r sub-total	16		ΔP·r sub-total	31		ΔP·r sub-total
2		ΔP·r sub-total	17		ΔP·r sub-total	32		ΔP·r sub-total
3		ΔP·r sub-total	18		ΔP·r sub-total	33		ΔP·r sub-total
4		ΔP·r sub-total	19		ΔP·r sub-total	34		ΔP·r sub-total
5		ΔP·r sub-total	20		ΔP·r sub-total	35		ΔP·r sub-total
6		ΔP·r sub-total	21		ΔP·r sub-total	36		ΔP·r sub-total
7		ΔP·r sub-total	22		ΔP·r sub-total	37		ΔP·r sub-total
8		ΔP·r sub-total	23		ΔP·r sub-total	38		ΔP·r sub-total
9		ΔP·r sub-total	24		ΔP·r sub-total	39		ΔP·r sub-total
10		ΔP·r sub-total	25		ΔP·r sub-total	40		ΔP·r sub-total
11		ΔP·r sub-total	26		ΔP·r sub-total	41		ΔP·r sub-total
12		ΔP·r sub-total	27		ΔP·r sub-total	42		ΔP·r sub-total
13		ΔP·r sub-total	28		ΔP·r sub-total	43		ΔP·r sub-total
14		ΔP·r sub-total	29		ΔP·r sub-total	44		ΔP·r sub-total
15		ΔP·r sub-total	30		ΔP·r sub-total	45		ΔP·r sub-total

FIGURE 13.7.7. Form WBAN 54–7.4, "Pressure Reduction Computations. Calculation, by Successive Additions, of Pressure Reduced to Sea Level (P_o) for Reduction Table in Extenso, giving P_o as a function of Station Temperature Argument (t_s) and Station Pressure (P)." (Reduced to 90% of original dimensions.)

CHAPTER 14

TABLES

TABLE 1.3.1

Feet Converted to Meters

[Conversion factor: 1 foot = 0.3048 meter]

(a) Hundreds of feet converted to meters

Feet	0	100	200	300	400	500	600	700	800	900
	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.
0	0	30.48	60.96	91.44	121.92	152.40	182.88	213.36	243.84	274.32
1000	304.80	335.28	365.76	396.24	426.72	457.20	487.68	518.16	548.64	579.12
2000	609.60	640.08	670.56	701.04	731.52	762.00	792.48	822.96	853.44	883.92
3000	914.40	944.88	975.36	1005.84	1036.32	1066.80	1097.28	1127.76	1158.24	1188.72
4000	1219.20	1249.68	1280.16	1310.64	1341.12	1371.60	1402.08	1432.56	1463.04	1493.52
5000	1524.00	1554.48	1584.96	1615.44	1645.92	1676.40	1706.88	1737.36	1767.84	1798.32
6000	1828.80	1859.28	1889.76	1920.24	1950.72	1981.20	2011.68	2042.16	2072.64	2103.12
7000	2133.60	2164.08	2194.56	2225.04	2255.52	2286.00	2316.48	2346.96	2377.44	2407.92
8000	2438.40	2468.88	2499.36	2529.84	2560.32	2590.80	2621.28	2651.76	2682.24	2712.72
9000	2743.20	2773.68	2804.16	2834.64	2865.12	2895.60	2926.08	2956.56	2987.04	3017.52
10000	3048.00	3078.48	3108.96	3139.44	3169.92	3200.40	3230.88	3261.36	3291.84	3322.32

(b) Tens and units of feet converted to meters

Feet	0	1	2	3	4	5	6	7	8	9
	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.
0	0	0.30	0.61	0.91	1.22	1.52	1.83	2.13	2.44	2.74
10	3.05	3.35	3.66	3.96	4.27	4.57	4.88	5.18	5.49	5.79
20	6.10	6.40	6.71	7.01	7.32	7.62	7.92	8.23	8.53	8.84
30	9.14	9.45	9.75	10.06	10.36	10.67	10.97	11.28	11.58	11.89
40	12.19	12.50	12.80	13.11	13.41	13.72	14.02	14.33	14.63	14.94
50	15.24	15.54	15.85	16.15	16.46	16.76	17.07	17.37	17.68	17.98
60	18.29	18.59	18.90	19.20	19.51	19.81	20.12	20.42	20.73	21.03
70	21.34	21.64	21.95	22.25	22.56	22.86	23.16	23.47	23.77	24.08
80	24.38	24.69	24.99	25.30	25.60	25.91	26.21	26.52	26.82	27.13
90	27.43	27.74	28.04	28.35	28.65	28.96	29.26	29.57	29.87	30.18

(c) Tenths of feet converted to meters

Feet	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	m.	m.	m.	m.	m.	m.	m.	m.	m.
Meters	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27

TABLE 1.3.2

Gravity Factor, $(g_{\phi,o}/9.8)$

Latitude, degrees	$(g_{\phi,o}/9.8)$	Latitude, degrees	$(g_{\phi,o}/9.8)$	Latitude, degrees	$(g_{\phi,o}/9.8)$
0	0.99800	30	0.99931	60	1.00195
1	.99800	31	.99939	61	1.00203
2	.99800	32	.99947	62	1.00211
3	.99801	33	.99956	63	1.00218
4	.99802	34	.99964	64	1.00225
5	.99804	35	.99973	65	1.00233
6	.99805	36	.99981	66	1.00240
7	.99807	37	.99990	67	1.00246
8	.99810	38	.99999	68	1.00253
9	.99812	39	1.00008	69	1.00259
10	.99815	40	1.00017	70	1.00265
11	.99819	41	1.00026	71	1.00271
12	.99822	42	1.00035	72	1.00277
13	.99826	43	1.00044	73	1.00282
14	.99830	44	1.00054	74	1.00287
15	.99835	45	1.00063	75	1.00292
16	.99839	46	1.00072	76	1.00296
17	.99844	47	1.00081	77	1.00300
18	.99850	48	1.00090	78	1.00304
19	.99855	49	1.00100	79	1.00308
20	.99861	50	1.00109	80	1.00311
21	.99867	51	1.00118	81	1.00314
22	.99873	52	1.00127	82	1.00317
23	.99880	53	1.00136	83	1.00319
24	.99887	54	1.00144	84	1.00322
25	.99894	55	1.00153	85	1.00323
26	.99901	56	1.00162	86	1.00325
27	.99908	57	1.00170	87	1.00326
28	.99915	58	1.00179	88	1.00327
29	.99923	59	1.00187	89	1.00327
				90	1.00327

TABLE 1.3.3

Altitude Correction Applicable to First Term of Geopotential Formula, $0.0000001574\ H_p^2$ *as a Function of* H_p

Station elevation H_p meters	Altitude correction $0.0000001574\ H_p^2$ gpm.	Station elevation H_p meters	Altitude correction $0.0000001574\ H_p^2$ gpm.	Station elevation H_p meters	Altitude correction $0.0000001574\ H_p^2$ gpm.
0	0	1000	0.16	2000	0.63
100	0.00	1100	.19	2100	.69
200	.01	1200	.23	2200	.76
300	.01	1300	.27	2300	.83
400	.03	1400	.31	2400	.91
500	.04	1500	.35	2500	.98
600	.06	1600	.40	2600	1.06
700	.08	1700	.45	2700	1.15
800	.10	1800	.51	2800	1.23
900	.13	1900	.57	2900	1.32
				3000	1.42

TABLE 1.4.1

Inches of Mercury to Millibars

[1 inch of mercury = 33.86389 millibars.]

In. Hg	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
0.00	0.00	0.34	0.68	1.02	1.35	1.69	2.03	2.37	2.71	3.05
.10	3.39	3.73	4.06	4.40	4.74	5.08	5.42	5.76	6.10	6.43
.20	6.77	7.11	7.45	7.79	8.13	8.47	8.80	9.14	9.48	9.82
.30	10.16	10.50	10.84	11.18	11.51	11.85	12.19	12.53	12.87	13.21
.40	13.55	13.88	14.22	14.56	14.90	15.24	15.58	15.92	16.25	16.59
0.50	16.93	17.27	17.61	17.95	18.29	18.63	18.96	19.30	19.64	19.98
.60	20.32	20.66	21.00	21.33	21.67	22.01	22.35	22.69	23.03	23.37
.70	23.70	24.04	24.38	24.72	25.06	25.40	25.74	26.08	26.41	26.75
.80	27.09	27.43	27.77	28.11	28.45	28.78	29.12	29.46	29.80	30.14
.90	30.48	30.82	31.15	31.49	31.83	32.17	32.51	32.85	33.19	33.53
1.00	33.86	34.20	34.54	34.88	35.22	35.56	35.90	36.23	36.57	36.91
1.10	37.25	37.59	37.93	38.27	38.60	38.94	39.28	39.62	39.96	40.30
1.20	40.64	40.98	41.31	41.65	41.99	42.33	42.67	43.01	43.35	43.68
1.30	44.02	44.36	44.70	45.04	45.38	45.72	46.05	46.39	46.73	47.07
1.40	47.41	47.75	48.09	48.43	48.76	49.10	49.44	49.78	50.12	50.46
1.50	50.80	51.13	51.47	51.81	52.15	52.49	52.83	53.17	53.50	53.84
1.60	54.18	54.52	54.86	55.20	55.54	55.88	56.21	56.55	56.89	57.23
1.70	57.57	57.91	58.25	58.58	58.92	59.26	59.60	59.94	60.28	60.62
1.80	60.96	61.29	61.63	61.97	62.31	62.65	62.99	63.33	63.66	64.00
1.90	64.34	64.68	65.02	65.36	65.70	66.03	66.37	66.71	67.05	67.39
2.00	67.73	68.07	68.41	68.74	69.08	69.42	69.76	70.10	70.44	70.78
2.10	71.11	71.45	71.79	72.13	72.47	72.81	73.15	73.48	73.82	74.16
2.20	74.50	74.84	75.18	75.52	75.86	76.19	76.53	76.87	77.21	77.55
2.30	77.89	78.23	78.56	78.90	79.24	79.58	79.92	80.26	80.60	80.93
2.40	81.27	81.61	81.95	82.29	82.63	82.97	83.31	83.64	83.98	84.32
2.50	84.66	85.00	85.34	85.68	86.01	86.35	86.69	87.03	87.37	87.71
2.60	88.05	88.38	88.72	89.06	89.40	89.74	90.08	90.42	90.76	91.09
2.70	91.43	91.77	92.11	92.45	92.79	93.13	93.46	93.80	94.14	94.48
2.80	94.82	95.16	95.50	95.83	96.17	96.51	96.85	97.19	97.53	97.87
2.90	98.21	98.54	98.88	99.22	99.56	99.90	100.24	100.58	100.91	101.25
3.00	101.59	101.93	102.27	102.61	102.95	103.28	103.62	103.96	104.30	104.64
3.10	104.98	105.32	105.66	105.99	106.33	106.67	107.01	107.35	107.69	108.03
3.20	108.36	108.70	109.04	109.38	109.72	110.06	110.40	110.73	111.07	111.41
3.30	111.75	112.09	112.43	112.77	113.11	113.44	113.78	114.12	114.46	114.80
3.40	115.14	115.48	115.81	116.15	116.49	116.83	117.17	117.51	117.85	118.18
3.50	118.52	118.86	119.20	119.54	119.88	120.22	120.56	120.89	121.23	121.57
3.60	121.91	122.25	122.59	122.93	123.26	123.60	123.94	124.28	124.62	124.96
3.70	125.30	125.64	125.97	126.31	126.65	126.99	127.33	127.67	128.01	128.34
3.80	128.68	129.02	129.36	129.70	130.04	130.38	130.71	131.05	131.39	131.73
3.90	132.07	132.41	132.75	133.09	133.42	133.76	134.10	134.44	134.78	135.12
4.00	135.46	135.79	136.13	136.47	136.81	137.15	137.49	137.83	138.16	138.50
4.10	138.84	139.18	139.52	139.86	140.20	140.54	140.87	141.21	141.55	141.89
4.20	142.23	142.57	142.91	143.24	143.58	143.92	144.26	144.60	144.94	145.28
4.30	145.61	145.95	146.29	146.63	146.97	147.31	147.65	147.99	148.32	148.66
4.40	149.00	149.34	149.68	150.02	150.36	150.69	151.03	151.37	151.71	152.05
4.50	152.39	152.73	153.06	153.40	153.74	154.08	154.42	154.76	155.10	155.44
4.60	155.77	156.11	156.45	156.79	157.13	157.47	157.81	158.14	158.48	158.82
4.70	159.16	159.50	159.84	160.18	160.51	160.85	161.19	161.53	161.87	162.21
4.80	162.55	162.89	163.22	163.56	163.90	164.24	164.58	164.92	165.26	165.59
4.90	165.93	166.27	166.61	166.95	167.29	167.63	167.96	168.30	168.64	168.98
5.00	169.32	169.66	170.00	170.34	170.67	171.01	171.35	171.69	172.03	172.37

(continued)

Proportional parts										
	in. Hg	.001	.002	.003	.004	.005	.006	.007	.008	.009
	mb.	.03	.07	.10	.14	.17	.20	.24	.27	.30

TABLE 1.4.1 (CONTINUED)

Inches of Mercury to Millibars

[1 inch of mercury = 33.86389 millibars.]

In. Hg	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
5.00	169.32	169.66	170.00	170.34	170.67	171.01	171.35	171.69	172.03	172.37
5.10	172.71	173.04	173.38	173.72	174.06	174.40	174.74	175.08	175.41	175.75
5.20	176.09	176.43	176.77	177.11	177.45	177.79	178.12	178.46	178.80	179.14
5.30	179.48	179.82	180.16	180.49	180.83	181.17	181.51	181.85	182.19	182.53
5.40	182.87	183.20	183.54	183.88	184.22	184.56	184.90	185.24	185.57	185.91
5.50	186.25	186.59	186.93	187.27	187.61	187.94	188.28	188.62	188.96	189.30
5.60	189.64	189.98	190.32	190.65	190.99	191.33	191.67	192.01	192.35	192.69
5.70	193.02	193.36	193.70	194.04	194.38	194.72	195.06	195.39	195.73	196.07
5.80	196.41	196.75	197.09	197.43	197.77	198.10	198.44	198.78	199.12	199.46
5.90	199.80	200.14	200.47	200.81	201.15	201.49	201.83	202.17	202.51	202.84
6.00	203.18	203.52	203.86	204.20	204.54	204.88	205.22	205.55	205.89	206.23
6.10	206.57	206.91	207.25	207.59	207.92	208.26	208.60	208.94	209.28	209.62
6.20	209.96	210.29	210.63	210.97	211.31	211.65	211.99	212.33	212.67	213.00
6.30	213.34	213.68	214.02	214.36	214.70	215.04	215.37	215.71	216.05	216.39
6.40	216.73	217.07	217.41	217.74	218.08	218.42	218.76	219.10	219.44	219.78
6.50	220.12	220.45	220.79	221.13	221.47	221.81	222.15	222.49	222.82	223.16
6.60	223.50	223.84	224.18	224.52	224.86	225.19	225.53	225.87	226.21	226.55
6.70	226.89	227.23	227.57	227.90	228.24	228.58	228.92	229.26	229.60	229.94
6.80	230.27	230.61	230.95	231.29	231.63	231.97	232.31	232.64	232.98	233.32
6.90	233.66	234.00	234.34	234.68	235.02	235.35	235.69	236.03	236.37	236.71
7.00	237.05	237.39	237.72	238.06	238.40	238.74	239.08	239.42	239.76	240.09
7.10	240.43	240.77	241.11	241.45	241.79	242.13	242.47	242.80	243.14	243.48
7.20	243.82	244.16	244.50	244.84	245.17	245.51	245.85	246.19	246.53	246.87
7.30	247.21	247.55	247.88	248.22	248.56	248.90	249.24	249.58	249.92	250.25
7.40	250.59	250.93	251.27	251.61	251.95	252.29	252.62	252.96	253.30	253.64
7.50	253.98	254.32	254.66	255.00	255.33	255.67	256.01	256.35	256.69	257.03
7.60	257.37	257.70	258.04	258.38	258.72	259.06	259.40	259.74	260.07	260.41
7.70	260.75	261.09	261.43	261.77	262.11	262.45	262.78	263.12	263.46	263.80
7.80	264.14	264.48	264.82	265.15	265.49	265.83	266.17	266.51	266.85	267.19
7.90	267.52	267.86	268.20	268.54	268.88	269.22	269.56	269.90	270.23	270.57
8.00	270.91	271.25	271.59	271.93	272.27	272.60	272.94	273.28	273.62	273.96
8.10	274.30	274.64	274.97	275.31	275.65	275.99	276.33	276.67	277.01	277.35
8.20	277.68	278.02	278.36	278.70	279.04	279.38	279.72	280.05	280.39	280.73
8.30	281.07	281.41	281.75	282.09	282.42	282.76	283.10	283.44	283.78	284.12
8.40	284.46	284.80	285.13	285.47	285.81	286.15	286.49	286.83	287.17	287.50
8.50	287.84	288.18	288.52	288.86	289.20	289.54	289.87	290.21	290.55	290.89
8.60	291.23	291.57	291.91	292.25	292.58	292.92	293.26	293.60	293.94	294.28
8.70	294.62	294.95	295.29	295.63	295.97	296.31	296.65	296.99	297.32	297.66
8.80	298.00	298.34	298.68	299.02	299.36	299.70	300.03	300.37	300.71	301.05
8.90	301.39	301.73	302.07	302.40	302.74	303.08	303.42	303.76	304.10	304.44
9.00	304.78	305.11	305.45	305.79	306.13	306.47	306.81	307.15	307.48	307.82
9.10	308.16	308.50	308.84	309.18	309.52	309.85	310.19	310.53	310.87	311.21
9.20	311.55	311.89	312.23	312.56	312.90	313.24	313.58	313.92	314.26	314.60
9.30	314.93	315.27	315.61	315.95	316.29	316.63	316.97	317.30	317.64	317.98
9.40	318.32	318.66	319.00	319.34	319.68	320.01	320.35	320.69	321.03	321.37
9.50	321.71	322.05	322.38	322.72	323.06	323.40	323.74	324.08	324.42	324.75
9.60	325.09	325.43	325.77	326.11	326.45	326.79	327.13	327.46	327.80	328.14
9.70	328.48	328.82	329.16	329.50	329.83	330.17	330.51	330.85	331.19	331.53
9.80	331.87	332.20	332.54	332.88	333.22	333.56	333.90	334.24	334.58	334.91
9.90	335.25	335.59	335.93	336.27	336.61	336.95	337.28	337.62	337.96	338.30
10.00	338.64	338.98	339.32	339.65	339.99	340.33	340.67	341.01	341.35	341.69

(continued)

Proportional parts										
	in. Hg	.001	.002	.003	.004	.005	.006	.007	.008	.009
	mb.	.03	.07	.10	.14	.17	.20	.24	.27	.30

TABLE 1.4.1 (CONTINUED)

Inches of Mercury to Millibars

[1 inch of mercury = 33.86389 millibars.]

In. Hg	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
10.00	338.64	338.98	339.32	339.65	339.99	340.33	340.67	341.01	341.35	341.69
10.10	342.03	342.36	342.70	343.04	343.38	343.72	344.06	344.40	344.73	345.07
10.20	345.41	345.75	346.09	346.43	346.77	347.10	347.44	347.78	348.12	348.46
10.30	348.80	349.14	349.48	349.81	350.15	350.49	350.83	351.17	351.51	351.85
10.40	352.18	352.52	352.86	353.20	353.54	353.88	354.22	354.55	354.89	355.23
10.50	355.57	355.91	356.25	356.59	356.93	357.26	357.60	357.94	358.28	358.62
10.60	358.96	359.30	359.63	359.97	360.31	360.65	360.99	361.33	361.67	362.00
10.70	362.34	362.68	363.02	363.36	363.70	364.04	364.38	364.71	365.05	365.39
10.80	365.73	366.07	366.41	366.75	367.08	367.42	367.76	368.10	368.44	368.78
10.90	369.12	369.46	369.79	370.13	370.47	370.81	371.15	371.49	371.83	372.16
11.00	372.50	372.84	373.18	373.52	373.86	374.20	374.53	374.87	375.21	375.55
11.10	375.89	376.23	376.57	376.91	377.24	377.58	377.92	378.26	378.60	378.94
11.20	379.28	379.61	379.95	380.29	380.63	380.97	381.31	381.65	381.98	382.32
11.30	382.66	383.00	383.34	383.68	384.02	384.36	384.69	385.03	385.37	385.71
11.40	386.05	386.39	386.73	387.06	387.40	387.74	388.08	388.42	388.76	389.10
11.50	389.43	389.77	390.11	390.45	390.79	391.13	391.47	391.81	392.14	392.48
11.60	392.82	393.16	393.50	393.84	394.18	394.51	394.85	395.19	395.53	395.87
11.70	396.21	396.55	396.88	397.22	397.56	397.90	398.24	398.58	398.92	399.26
11.80	399.59	399.93	400.27	400.61	400.95	401.29	401.63	401.96	402.30	402.64
11.90	402.98	403.32	403.66	404.00	404.33	404.67	405.01	405.35	405.69	406.03
12.00	406.37	406.71	407.04	407.38	407.72	408.06	408.40	408.74	409.08	409.41
12.10	409.75	410.09	410.43	410.77	411.11	411.45	411.78	412.12	412.46	412.80
12.20	413.14	413.48	413.82	414.16	414.49	414.83	415.17	415.51	415.85	416.19
12.30	416.53	416.86	417.20	417.54	417.88	418.22	418.56	418.90	419.23	419.57
12.40	419.91	420.25	420.59	420.93	421.27	421.61	421.94	422.28	422.62	422.96
12.50	423.30	423.64	423.98	424.31	424.65	424.99	425.33	425.67	426.01	426.35
12.60	426.69	427.02	427.36	427.70	428.04	428.38	428.72	429.06	429.39	429.73
12.70	430.07	430.41	430.75	431.09	431.43	431.76	432.10	432.44	432.78	433.12
12.80	433.46	433.80	434.14	434.47	434.81	435.15	435.49	435.83	436.17	436.51
12.90	436.84	437.18	437.52	437.86	438.20	438.54	438.88	439.21	439.55	439.89
13.00	440.23	440.57	440.91	441.25	441.59	441.92	442.26	442.60	442.94	443.28
13.10	443.62	443.96	444.29	444.63	444.97	445.31	445.65	445.99	446.33	446.66
13.20	447.00	447.34	447.68	448.02	448.36	448.70	449.04	449.37	449.71	450.05
13.30	450.39	450.73	451.07	451.41	451.74	452.08	452.42	452.76	453.10	453.44
13.40	453.78	454.11	454.45	454.79	455.13	455.47	455.81	456.15	456.49	456.82
13.50	457.16	457.50	457.84	458.18	458.52	458.86	459.19	459.53	459.87	460.21
13.60	460.55	460.89	461.23	461.56	461.90	462.24	462.58	462.92	463.26	463.60
13.70	463.94	464.27	464.61	464.95	465.29	465.63	465.97	466.31	466.64	466.98
13.80	467.32	467.66	468.00	468.34	468.68	469.01	469.35	469.69	470.03	470.37
13.90	470.71	471.05	471.39	471.72	472.06	472.40	472.74	473.08	473.42	473.76
14.00	474.09	474.43	474.77	475.11	475.45	475.79	476.13	476.46	476.80	477.14
14.10	477.48	477.82	478.16	478.50	478.84	479.17	479.51	479.85	480.19	480.53
14.20	480.87	481.21	481.54	481.88	482.22	482.56	482.90	483.24	483.58	483.91
14.30	484.25	484.59	484.93	485.27	485.61	485.95	486.29	486.62	486.96	487.30
14.40	487.64	487.98	488.32	488.66	488.99	489.33	489.67	490.01	490.35	490.69
14.50	491.03	491.37	491.70	492.04	492.38	492.72	493.06	493.40	493.74	494.07
14.60	494.41	494.75	495.09	495.43	495.77	496.11	496.44	496.78	497.12	497.46
14.70	497.80	498.14	498.48	498.82	499.15	499.49	499.83	500.17	500.51	500.85
14.80	501.19	501.52	501.86	502.20	502.54	502.88	503.22	503.56	503.89	504.23
14.90	504.57	504.91	505.25	505.59	505.93	506.27	506.60	506.94	507.28	507.62
15.00	507.96	508.30	508.64	508.97	509.31	509.65	509.99	510.33	510.67	511.01

(continued)

Proportional parts	in. Hg	.001	.002	.003	.004	.005	.006	.007	.008	.009
	mb.	.03	.07	.10	.14	.17	.20	.24	.27	.30

TABLE 1.4.1 (CONTINUED)

Inches of Mercury to Millibars

[1 inch of mercury = 33.86389 millibars.]

In. Hg	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
15.00	507.96	508.30	508.64	508.97	509.31	509.65	509.99	510.33	510.67	511.01
15.10	511.34	511.68	512.02	512.36	512.70	513.04	513.38	513.72	514.05	514.39
15.20	514.73	515.07	515.41	515.75	516.09	516.42	516.76	517.10	517.44	517.78
15.30	518.12	518.46	518.79	519.13	519.47	519.81	520.15	520.49	520.83	521.17
15.40	521.50	521.84	522.18	522.52	522.86	523.20	523.54	523.87	524.21	524.55
15.50	524.89	525.23	525.57	525.91	526.24	526.58	526.92	527.26	527.60	527.94
15.60	528.28	528.62	528.95	529.29	529.63	529.97	530.31	530.65	530.99	531.32
15.70	531.66	532.00	532.34	532.68	533.02	533.36	533.69	534.03	534.37	534.71
15.80	535.05	535.39	535.73	536.07	536.40	536.74	537.08	537.42	537.76	538.10
15.90	538.44	538.77	539.11	539.45	539.79	540.13	540.47	540.81	541.14	541.48
16.00	541.82	542.16	542.50	542.84	543.18	543.52	543.85	544.19	544.53	544.87
16.10	545.21	545.55	545.89	546.22	546.56	546.90	547.24	547.58	547.92	548.26
16.20	548.60	548.93	549.27	549.61	549.95	550.29	550.63	550.97	551.30	551.64
16.30	551.98	552.32	552.66	553.00	553.34	553.67	554.01	554.35	554.69	555.03
16.40	555.37	555.71	556.05	556.38	556.72	557.06	557.40	557.74	558.08	558.42
16.50	558.75	559.09	559.43	559.77	560.11	560.45	560.79	561.12	561.46	561.80
16.60	562.14	562.48	562.82	563.16	563.50	563.83	564.17	564.51	564.85	565.19
16.70	565.53	565.87	566.20	566.54	566.88	567.22	567.56	567.90	568.24	568.57
16.80	568.91	569.25	569.59	569.93	570.27	570.61	570.95	571.28	571.62	571.96
16.90	572.30	572.64	572.98	573.32	573.65	573.99	574.33	574.67	575.01	575.35
17.00	575.69	576.02	576.36	576.70	577.04	577.38	577.72	578.06	578.40	578.73
17.10	579.07	579.41	579.75	580.09	580.43	580.77	581.10	581.44	581.78	582.12
17.20	582.46	582.80	583.14	583.47	583.81	584.15	584.49	584.83	585.17	585.51
17.30	585.85	586.18	586.52	586.86	587.20	587.54	587.88	588.22	588.55	588.89
17.40	589.23	589.57	589.91	590.25	590.59	590.92	591.26	591.60	591.94	592.28
17.50	592.62	592.96	593.30	593.63	593.97	594.31	594.65	594.99	595.33	595.67
17.60	596.00	596.34	596.68	597.02	597.36	597.70	598.04	598.37	598.71	599.05
17.70	599.39	599.73	600.07	600.41	600.75	601.08	601.42	601.76	602.10	602.44
17.80	602.78	603.12	603.45	603.79	604.13	604.47	604.81	605.15	605.49	605.82
17.90	606.16	606.50	606.84	607.18	607.52	607.86	608.20	608.53	608.87	609.21
18.00	609.55	609.89	610.23	610.57	610.90	611.24	611.58	611.92	612.26	612.60
18.10	612.94	613.28	613.61	613.95	614.29	614.63	614.97	615.31	615.65	615.98
18.20	616.32	616.66	617.00	617.34	617.68	618.02	618.35	618.69	619.03	619.37
18.30	619.71	620.05	620.39	620.73	621.06	621.40	621.74	622.08	622.42	622.76
18.40	623.10	623.43	623.77	624.11	624.45	624.79	625.13	625.47	625.80	626.14
18.50	626.48	626.82	627.16	627.50	627.84	628.18	628.51	628.85	629.19	629.53
18.60	629.87	630.21	630.55	630.88	631.22	631.56	631.90	632.24	632.58	632.92
18.70	633.25	633.59	633.93	634.27	634.61	634.95	635.29	635.63	635.96	636.30
18.80	636.64	636.98	637.32	637.66	638.00	638.33	638.67	639.01	639.35	639.69
18.90	640.03	640.37	640.70	641.04	641.38	641.72	642.06	642.40	642.74	643.08
19.00	643.41	643.75	644.09	644.43	644.77	645.11	645.45	645.78	646.12	646.46
19.10	646.80	647.14	647.48	647.82	648.15	648.49	648.83	649.17	649.51	649.85
19.20	650.19	650.53	650.86	651.20	651.54	651.88	652.22	652.56	652.90	653.23
19.30	653.57	653.91	654.25	654.59	654.93	655.27	655.60	655.94	656.28	656.62
19.40	656.96	657.30	657.64	657.98	658.31	658.65	658.99	659.33	659.67	660.01
19.50	660.35	660.68	661.02	661.36	661.70	662.04	662.38	662.72	663.05	663.39
19.60	663.73	664.07	664.41	664.75	665.09	665.43	665.76	666.10	666.44	666.78
19.70	667.12	667.46	667.80	668.13	668.47	668.81	669.15	669.49	669.83	670.17
19.80	670.51	670.84	671.18	671.52	671.86	672.20	672.54	672.88	673.21	673.55
19.90	673.89	674.23	674.57	674.91	675.25	675.58	675.92	676.26	676.60	676.94
20.00	677.28	677.62	677.96	678.29	678.63	678.97	679.31	679.65	679.99	680.33

(continued)

Proportional parts										
	in. Hg	.001	.002	.003	.004	.005	.006	.007	.008	.009
	mb.	.03	.07	.10	.14	.17	.20	.24	.27	.30

TABLE 1.4.1 (CONTINUED)

Inches of Mercury to Millibars

[1 inch of mercury = 33.86389 millibars.]

In. Hg	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
20.00	677.28	677.62	677.96	678.29	678.63	678.97	679.31	679.65	679.99	680.33
20.10	680.66	681.00	681.34	681.68	682.02	682.36	682.70	683.03	683.37	683.71
20.20	684.05	684.39	684.73	685.07	685.41	685.74	686.08	686.42	686.76	687.10
20.30	687.44	687.78	688.11	688.45	688.79	689.13	689.47	689.81	690.15	690.48
20.40	690.82	691.16	691.50	691.84	692.18	692.52	692.86	693.19	693.53	693.87
20.50	694.21	694.55	694.89	695.23	695.56	695.90	696.24	696.58	696.92	697.26
20.60	697.60	697.93	698.27	698.61	698.95	699.29	699.63	699.97	700.31	700.64
20.70	700.98	701.32	701.66	702.00	702.34	702.68	703.01	703.35	703.69	704.03
20.80	704.37	704.71	705.05	705.38	705.72	706.06	706.40	706.74	707.08	707.42
20.90	707.76	708.09	708.43	708.77	709.11	709.45	709.79	710.13	710.46	710.80
21.00	711.14	711.48	711.82	712.16	712.50	712.83	713.17	713.51	713.85	714.19
21.10	714.53	714.87	715.21	715.54	715.88	716.22	716.56	716.90	717.24	717.58
21.20	717.91	718.25	718.59	718.93	719.27	719.61	719.95	720.28	720.62	720.96
21.30	721.30	721.64	721.98	722.32	722.66	722.99	723.33	723.67	724.01	724.35
21.40	724.69	725.03	725.36	725.70	726.04	726.38	726.72	727.06	727.40	727.73
21.50	728.07	728.41	728.75	729.09	729.43	729.77	730.11	730.44	730.78	731.12
21.60	731.46	731.80	732.14	732.48	732.81	733.15	733.49	733.83	734.17	734.51
21.70	734.85	735.19	735.52	735.86	736.20	736.54	736.88	737.22	737.56	737.89
21.80	738.23	738.57	738.91	739.25	739.59	739.93	740.26	740.60	740.94	741.28
21.90	741.62	741.96	742.30	742.64	742.97	743.31	743.65	743.99	744.33	744.67
22.00	745.01	745.34	745.68	746.02	746.36	746.70	747.04	747.38	747.71	748.05
22.10	748.39	748.73	749.07	749.41	749.75	750.09	750.42	750.76	751.10	751.44
22.20	751.78	752.12	752.46	752.79	753.13	753.47	753.81	754.15	754.49	754.83
22.30	755.16	755.50	755.84	756.18	756.52	756.86	757.20	757.54	757.87	758.21
22.40	758.55	758.89	759.23	759.57	759.91	760.24	760.58	760.92	761.26	761.60
22.50	761.94	762.28	762.61	762.95	763.29	763.63	763.97	764.31	764.65	764.99
22.60	765.32	765.66	766.00	766.34	766.68	767.02	767.36	767.69	768.03	768.37
22.70	768.71	769.05	769.39	769.73	770.06	770.40	770.74	771.08	771.42	771.76
22.80	772.10	772.44	772.77	773.11	773.45	773.79	774.13	774.47	774.81	775.14
22.90	775.48	775.82	776.16	776.50	776.84	777.18	777.51	777.85	778.19	778.53
23.00	778.87	779.21	779.55	779.89	780.22	780.56	780.90	781.24	781.58	781.92
23.10	782.26	782.59	782.93	783.27	783.61	783.95	784.29	784.63	784.96	785.30
23.20	785.64	785.98	786.32	786.66	787.00	787.34	787.67	788.01	788.35	788.69
23.30	789.03	789.37	789.71	790.04	790.38	790.72	791.06	791.40	791.74	792.08
23.40	792.42	792.75	793.09	793.43	793.77	794.11	794.45	794.79	795.12	795.46
23.50	795.80	796.14	796.48	796.82	797.16	797.49	797.83	798.17	798.51	798.85
23.60	799.19	799.53	799.87	800.20	800.54	800.88	801.22	801.56	801.90	802.24
23.70	802.57	802.91	803.25	803.59	803.93	804.27	804.61	804.94	805.28	805.62
23.80	805.96	806.30	806.64	806.98	807.32	807.65	807.99	808.33	808.67	809.01
23.90	809.35	809.69	810.02	810.36	810.70	811.04	811.38	811.72	812.06	812.39
24.00	812.73	813.07	813.41	813.75	814.09	814.43	814.77	815.10	815.44	815.78
24.10	816.12	816.46	816.80	817.14	817.47	817.81	818.15	818.49	818.83	819.17
24.20	819.51	819.84	820.18	820.52	820.86	821.20	821.54	821.88	822.22	822.55
24.30	822.89	823.23	823.57	823.91	824.25	824.59	824.92	825.26	825.60	825.94
24.40	826.28	826.62	826.96	827.29	827.63	827.97	828.31	828.65	828.99	829.33
24.50	829.67	830.00	830.34	830.68	831.02	831.36	831.70	832.04	832.37	832.71
24.60	833.05	833.39	833.73	834.07	834.41	834.74	835.08	835.42	835.76	836.10
24.70	836.44	836.78	837.12	837.45	837.79	838.13	838.47	838.81	839.15	839.49
24.80	839.82	840.16	840.50	840.84	841.18	841.52	841.86	842.19	842.53	842.87
24.90	843.21	843.55	843.89	844.23	844.57	844.90	845.24	845.58	845.92	846.26
25.00	846.60	846.94	847.27	847.61	847.95	848.29	848.63	848.97	849.31	849.65

(continued)

Proportional parts	in. Hg	.001	.002	.003	.004	.005	.006	.007	.008	.009
	mb.	.03	.07	.10	.14	.17	.20	.24	.27	.30

TABLE 1.4.1 (CONTINUED)

Inches of Mercury to Millibars

[1 inch of mercury = 33.86389 millibars.]

In. Hg	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
25.00	846.60	846.94	847.27	847.61	847.95	848.29	848.63	848.97	849.31	849.65
25.10	849.98	850.32	850.66	851.00	851.34	851.68	852.02	852.35	852.69	853.03
25.20	853.37	853.71	854.05	854.39	854.72	855.06	855.40	855.74	856.08	856.42
25.30	856.76	857.10	857.43	857.77	858.11	858.45	858.79	859.13	859.47	859.80
25.40	860.14	860.48	860.82	861.16	861.50	861.84	862.17	862.51	862.85	863.19
25.50	863.53	863.87	864.21	864.55	864.88	865.22	865.56	865.90	866.24	866.58
25.60	866.92	867.25	867.59	867.93	868.27	868.61	868.95	869.29	869.62	869.96
25.70	870.30	870.64	870.98	871.32	871.66	872.00	872.33	872.67	873.01	873.35
25.80	873.69	874.03	874.37	874.70	875.04	875.38	875.72	876.06	876.40	876.74
25.90	877.07	877.41	877.75	878.09	878.43	878.77	879.11	879.45	879.78	880.12
26.00	880.46	880.80	881.14	881.48	881.82	882.15	882.49	882.83	883.17	883.51
26.10	883.85	884.19	884.52	884.86	885.20	885.54	885.88	886.22	886.56	886.90
26.20	887.23	887.57	887.91	888.25	888.59	888.93	889.27	889.60	889.94	890.28
26.30	890.62	890.96	891.30	891.64	891.97	892.31	892.65	892.99	893.33	893.67
26.40	894.01	894.35	894.68	895.02	895.36	895.70	896.04	896.38	896.72	897.05
26.50	897.39	897.73	898.07	898.41	898.75	899.09	899.42	899.76	900.10	900.44
26.60	900.78	901.12	901.46	901.80	902.13	902.47	902.81	903.15	903.49	903.83
26.70	904.17	904.50	904.84	905.18	905.52	905.86	906.20	906.54	906.87	907.21
26.80	907.55	907.89	908.23	908.57	908.91	909.25	909.58	909.92	910.26	910.60
26.90	910.94	911.28	911.62	911.95	912.29	912.63	912.97	913.31	913.65	913.99
27.00	914.33	914.66	915.00	915.34	915.68	916.02	916.36	916.70	917.03	917.37
27.10	917.71	918.05	918.39	918.73	919.07	919.40	919.74	920.08	920.42	920.76
27.20	921.10	921.44	921.78	922.11	922.45	922.79	923.13	923.47	923.81	924.15
27.30	924.48	924.82	925.16	925.50	925.84	926.18	926.52	926.85	927.19	927.53
27.40	927.87	928.21	928.55	928.89	929.23	929.56	929.90	930.24	930.58	930.92
27.50	931.26	931.60	931.93	932.27	932.61	932.95	933.29	933.63	933.97	934.30
27.60	934.64	934.98	935.32	935.66	936.00	936.34	936.68	937.01	937.35	937.69
27.70	938.03	938.37	938.71	939.05	939.38	939.72	940.06	940.40	940.74	941.08
27.80	941.42	941.75	942.09	942.43	942.77	943.11	943.45	943.79	944.13	944.46
27.90	944.80	945.14	945.48	945.82	946.16	946.50	946.83	947.17	947.51	947.85
28.00	948.19	948.53	948.87	949.20	949.54	949.88	950.22	950.56	950.90	951.24
28.10	951.58	951.91	952.25	952.59	952.93	953.27	953.61	953.95	954.28	954.62
28.20	954.96	955.30	955.64	955.98	956.32	956.65	956.99	957.33	957.67	958.01
28.30	958.35	958.69	959.03	959.36	959.70	960.04	960.38	960.72	961.06	961.40
28.40	961.73	962.07	962.41	962.75	963.09	963.43	963.77	964.10	964.44	964.78
28.50	965.12	965.46	965.80	966.14	966.48	966.81	967.15	967.49	967.83	968.17
28.60	968.51	968.85	969.18	969.52	969.86	970.20	970.54	970.88	971.22	971.56
28.70	971.89	972.23	972.57	972.91	973.25	973.59	973.93	974.26	974.60	974.94
28.80	975.28	975.62	975.96	976.30	976.63	976.97	977.31	977.65	977.99	978.33
28.90	978.67	979.01	979.34	979.68	980.02	980.36	980.70	981.04	981.38	981.71
29.00	982.05	982.39	982.73	983.07	983.41	983.75	984.08	984.42	984.76	985.10
29.10	985.44	985.78	986.12	986.46	986.79	987.13	987.47	987.81	988.15	988.49
29.20	988.83	989.16	989.50	989.84	990.18	990.52	990.86	991.20	991.53	991.87
29.30	992.21	992.55	992.89	993.23	993.57	993.91	994.24	994.58	994.92	995.26
29.40	995.60	995.94	996.28	996.61	996.95	997.29	997.63	997.97	998.31	998.65
29.50	998.98	999.32	999.66	1000.00	1000.34	1000.68	1001.02	1001.36	1001.69	1002.03
29.60	1002.37	1001.71	1003.05	1003.39	1003.73	1004.06	1004.40	1004.74	1005.08	1005.42
29.70	1005.76	1006.10	1006.43	1006.77	1007.11	1007.45	1007.79	1008.13	1008.47	1008.81
29.80	1009.14	1009.48	1009.82	1010.16	1010.50	1010.84	1011.18	1011.51	1011.85	1012.19
29.90	1012.53	1012.87	1013.21	1013.55	1013.88	1014.22	1014.56	1014.90	1015.24	1015.58
30.00	1015.92	1016.26	1016.59	1016.93	1017.27	1017.61	1017.95	1018.29	1018.63	1018.96

(continued)

Proportional parts	in. Hg	.001	.002	.003	.004	.005	.006	.007	.008	.009
	mb.	.03	.07	.10	.14	.17	.20	.24	.27	.30

TABLE 1.4.1 (CONTINUED)

Inches of Mercury to Millibars

[1 inch of mercury = 33.86389 millibars.]

In. Hg	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
30.00	1015.92	1016.26	1016.59	1016.93	1017.27	1017.61	1017.95	1018.29	1018.63	1018.96
30.10	1019.30	1019.64	1019.98	1020.32	1020.66	1021.00	1021.33	1021.67	1022.01	1022.35
30.20	1022.69	1023.03	1023.37	1023.71	1024.04	1024.38	1024.72	1025.06	1025.40	1025.74
30.30	1026.08	1026.41	1026.75	1027.09	1027.43	1027.77	1028.11	1028.45	1028.78	1029.12
30.40	1029.46	1029.80	1030.14	1030.48	1030.82	1031.16	1031.49	1031.83	1032.17	1032.51
30.50	1032.85	1033.19	1033.53	1033.86	1034.20	1034.54	1034.88	1035.22	1035.56	1035.90
30.60	1036.24	1036.57	1036.91	1037.25	1037.59	1037.93	1038.27	1038.61	1038.94	1039.28
30.70	1039.62	1039.96	1040.30	1040.64	1040.98	1041.31	1041.65	1041.99	1042.33	1042.67
30.80	1043.01	1043.35	1043.69	1044.02	1044.36	1044.70	1045.04	1045.38	1045.72	1046.06
30.90	1046.39	1046.73	1047.07	1047.41	1047.75	1048.09	1048.43	1048.76	1049.10	1049.44
31.00	1049.78	1050.12	1050.46	1050.80	1051.14	1051.47	1051.81	1052.15	1052.49	1052.83
31.10	1053.17	1053.51	1053.84	1054.18	1054.52	1054.86	1055.20	1055.54	1055.88	1056.21
31.20	1056.55	1056.89	1057.23	1057.57	1057.91	1058.25	1058.59	1058.92	1059.26	1059.60
31.30	1059.94	1060.28	1060.62	1060.96	1061.29	1061.63	1061.97	1062.31	1062.65	1062.99
31.40	1063.33	1063.66	1064.00	1064.34	1064.68	1065.02	1065.36	1065.70	1066.04	1066.37
31.50	1066.71	1067.05	1067.39	1067.73	1068.07	1068.41	1068.74	1069.08	1069.42	1069.76
31.60	1070.10	1070.44	1070.78	1071.11	1071.45	1071.79	1072.13	1072.47	1072.81	1073.15
31.70	1073.49	1073.82	1074.16	1074.50	1074.84	1075.18	1075.52	1075.86	1076.19	1076.53
31.80	1076.87	1077.21	1077.55	1077.89	1078.23	1078.56	1078.90	1079.24	1079.58	1079.92
31.90	1080.26	1080.60	1080.94	1081.27	1081.61	1081.95	1082.29	1082.63	1082.97	1083.31

(*end*)

Proportional parts	in. Hg	.001	.002	.003	.004	.005	.006	.007	.008	.009
	mb.	.03	.07	.10	.14	.17	.20	.24	.27	.30

TABLE 1.4.2

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Millibars	0	1	2	3	4	5	6	7	8	9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
0	0.000	0.030	0.059	0.089	0.118	0.148	0.177	0.207	0.236	0.266
10	.295	.325	.354	.384	.413	.443	.472	.502	.532	.561
20	.591	.620	.650	.679	.709	.738	.768	.797	.827	.856
30	.886	.915	.945	.974	1.004	1.034	1.063	1.093	1.122	1.152
40	1.181	1.211	1.240	1.270	1.299	1.329	1.358	1.388	1.417	1.447
50	1.476	1.506	1.536	1.565	1.595	1.624	1.654	1.683	1.713	1.742
60	1.772	1.801	1.831	1.860	1.890	1.919	1.949	1.979	2.008	2.038
70	2.067	2.097	2.126	2.156	2.185	2.215	2.244	2.274	2.303	2.333
80	2.362	2.392	2.421	2.451	2.481	2.510	2.540	2.569	2.599	2.628
90	2.658	2.687	2.717	2.746	2.776	2.805	2.835	2.864	2.894	2.923
100	2.953	2.983	3.012	3.042	3.071	3.101	3.130	3.160	3.189	3.219
110	3.248	3.278	3.307	3.337	3.366	3.396	3.425	3.455	3.485	3.514
120	3.544	3.573	3.603	3.632	3.662	3.691	3.721	3.750	3.780	3.809
130	3.839	3.868	3.898	3.927	3.957	3.987	4.016	4.046	4.075	4.105
140	4.134	4.164	4.193	4.223	4.252	4.282	4.311	4.341	4.370	4.400
150	4.429	4.459	4.489	4.518	4.548	4.577	4.607	4.636	4.666	4.695
160	4.725	4.754	4.784	4.813	4.843	4.872	4.902	4.932	4.961	4.991
170	5.020	5.050	5.079	5.109	5.138	5.168	5.197	5.227	5.256	5.286
180	5.315	5.345	5.374	5.404	5.434	5.463	5.493	5.522	5.552	5.581
190	5.611	5.640	5.670	5.699	5.729	5.758	5.788	5.817	5.847	5.876
200	5.906	5.936	5.965	5.995	6.024	6.054	6.083	6.113	6.142	6.172
210	6.201	6.231	6.260	6.290	6.319	6.349	6.378	6.408	6.438	6.467
220	6.497	6.526	6.556	6.585	6.615	6.644	6.674	6.703	6.733	6.762
230	6.792	6.821	6.851	6.880	6.910	6.940	6.969	6.999	7.028	7.058
240	7.087	7.117	7.146	7.176	7.205	7.235	7.264	7.294	7.323	7.353
250	7.382	7.412	7.442	7.471	7.501	7.530	7.560	7.589	7.619	7.648
260	7.678	7.707	7.737	7.766	7.796	7.825	7.855	7.885	7.914	7.944
270	7.973	8.003	8.032	8.062	8.091	8.121	8.150	8.180	8.209	8.239
280	8.268	8.298	8.327	8.357	8.387	8.416	8.446	8.475	8.505	8.534
290	8.564	8.593	8.623	8.652	8.682	8.711	8.741	8.770	8.800	8.829
300	8.859	8.889	8.918	8.948	8.977	9.007	9.036	9.066	9.095	9.125
310	9.154	9.184	9.213	9.243	9.272	9.302	9.331	9.361	9.391	9.420
320	9.450	9.479	9.509	9.538	9.568	9.597	9.627	9.656	9.686	9.715
330	9.745	9.774	9.804	9.833	9.863	9.893	9.922	9.952	9.981	10.011
340	10.040	10.070	10.099	10.129	10.158	10.188	10.217	10.247	10.276	10.306
350	10.335	10.365	10.395	10.424	10.454	10.483	10.513	10.542	10.572	10.601
360	10.631	10.660	10.690	10.719	10.749	10.778	10.808	10.838	10.867	10.897
370	10.926	10.956	10.985	11.015	11.044	11.074	11.103	11.133	11.162	11.192
380	11.221	11.251	11.280	11.310	11.340	11.369	11.399	11.428	11.458	11.487
390	11.517	11.546	11.576	11.605	11.635	11.664	11.694	11.723	11.753	11.782
400	11.812	11.842	11.871	11.901	11.930	11.960	11.989	12.019	12.048	12.078
410	12.107	12.137	12.166	12.196	12.225	12.255	12.284	12.314	12.344	12.373
420	12.403	12.432	12.462	12.491	12.521	12.550	12.580	12.609	12.639	12.668
430	12.698	12.727	12.757	12.786	12.816	12.846	12.875	12.905	12.934	12.964
440	12.993	13.023	13.052	13.082	13.111	13.141	13.170	13.200	13.229	13.259
450	13.288	13.318	13.348	13.377	13.407	13.436	13.466	13.495	13.525	13.554
460	13.584	13.613	13.643	13.672	13.702	13.731	13.761	13.791	13.820	13.850
470	13.879	13.909	13.938	13.968	13.997	14.027	14.056	14.086	14.115	14.145
480	14.174	14.204	14.233	14.263	14.293	14.322	14.352	14.381	14.411	14.440
490	14.470	14.499	14.529	14.558	14.588	14.617	14.647	14.676	14.706	14.735
500	14.765	14.795	14.824	14.854	14.883	14.913	14.942	14.972	15.001	15.031

(continued)

Proportional parts										
	mb.	.1	.2	.3	.4	.5	.6	.7	.8	.9
	in. Hg	.003	.006	.009	.012	.015	.018	.021	.024	.027

TABLE 1.4.2 (CONTINUED)

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Millibars	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
500	14.765	14.768	14.771	14.774	14.777	14.780	14.783	14.786	14.789	14.792
501	14.795	14.797	14.800	14.803	14.806	14.809	14.812	14.815	14.818	14.821
502	14.824	14.827	14.830	14.833	14.836	14.839	14.842	14.845	14.848	14.851
503	14.854	14.857	14.859	14.862	14.865	14.868	14.871	14.874	14.877	14.880
504	14.883	14.886	14.889	14.892	14.895	14.898	14.901	14.904	14.907	14.910
505	14.913	14.916	14.919	14.921	14.924	14.927	14.930	14.933	14.936	14.939
506	14.942	14.945	14.948	14.951	14.954	14.957	14.960	14.963	14.966	14.969
507	14.972	14.975	14.978	14.981	14.984	14.986	14.989	14.992	14.995	14.998
508	15.001	15.004	15.007	15.010	15.013	15.016	15.019	15.022	15.025	15.028
509	15.031	15.034	15.037	15.040	15.043	15.046	15.048	15.051	15.054	15.057
510	15.060	15.063	15.066	15.069	15.072	15.075	15.078	15.081	15.084	15.087
511	15.090	15.093	15.096	15.099	15.102	15.105	15.108	15.110	15.113	15.116
512	15.119	15.122	15.125	15.128	15.131	15.134	15.137	15.140	15.143	15.146
513	15.149	15.152	15.155	15.158	15.161	15.164	15.167	15.170	15.173	15.175
514	15.178	15.181	15.184	15.187	15.190	15.193	15.196	15.199	15.202	15.205
515	15.208	15.211	15.214	15.217	15.220	15.223	15.226	15.229	15.232	15.235
516	15.237	15.240	15.243	15.246	15.249	15.252	15.255	15.258	15.261	15.264
517	15.267	15.270	15.273	15.276	15.279	15.282	15.285	15.288	15.291	15.294
518	15.297	15.299	15.302	15.305	15.308	15.311	15.314	15.317	15.320	15.323
519	15.326	15.329	15.332	15.335	15.338	15.341	15.344	15.347	15.350	15.353
520	15.356	15.359	15.361	15.364	15.367	15.370	15.373	15.376	15.379	15.382
521	15.385	15.388	15.391	15.394	15.397	15.400	15.403	15.406	15.409	15.412
522	15.415	15.418	15.421	15.424	15.426	15.429	15.432	15.435	15.438	15.441
523	15.444	15.447	15.450	15.453	15.456	15.459	15.462	15.465	15.468	15.471
524	15.474	15.477	15.480	15.483	15.486	15.488	15.491	15.494	15.497	15.500
525	15.503	15.506	15.509	15.512	15.515	15.518	15.521	15.524	15.527	15.530
526	15.533	15.536	15.539	15.542	15.545	15.548	15.550	15.553	15.556	15.559
527	15.562	15.565	15.568	15.571	15.574	15.577	15.580	15.583	15.586	15.589
528	15.592	15.595	15.598	15.601	15.604	15.607	15.610	15.613	15.615	15.618
529	15.621	15.624	15.627	15.630	15.633	15.636	15.639	15.642	15.645	15.648
530	15.651	15.654	15.657	15.660	15.663	15.666	15.669	15.672	15.675	15.677
531	15.680	15.683	15.686	15.689	15.692	15.695	15.698	15.701	15.704	15.707
532	15.710	15.713	15.716	15.719	15.722	15.725	15.728	15.731	15.734	15.737
533	15.739	15.742	15.745	15.748	15.751	15.754	15.757	15.760	15.763	15.766
534	15.769	15.772	15.775	15.778	15.781	15.784	15.787	15.790	15.793	15.796
535	15.799	15.801	15.804	15.807	15.810	15.813	15.816	15.819	15.822	15.825
536	15.828	15.831	15.834	15.837	15.840	15.843	15.846	15.849	15.852	15.855
537	15.858	15.861	15.864	15.866	15.869	15.872	15.875	15.878	15.881	15.884
538	15.887	15.890	15.893	15.896	15.899	15.902	15.905	15.908	15.911	15.914
539	15.917	15.920	15.923	15.926	15.928	15.931	15.934	15.937	15.940	15.943
540	15.946	15.949	15.952	15.955	15.958	15.961	15.964	15.967	15.970	15.973
541	15.976	15.979	15.982	15.985	15.988	15.990	15.993	15.996	15.999	16.002
542	16.005	16.008	16.011	16.014	16.017	16.020	16.023	16.026	16.029	16.032
543	16.035	16.038	16.041	16.044	16.047	16.050	16.052	16.055	16.058	16.061
544	16.064	16.067	16.070	16.073	16.076	16.079	16.082	16.085	16.088	16.091
545	16.094	16.097	16.100	16.103	16.106	16.109	16.112	16.115	16.117	16.120
546	16.123	16.126	16.129	16.132	16.135	16.138	16.141	16.144	16.147	16.150
547	16.153	16.156	16.159	16.162	16.165	16.168	16.171	16.174	16.177	16.179
548	16.182	16.185	16.188	16.191	16.194	16.197	16.200	16.203	16.206	16.209
549	16.212	16.215	16.218	16.221	16.224	16.227	16.230	16.233	16.236	16.239
550	16.241	16.244	16.247	16.250	16.253	16.256	16.259	16.262	16.265	16.268

(continued)

Proportional parts	mb.	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in. Hg	.000	.001	.001	.001	.001	.002	.002	.002	.003

TABLE 1.4.2 (CONTINUED)

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Milli-bars	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
550	16.241	16.244	16.247	16.250	16.253	16.256	16.259	16.262	16.265	16.268
551	16.271	16.274	16.277	16.280	16.283	16.286	16.289	16.292	16.295	16.298
552	16.301	16.304	16.306	16.309	16.312	16.315	16.318	16.321	16.324	16.327
553	16.330	16.333	16.336	16.339	16.342	16.345	16.348	16.351	16.354	16.357
554	16.360	16.363	16.366	16.368	16.371	16.374	16.377	16.380	16.383	16.386
555	16.389	16.392	16.395	16.398	16.401	16.404	16.407	16.410	16.413	16.416
556	16.419	16.422	16.425	16.428	16.430	16.433	16.436	16.439	16.442	16.445
557	16.448	16.451	16.454	16.457	16.460	16.463	16.466	16.469	16.472	16.475
558	16.478	16.481	16.484	16.487	16.490	16.492	16.495	16.498	16.501	16.504
559	16.507	16.510	16.513	16.516	16.519	16.522	16.525	16.528	16.531	16.534
560	16.537	16.540	16.543	16.546	16.549	16.552	16.555	16.557	16.560	16.563
561	16.566	16.569	16.572	16.575	16.578	16.581	16.584	16.587	16.590	16.593
562	16.596	16.599	16.602	16.605	16.608	16.611	16.614	16.617	16.619	16.622
563	16.625	16.628	16.631	16.634	16.637	16.640	16.643	16.646	16.649	16.652
564	16.655	16.658	16.661	16.664	16.667	16.670	16.673	16.676	16.679	16.681
565	16.684	16.687	16.690	16.693	16.696	16.699	16.702	16.705	16.708	16.711
566	16.714	16.717	16.720	16.723	16.726	16.729	16.732	16.735	16.738	16.741
567	16.743	16.746	16.749	16.752	16.755	16.758	16.761	16.764	16.767	16.770
568	16.773	16.776	16.779	16.782	16.785	16.788	16.791	16.794	16.797	16.800
569	16.803	16.806	16.808	16.811	16.814	16.817	16.820	16.823	16.826	16.829
570	16.832	16.835	16.838	16.841	16.844	16.847	16.850	16.853	16.856	16.859
571	16.862	16.865	16.868	16.870	16.873	16.876	16.879	16.882	16.885	16.888
572	16.891	16.894	16.897	16.900	16.903	16.906	16.909	16.912	16.915	16.918
573	16.921	16.924	16.927	16.930	16.932	16.935	16.938	16.941	16.944	16.947
574	16.950	16.953	16.956	16.959	16.962	16.965	16.968	16.971	16.974	16.977
575	16.980	16.983	16.986	16.989	16.992	16.995	16.997	17.000	17.003	17.006
576	17.009	17.012	17.015	17.018	17.021	17.024	17.027	17.030	17.033	17.036
577	17.039	17.042	17.045	17.048	17.051	17.054	17.057	17.059	17.062	17.065
578	17.068	17.071	17.074	17.077	17.080	17.083	17.086	17.089	17.092	17.095
579	17.098	17.101	17.104	17.107	17.110	17.113	17.116	17.119	17.121	17.124
580	17.127	17.130	17.133	17.136	17.139	17.142	17.145	17.148	17.151	17.154
581	17.157	17.160	17.163	17.166	17.169	17.172	17.175	17.178	17.181	17.183
582	17.186	17.189	17.192	17.195	17.198	17.201	17.204	17.207	17.210	17.213
583	17.216	17.219	17.222	17.225	17.228	17.231	17.234	17.237	17.240	17.243
584	17.246	17.248	17.251	17.254	17.257	17.260	17.263	17.266	17.269	17.272
585	17.275	17.278	17.281	17.284	17.287	17.290	17.293	17.296	17.299	17.302
586	17.305	17.308	17.310	17.313	17.316	17.319	17.322	17.325	17.328	17.331
587	17.334	17.337	17.340	17.343	17.346	17.349	17.352	17.355	17.358	17.361
588	17.364	17.367	17.370	17.372	17.375	17.378	17.381	17.384	17.387	17.390
589	17.393	17.396	17.399	17.402	17.405	17.408	17.411	17.414	17.417	17.420
590	17.423	17.426	17.429	17.432	17.435	17.437	17.440	17.443	17.446	17.449
591	17.452	17.455	17.458	17.461	17.464	17.467	17.470	17.473	17.476	17.479
592	17.482	17.485	17.488	17.491	17.494	17.497	17.499	17.502	17.505	17.508
593	17.511	17.514	17.517	17.520	17.523	17.526	17.529	17.532	17.535	17.538
594	17.541	17.544	17.547	17.550	17.553	17.556	17.559	17.561	17.564	17.567
595	17.570	17.573	17.576	17.579	17.582	17.585	17.588	17.591	17.594	17.597
596	17.600	17.603	17.606	17.609	17.612	17.615	17.618	17.621	17.623	17.626
597	17.629	17.632	17.635	17.638	17.641	17.644	17.647	17.650	17.653	17.656
598	17.659	17.662	17.665	17.668	17.671	17.674	17.677	17.680	17.683	17.686
599	17.688	17.691	17.694	17.697	17.700	17.703	17.706	17.709	17.712	17.715
600	17.718	17.721	17.724	17.727	17.730	17.733	17.736	17.739	17.742	17.745

(*continued*)

Proportional parts										
	mb.	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in. Hg	.000	.001	.001	.001	.001	.002	.002	.002	.003

TABLE 1.4.2 (CONTINUED)

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Millibars	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
600	17.718	17.721	17.724	17.727	17.730	17.733	17.736	17.739	17.742	17.745
601	17.748	17.750	17.753	17.756	17.759	17.762	17.765	17.768	17.771	17.774
602	17.777	17.780	17.783	17.786	17.789	17.792	17.795	17.798	17.801	17.804
603	17.807	17.810	17.812	17.815	17.818	17.821	17.824	17.827	17.830	17.833
604	17.836	17.839	17.842	17.845	17.848	17.851	17.854	17.857	17.860	17.863
605	17.866	17.869	17.872	17.874	17.877	17.880	17.883	17.886	17.889	17.892
606	17.895	17.898	17.901	17.904	17.907	17.910	17.913	17.916	17.919	17.922
607	17.925	17.928	17.931	17.934	17.937	17.939	17.942	17.945	17.948	17.951
608	17.954	17.957	17.960	17.963	17.966	17.969	17.972	17.975	17.978	17.981
609	17.984	17.987	17.990	17.993	17.996	17.999	18.001	18.004	18.007	18.010
610	18.013	18.016	18.019	18.022	18.025	18.028	18.031	18.034	18.037	18.040
611	18.043	18.046	18.049	18.052	18.055	18.058	18.061	18.063	18.066	18.069
612	18.072	18.075	18.078	18.081	18.084	18.087	18.090	18.093	18.096	18.099
613	18.102	18.105	18.108	18.111	18.114	18.117	18.120	18.123	18.126	18.128
614	18.131	18.134	18.137	18.140	18.143	18.146	18.149	18.152	18.155	18.158
615	18.161	18.164	18.167	18.170	18.173	18.176	18.179	18.182	18.185	18.188
616	18.190	18.193	18.196	18.199	18.202	18.205	18.208	18.211	18.214	18.217
617	18.220	18.223	18.226	18.229	18.232	18.235	18.238	18.241	18.244	18.247
618	18.250	18.252	18.255	18.258	18.261	18.264	18.267	18.270	18.273	18.276
619	18.279	18.282	18.285	18.288	18.291	18.294	18.297	18.300	18.303	18.306
620	18.309	18.312	18.314	18.317	18.320	18.323	18.326	18.329	18.332	18.335
621	18.338	18.341	18.344	18.347	18.350	18.353	18.356	18.359	18.362	18.365
622	18.368	18.371	18.374	18.377	18.379	18.382	18.385	18.388	18.391	18.394
623	18.397	18.400	18.403	18.406	18.409	18.412	18.415	18.418	18.421	18.424
624	18.427	18.430	18.433	18.436	18.439	18.441	18.444	18.447	18.450	18.453
625	18.456	18.459	18.462	18.465	18.468	18.471	18.474	18.477	18.480	18.483
626	18.486	18.489	18.492	18.495	18.498	18.501	18.503	18.506	18.509	18.512
627	18.515	18.518	18.521	18.524	18.527	18.530	18.533	18.536	18.539	18.542
628	18.545	18.548	18.551	18.554	18.557	18.560	18.563	18.565	18.568	18.571
629	18.574	18.577	18.580	18.583	18.586	18.589	18.592	18.595	18.598	18.601
630	18.604	18.607	18.610	18.613	18.616	18.619	18.622	18.625	18.628	18.630
631	18.633	18.636	18.639	18.642	18.645	18.648	18.651	18.654	18.657	18.660
632	18.663	18.666	18.669	18.672	18.675	18.678	18.681	18.684	18.687	18.690
633	18.692	18.695	18.698	18.701	18.704	18.707	18.710	18.713	18.716	18.719
634	18.722	18.725	18.728	18.731	18.734	18.737	18.740	18.743	18.746	18.749
635	18.752	18.754	18.757	18.760	18.763	18.766	18.769	18.772	18.775	18.778
636	18.781	18.784	18.787	18.790	18.793	18.796	18.799	18.802	18.805	18.808
637	18.811	18.814	18.817	18.819	18.822	18.825	18.828	18.831	18.834	18.837
638	18.840	18.843	18.846	18.849	18.852	18.855	18.858	18.861	18.864	18.867
639	18.870	18.873	18.876	18.879	18.881	18.884	18.887	18.890	18.893	18.896
640	18.899	18.902	18.905	18.908	18.911	18.914	18.917	18.920	18.923	18.926
641	18.929	18.932	18.935	18.938	18.941	18.943	18.946	18.949	18.952	18.955
642	18.958	18.961	18.964	18.967	18.970	18.973	18.976	18.979	18.982	18.985
643	18.988	18.991	18.994	18.997	19.000	19.003	19.005	19.008	19.011	19.014
644	19.017	19.020	19.023	19.026	19.029	19.032	19.035	19.038	19.041	19.044
645	19.047	19.050	19.053	19.056	19.059	19.062	19.065	19.068	19.070	19.073
646	19.076	19.079	19.082	19.085	19.088	19.091	19.094	19.097	19.100	19.103
647	19.106	19.109	19.112	19.115	19.118	19.121	19.124	19.127	19.130	19.132
648	19.135	19.138	19.141	19.144	19.147	19.150	19.153	19.156	19.159	19.162
649	19.165	19.168	19.171	19.174	19.177	19.180	19.183	19.186	19.189	19.192
650	19.194	19.197	19.200	19.203	19.206	19.209	19.212	19.215	19.218	19.221

(*continued*)

Proportional parts	mb.	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in. Hg	.000	.001	.001	.001	.001	.002	.002	.002	.003

TABLE 1.4.2 (CONTINUED)

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Milli-bars	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
650	19.194	19.197	19.200	19.203	19.206	19.209	19.212	19.215	19.218	19.221
651	19.224	19.227	19.230	19.233	19.236	19.239	19.242	19.245	19.248	19.251
652	19.254	19.256	19.259	19.262	19.265	19.268	19.271	19.274	19.277	19.280
653	19.283	19.286	19.289	19.292	19.295	19.298	19.301	19.304	19.307	19.310
654	19.313	19.316	19.319	19.321	19.324	19.327	19.330	19.333	19.336	19.339
655	19.342	19.345	19.348	19.351	19.354	19.357	19.360	19.363	19.366	19.369
656	19.372	19.375	19.378	19.381	19.383	19.386	19.389	19.392	19.395	19.398
657	19.401	19.404	19.407	19.410	19.413	19.416	19.419	19.422	19.425	19.428
658	19.431	19.434	19.437	19.440	19.443	19.445	19.448	19.451	19.454	19.457
659	19.460	19.463	19.466	19.469	19.472	19.475	19.478	19.481	19.484	19.487
660	19.490	19.493	19.496	19.499	19.502	19.505	19.508	19.510	19.513	19.516
661	19.519	19.522	19.525	19.528	19.531	19.534	19.537	19.540	19.543	19.546
662	19.549	19.552	19.555	19.558	19.561	19.564	19.567	19.570	19.572	19.575
663	19.578	19.581	19.584	19.587	19.590	19.593	19.596	19.599	19.602	19.605
664	19.608	19.611	19.614	19.617	19.620	19.623	19.626	19.629	19.632	19.634
665	19.637	19.640	19.643	19.646	19.649	19.652	19.655	19.658	19.661	19.664
666	19.667	19.670	19.673	19.676	19.679	19.682	19.685	19.688	19.691	19.694
667	19.696	19.699	19.702	19.705	19.708	19.711	19.714	19.717	19.720	19.723
668	19.726	19.729	19.732	19.735	19.738	19.741	19.744	19.747	19.750	19.753
669	19.756	19.759	19.761	19.764	19.767	19.770	19.773	19.776	19.779	19.782
670	19.785	19.788	19.791	19.794	19.797	19.800	19.803	19.806	19.809	19.812
671	19.815	19.818	19.821	19.823	19.826	19.829	19.832	19.835	19.838	19.841
672	19.844	19.847	19.850	19.853	19.856	19.859	19.862	19.865	19.868	19.871
673	19.874	19.877	19.880	19.883	19.885	19.888	19.891	19.894	19.897	19.900
674	19.903	19.906	19.909	19.912	19.915	19.918	19.921	19.924	19.927	19.930
675	19.933	19.936	19.939	19.942	19.945	19.948	19.950	19.953	19.956	19.959
676	19.962	19.965	19.968	19.971	19.974	19.977	19.980	19.983	19.986	19.989
677	19.992	19.995	19.998	20.001	20.004	20.007	20.010	20.012	20.015	20.018
678	20.021	20.024	20.027	20.030	20.033	20.036	20.039	20.042	20.045	20.048
679	20.051	20.054	20.057	20.060	20.063	20.066	20.069	20.072	20.074	20.077
680	20.080	20.083	20.086	20.089	20.092	20.095	20.098	20.101	20.104	20.107
681	20.110	20.113	20.116	20.119	20.122	20.125	20.128	20.131	20.134	20.136
682	20.139	20.142	20.145	20.148	20.151	20.154	20.157	20.160	20.163	20.166
683	20.169	20.172	20.175	20.178	20.181	20.184	20.187	20.190	20.193	20.196
684	20.199	20.201	20.204	20.207	20.210	20.213	20.216	20.219	20.222	20.225
685	20.228	20.231	20.234	20.237	20.240	20.243	20.246	20.249	20.252	20.255
686	20.258	20.261	20.263	20.266	20.269	20.272	20.275	20.278	20.281	20.284
687	20.287	20.290	20.293	20.296	20.299	20.302	20.305	20.308	20.311	20.314
688	20.317	20.320	20.323	20.325	20.328	20.331	20.334	20.337	20.340	20.343
689	20.346	20.349	20.352	20.355	20.358	20.361	20.364	20.367	20.370	20.373
690	20.376	20.379	20.382	20.385	20.387	20.390	20.393	20.396	20.399	20.402
691	20.405	20.408	20.411	20.414	20.417	20.420	20.423	20.426	20.429	20.432
692	20.435	20.438	20.441	20.444	20.447	20.450	20.452	20.455	20.458	20.461
693	20.464	20.467	20.470	20.473	20.476	20.479	20.482	20.485	20.488	20.491
694	20.494	20.497	20.500	20.503	20.506	20.509	20.512	20.514	20.517	20.520
695	20.523	20.526	20.529	20.532	20.535	20.538	20.541	20.544	20.547	20.550
696	20.553	20.556	20.559	20.562	20.565	20.568	20.571	20.574	20.576	20.579
697	20.582	20.585	20.588	20.591	20.594	20.597	20.600	20.603	20.606	20.609
698	20.612	20.615	20.618	20.621	20.624	20.627	20.630	20.633	20.636	20.639
699	20.641	20.644	20.647	20.650	20.653	20.656	20.659	20.662	20.665	20.668
700	20.671	20.674	20.677	20.680	20.683	20.686	20.689	20.692	20.695	20.698

(continued)

Proportional parts	mb.	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in. Hg	.000	.001	.001	.001	.001	.002	.002	.002	.003

TABLE 1.4.2 (CONTINUED)

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Millibars	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
700	20.671	20.674	20.677	20.680	20.683	20.686	20.689	20.692	20.695	20.698
701	20.701	20.703	20.706	20.709	20.712	20.715	20.718	20.721	20.724	20.727
702	20.730	20.733	20.736	20.739	20.742	20.745	20.748	20.751	20.754	20.757
703	20.760	20.763	20.765	20.768	20.771	20.774	20.777	20.780	20.783	20.786
704	20.789	20.792	20.795	20.798	20.801	20.804	20.807	20.810	20.813	20.816
705	20.819	20.822	20.825	20.827	20.830	20.833	20.836	20.839	20.842	20.845
706	20.848	20.851	20.854	20.857	20.860	20.863	20.866	20.869	20.872	20.875
707	20.878	20.881	20.884	20.887	20.890	20.892	20.895	20.898	20.901	20.904
708	20.907	20.910	20.913	20.916	20.919	20.922	20.925	20.928	20.931	20.934
709	20.937	20.940	20.943	20.946	20.949	20.952	20.954	20.957	20.960	20.963
710	20.966	20.969	20.972	20.975	20.978	20.981	20.984	20.987	20.990	20.993
711	20.996	20.999	21.002	21.005	21.008	21.011	21.014	21.016	21.019	21.022
712	21.025	21.028	21.031	21.034	21.037	21.040	21.043	21.046	21.049	21.052
713	21.055	21.058	21.061	21.064	21.067	21.070	21.073	21.076	21.078	21.081
714	21.084	21.087	21.090	21.093	21.096	21.099	21.102	21.105	21.108	21.111
715	21.114	21.117	21.120	21.123	21.126	21.129	21.132	21.135	21.138	21.141
716	21.143	21.146	21.149	21.152	21.155	21.158	21.161	21.164	21.167	21.170
717	21.173	21.176	21.179	21.182	21.185	21.188	21.191	21.194	21.197	21.200
718	21.203	21.205	21.208	21.211	21.214	21.217	21.220	21.223	21.226	21.229
719	21.232	21.235	21.238	21.241	21.244	21.247	21.250	21.253	21.256	21.259
720	21.262	21.265	21.267	21.270	21.273	21.276	21.279	21.282	21.285	21.288
721	21.291	21.294	21.297	21.300	21.303	21.306	21.309	21.312	21.315	21.318
722	21.321	21.324	21.327	21.330	21.332	21.335	21.338	21.341	21.344	21.347
723	21.350	21.353	21.356	21.359	21.362	21.365	21.368	21.371	21.374	21.377
724	21.380	21.383	21.386	21.389	21.392	21.394	21.397	21.400	21.403	21.406
725	21.409	21.412	21.415	21.418	21.421	21.424	21.427	21.430	21.433	21.436
726	21.439	21.442	21.445	21.448	21.451	21.454	21.456	21.459	21.462	21.465
727	21.468	21.471	21.474	21.477	21.480	21.483	21.486	21.489	21.492	21.495
728	21.498	21.501	21.504	21.507	21.510	21.513	21.516	21.518	21.521	21.524
729	21.527	21.530	21.533	21.536	21.539	21.542	21.545	21.548	21.551	21.554
730	21.557	21.560	21.563	21.566	21.569	21.572	21.575	21.578	21.581	21.583
731	21.586	21.589	21.592	21.595	21.598	21.601	21.604	21.607	21.610	21.613
732	21.616	21.619	21.622	21.625	21.628	21.631	21.634	21.637	21.640	21.643
733	21.645	21.648	21.651	21.654	21.657	21.660	21.663	21.666	21.669	21.672
734	21.675	21.678	21.681	21.684	21.687	21.690	21.693	21.696	21.699	21.702
735	21.705	21.707	21.710	21.713	21.716	21.719	21.722	21.725	21.728	21.731
736	21.734	21.737	21.740	21.743	21.746	21.749	21.752	21.755	21.758	21.761
737	21.764	21.767	21.770	21.772	21.775	21.778	21.781	21.784	21.787	21.790
738	21.793	21.796	21.799	21.802	21.805	21.808	21.811	21.814	21.817	21.820
739	21.823	21.826	21.829	21.832	21.834	21.837	21.840	21.843	21.846	21.849
740	21.852	21.855	21.858	21.861	21.864	21.867	21.870	21.873	21.876	21.879
741	21.882	21.885	21.888	21.891	21.894	21.896	21.899	21.902	21.905	21.908
742	21.911	21.914	21.917	21.920	21.923	21.926	21.929	21.932	21.935	21.938
743	21.941	21.944	21.947	21.950	21.953	21.956	21.958	21.961	21.964	21.967
744	21.970	21.973	21.976	21.979	21.982	21.985	21.988	21.991	21.994	21.997
745	22.000	22.003	22.006	22.009	22.012	22.015	22.018	22.021	22.023	22.026
746	22.029	22.032	22.035	22.038	22.041	22.044	22.047	22.050	22.053	22.056
747	22.059	22.062	22.065	22.068	22.071	22.074	22.077	22.080	22.083	22.085
748	22.088	22.091	22.094	22.097	22.100	22.103	22.106	22.109	22.112	22.115
749	22.118	22.121	22.124	22.127	22.130	22.133	22.136	22.139	22.142	22.145
750	22.147	22.150	22.153	22.156	22.159	22.162	22.165	22.168	22.171	22.174

(continued)

Proportional parts	mb.	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in. Hg	.000	.001	.001	.001	.001	.002	.002	.002	.003

TABLE 1.4.2 (CONTINUED)

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Millibars	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
750	22.147	22.150	22.153	22.156	22.159	22.162	22.165	22.168	22.171	22.174
751	22.177	22.180	22.183	22.186	22.189	22.192	22.195	22.198	22.201	22.204
752	22.207	22.209	22.212	22.215	22.218	22.221	22.224	22.227	22.230	22.233
753	22.236	22.239	22.242	22.245	22.248	22.251	22.254	22.257	22.260	22.263
754	22.266	22.269	22.272	22.274	22.277	22.280	22.283	22.286	22.289	22.292
755	22.295	22.298	22.301	22.304	22.307	22.310	22.313	22.316	22.319	22.322
756	22.325	22.328	22.331	22.334	22.336	22.339	22.342	22.345	22.348	22.351
757	22.354	22.357	22.360	22.363	22.366	22.369	22.372	22.375	22.378	22.381
758	22.384	22.387	22.390	22.393	22.396	22.398	22.401	22.404	22.407	22.410
759	22.413	22.416	22.419	22.422	22.425	22.428	22.431	22.434	22.437	22.440
760	22.443	22.446	22.449	22.452	22.455	22.458	22.461	22.463	22.466	22.469
761	22.472	22.475	22.478	22.481	22.484	22.487	22.490	22.493	22.496	22.499
762	22.502	22.505	22.508	22.511	22.514	22.517	22.520	22.523	22.525	22.528
763	22.531	22.534	22.537	22.540	22.543	22.546	22.549	22.552	22.555	22.558
764	22.561	22.564	22.567	22.570	22.573	22.576	22.579	22.582	22.585	22.587
765	22.590	22.593	22.596	22.599	22.602	22.605	22.608	22.611	22.614	22.617
766	22.620	22.623	22.626	22.629	22.632	22.635	22.638	22.641	22.644	22.647
767	22.649	22.652	22.655	22.658	22.661	22.664	22.667	22.670	22.673	22.676
768	22.679	22.682	22.685	22.688	22.691	22.694	22.697	22.700	22.703	22.706
769	22.709	22.712	22.714	22.717	22.720	22.723	22.726	22.729	22.732	22.735
770	22.738	22.741	22.744	22.747	22.750	22.753	22.756	22.759	22.762	22.765
771	22.768	22.771	22.774	22.776	22.779	22.782	22.785	22.788	22.791	22.794
772	22.797	22.800	22.803	22.806	22.809	22.812	22.815	22.818	22.821	22.824
773	22.827	22.830	22.833	22.836	22.838	22.841	22.844	22.847	22.850	22.853
774	22.856	22.859	22.862	22.865	22.868	22.871	22.874	22.877	22.880	22.883
775	22.886	22.889	22.892	22.895	22.898	22.900	22.903	22.906	22.909	22.912
776	22.915	22.918	22.921	22.924	22.927	22.930	22.933	22.936	22.939	22.942
777	22.945	22.948	22.951	22.954	22.957	22.960	22.963	22.965	22.968	22.971
778	22.974	22.977	22.980	22.983	22.986	22.989	22.992	22.995	22.998	23.001
779	23.004	23.007	23.010	23.013	23.016	23.019	23.022	23.025	23.027	23.030
780	23.033	23.036	23.039	23.042	23.045	23.048	23.051	23.054	23.057	23.060
781	23.063	23.066	23.069	23.072	23.075	23.078	23.081	23.084	23.087	23.089
782	23.092	23.095	23.098	23.101	23.104	23.107	23.110	23.113	23.116	23.119
783	23.122	23.125	23.128	23.131	23.134	23.137	23.140	23.143	23.146	23.149
784	23.152	23.154	23.157	23.160	23.163	23.166	23.169	23.172	23.175	23.178
785	23.181	23.184	23.187	23.190	23.193	23.196	23.199	23.202	23.205	23.208
786	23.211	23.214	23.216	23.219	23.222	23.225	23.228	23.231	23.234	23.237
787	23.240	23.243	23.246	23.249	23.252	23.255	23.258	23.261	23.264	23.267
788	23.270	23.273	23.276	23.278	23.281	23.284	23.287	23.290	23.293	23.296
789	23.299	23.302	23.305	23.308	23.311	23.314	23.317	23.320	23.323	23.326
790	23.329	23.332	23.335	23.338	23.340	23.343	23.346	23.349	23.252	23.355
791	23.358	23.361	23.364	23.367	23.370	23.373	23.376	23.379	23.382	23.385
792	23.388	23.391	23.394	23.397	23.400	23.403	23.405	23.408	23.411	23.414
793	23.417	23.420	23.423	23.426	23.429	23.432	23.435	23.438	23.441	23.444
794	23.447	23.450	23.453	23.456	23.459	23.462	23.465	23.467	23.470	23.473
795	23.476	23.479	23.482	23.485	23.488	23.491	23.494	23.497	23.500	23.503
796	23.506	23.509	23.512	23.515	23.518	23.521	23.524	23.527	23.529	23.532
797	23.535	23.538	23.541	23.544	23.547	23.550	23.553	23.556	23.559	23.562
798	23.565	23.568	23.571	23.574	23.577	23.580	23.583	23.586	23.589	23.592
799	23.594	23.597	23.600	23.603	23.606	23.609	23.612	23.615	23.618	23.621
800	23.624	23.627	23.630	23.633	23.636	23.639	23.642	23.645	23.648	23.651

(continued)

Proportional parts	mb.	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in. Hg	.000	.001	.001	.001	.001	.002	.002	.002	.003

TABLE 1.4.2 (CONTINUED)

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Milli-bars	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
800	23.624	23.627	23.630	23.633	23.636	23.639	23.642	23.645	23.648	23.651
801	23.654	23.656	23.659	23.662	23.665	23.668	23.671	23.674	23.677	23.680
802	23.683	23.686	23.689	23.692	23.695	23.698	23.701	23.704	23.707	23.710
803	23.713	23.716	23.718	23.721	23.724	23.727	23.730	23.733	23.736	23.739
804	23.742	23.745	23.748	23.751	23.754	23.757	23.760	23.763	23.766	23.769
805	23.772	23.775	23.778	23.780	23.783	23.786	23.789	23.792	23.795	23.798
806	23.801	23.804	23.807	23.810	23.813	23.816	23.819	23.822	23.825	23.828
807	23.831	23.834	23.837	23.840	23.843	23.845	23.848	23.851	23.854	23.857
808	23.860	23.863	23.866	23.869	23.872	23.875	23.878	23.881	23.884	23.887
809	23.890	23.893	23.896	23.899	23.902	23.905	23.907	23.910	23.913	23.916
810	23.919	23.922	23.925	23.928	23.931	23.934	23.937	23.940	23.943	23.946
811	23.949	23.952	23.955	23.958	23.961	23.964	23.967	23.969	23.972	23.975
812	23.978	23.981	23.984	23.937	23.990	23.993	23.996	23.999	24.002	24.005
813	24.008	24.011	24.014	24.017	24.020	24.023	24.026	24.029	24.031	24.034
814	24.037	24.040	24.043	24.046	24.049	24.052	24.055	24.058	24.061	24.064
815	24.067	24.070	24.073	24.076	24.079	24.082	24.085	24.088	24.091	24.094
816	24.096	24.099	24.102	24.105	24.108	24.111	24.114	24.117	24.120	24.123
817	24.126	24.129	24.132	24.135	24.138	24.141	24.144	24.147	24.150	24.153
818	24.156	24.158	24.161	24.164	24.167	24.170	24.173	24.176	24.179	24.182
819	24.185	24.188	24.191	24.194	24.197	24.200	24.203	24.206	24.209	24.212
820	24.215	24.218	24.220	24.223	24.226	24.229	24.232	24.235	24.238	24.241
821	24.244	24.247	24.250	24.253	24.256	24.259	24.262	24.265	24.268	24.271
822	24.274	24.277	24.280	24.283	24.285	24.288	24.291	24.294	24.297	24.300
823	24.303	24.306	24.309	24.312	24.315	24.318	24.321	24.324	24.327	24.330
824	24.333	24.336	24.339	24.342	24.345	24.347	24.350	24.353	24.356	24.359
825	24.362	24.365	24.368	24.371	24.374	24.377	24.380	24.383	24.386	24.389
826	24.392	24.395	24.398	24.401	24.404	24.407	24.409	24.412	24.415	24.418
827	24.421	24.424	24.427	24.430	24.433	24.436	24.439	24.442	24.445	24.448
828	24.451	24.454	24.457	24.460	24.463	24.466	24.469	24.471	24.474	24.477
829	24.480	24.483	24.486	24.489	24.492	24.495	24.498	24.501	24.504	24.507
830	24.510	24.513	24.516	24.519	24.522	24.525	24.528	24.531	24.534	24.536
831	24.539	24.542	24.545	24.548	24.551	24.554	24.557	24.560	24.563	24.566
832	24.569	24.572	24.575	24.578	24.581	24.584	24.587	24.590	24.593	24.596
833	24.598	24.601	24.604	24.607	24.610	24.613	24.616	24.619	24.622	24.625
834	24.628	24.631	24.634	24.637	24.640	24.643	24.646	24.649	24.652	24.655
835	24.658	24.660	24.663	24.666	24.669	24.672	24.675	24.678	24.681	24.684
836	24.687	24.690	24.693	24.696	24.699	24.702	24.705	24.708	24.711	24.714
837	24.717	24.720	24.722	24.725	24.728	24.731	24.734	24.737	24.740	24.743
838	24.746	24.749	24.752	24.755	24.758	24.761	24.764	24.767	24.770	24.773
839	24.776	24.779	24.782	24.785	24.787	24.790	24.793	24.796	24.799	24.802
840	24.805	24.808	24.811	24.814	24.817	24.820	24.823	24.826	24.829	24.832
841	24.835	24.838	24.841	24.844	24.847	24.849	24.852	24.855	24.858	24.861
842	24.864	24.867	24.870	24.873	24.876	24.879	24.882	24.885	24.888	24.891
843	24.894	24.897	24.900	24.903	24.906	24.909	24.911	24.914	24.917	24.920
844	24.923	24.926	24.929	24.932	24.935	24.938	24.941	24.944	24.947	24.950
845	24.953	24.956	24.959	24.962	24.965	24.968	24.971	24.974	24.976	24.979
846	24.982	24.985	24.988	24.991	24.994	24.997	25.000	25.003	25.006	25.009
847	25.012	25.015	25.018	25.021	25.024	25.027	25.030	25.033	25.036	25.038
848	25.041	25.044	25.047	25.050	25.053	25.056	25.059	25.062	25.065	25.068
849	25.071	25.074	25.077	25.080	25.083	25.086	25.089	25.092	25.095	25.098
850	25.100	25.103	25.106	25.109	25.112	25.115	25.118	25.121	25.124	25.127

(continued)

Proportional parts										
	mb.	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in. Hg	.000	.001	.001	.001	.001	.002	.002	.002	.003

TABLE 1.4.2 (CONTINUED)

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Millibars	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
850	25.100	25.103	25.106	25.109	25.112	25.115	25.118	25.121	25.124	25.127
851	25.130	25.133	25.136	25.139	25.142	25.145	25.148	25.151	25.154	25.157
852	25.160	25.162	25.165	25.168	25.171	25.174	25.177	25.180	25.183	25.186
853	25.189	25.192	25.195	25.198	25.201	25.204	25.207	25.210	25.213	25.216
854	25.219	25.222	25.225	25.227	25.230	25.233	25.236	25.239	25.242	25.245
855	25.248	25.251	25.254	25.257	25.260	25.263	25.266	25.269	25.272	25.275
856	25.278	25.281	25.284	25.287	25.289	25.292	25.295	25.298	25.301	25.304
857	25.307	25.310	25.313	25.316	25.319	25.322	25.325	25.328	25.331	25.334
858	25.337	25.340	25.343	25.346	25.349	25.351	25.354	25.357	25.360	25.363
859	25.366	25.269	25.372	25.375	25.378	25.381	25.384	25.387	25.390	25.393
860	25.396	25.399	25.402	25.405	25.408	25.411	25.414	25.416	25.419	25.422
861	25.425	25.428	25.431	25.434	25.437	25.440	25.443	25.446	25.449	25.452
862	25.455	25.458	25.461	25.464	25.467	25.470	25.473	25.476	25.478	25.481
863	25.484	25.487	25.490	25.493	25.496	25.499	25.502	25.505	25.508	25.511
864	25.514	25.517	25.520	25.523	25.526	25.529	25.532	25.535	25.538	25.540
865	25.543	25.546	25.549	25.552	25.555	25.558	25.561	25.564	25.567	25.570
866	25.573	25.576	25.579	25.582	25.585	25.588	25.591	25.594	25.597	25.600
867	25.602	25.605	25.608	25.611	25.614	25.617	25.620	25.623	25.626	25.629
868	25.632	25.635	25.638	25.641	25.644	25.647	25.650	25.653	25.656	25.659
869	25.662	25.665	25.667	25.670	25.673	25.676	25.679	25.682	25.685	25.688
870	25.691	25.694	25.697	25.700	25.703	25.706	25.709	25.712	25.715	25.718
871	25.721	25.724	25.727	25.729	25.732	25.735	25.738	25.741	25.744	25.747
872	25.750	25.753	25.756	25.759	25.762	25.765	25.768	25.771	25.774	25.777
873	25.780	25.783	25.786	25.789	25.791	25.794	25.797	25.800	25.803	25.806
874	25.809	25.812	25.815	25.818	25.821	25.824	25.827	25.830	25.833	25.836
875	25.839	25.842	25.845	25.848	25.851	25.853	25.856	25.859	25.862	25.865
876	25.868	25.871	25.874	25.877	25.880	25.883	25.886	25.889	25.892	25.895
877	25.898	25.901	25.904	25.907	25.910	25.913	25.916	25.918	25.921	25.924
878	25.927	25.930	25.933	25.936	25.939	25.942	25.945	25.948	25.951	25.954
879	25.957	25.960	25.963	25.966	25.969	25.972	25.975	25.978	25.980	25.983
880	25.986	25.989	25.992	25.995	25.998	26.001	26.004	26.007	26.010	26.013
881	26.016	26.019	26.022	26.025	26.028	26.031	26.034	26.037	26.040	26.042
882	26.045	26.048	26.051	26.054	26.057	26.060	26.063	26.066	26.069	26.072
883	26.075	26.078	26.081	26.084	26.087	26.090	26.093	26.096	26.099	26.102
884	26.105	26.107	26.110	26.113	26.116	26.119	26.122	26.125	26.128	26.131
885	26.134	26.137	26.140	26.143	26.146	26.149	26.152	26.155	26.158	26.161
886	26.164	26.167	26.169	26.172	26.175	26.178	26.181	26.184	26.187	26.190
887	26.193	26.196	26.199	26.202	26.205	26.208	26.211	26.214	26.217	26.220
888	26.223	26.226	26.229	26.231	26.234	26.237	26.240	26.243	26.246	26.249
889	26.252	26.255	26.258	26.261	26.264	26.267	26.270	26.273	26.276	26.279
890	26.282	26.285	26.288	26.291	26.293	26.296	26.299	26.302	26.305	26.308
891	26.311	26.314	26.317	26.320	26.323	26.326	26.329	26.332	26.335	26.338
892	26.341	26.344	26.347	26.350	26.353	26.356	26.358	26.361	26.364	26.367
893	26.370	26.373	26.376	26.379	26.382	26.385	26.388	26.391	26.394	26.397
894	26.400	26.403	26.406	26.409	26.412	26.415	26.418	26.420	26.423	26.426
895	26.429	26.432	26.435	26.438	26.441	26.444	26.447	26.450	26.453	26.456
896	26.459	26.462	26.465	26.468	26.471	26.474	26.477	26.480	26.482	26.485
897	26.488	26.491	26.494	26.497	26.500	26.503	26.506	26.509	26.512	26.515
898	26.518	26.521	26.524	26.527	26.530	26.533	26.536	26.539	26.542	26.544
899	26.547	26.550	26.553	26.556	26.559	26.562	26.565	26.568	26.571	26.574
900	26.577	26.580	26.583	26.586	26.589	26.592	26.595	26.598	26.601	26.604

(*continued*)

Proportional parts										
	mb.	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in. Hg	.000	.001	.001	.001	.001	.002	.002	.002	.003

TABLE 1.4.2 (CONTINUED)

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Millibars	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
900	26.577	26.580	26.583	26.586	26.589	26.592	26.595	26.598	26.601	26.604
901	26.607	26.609	26.612	26.615	26.618	26.621	26.624	26.627	26.630	26.633
902	26.636	26.639	26.642	26.645	26.648	26.651	26.654	26.657	26.660	26.663
903	26.666	26.669	26.671	26.674	26.677	26.680	26.683	26.686	26.689	26.692
904	26.695	26.698	26.701	26.704	26.707	26.710	26.713	26.716	26.719	26.722
905	26.725	26.728	26.731	26.733	26.736	26.739	26.742	26.745	26.748	26.751
906	26.754	26.757	26.760	26.763	26.766	26.769	26.772	26.775	26.778	26.781
907	26.784	26.787	26.790	26.793	26.796	26.798	26.801	26.804	26.807	26.810
908	26.813	26.816	26.819	26.822	26.825	26.828	26.831	26.834	26.837	26.840
909	26.843	26.846	26.849	26.852	26.855	26.858	26.860	26.863	26.866	26.869
910	26.872	26.875	26.878	26.881	26.884	26.887	26.890	26.893	26.896	26.899
911	26.902	26.905	26.908	26.911	26.914	26.917	26.920	26.922	26.925	26.928
912	26.931	26.934	26.937	26.940	26.943	26.946	26.949	26.952	26.955	26.958
913	26.961	26.964	26.967	26.970	26.973	26.976	26.979	26.982	26.984	26.987
914	26.990	26.993	26.996	26.999	27.002	27.005	27.008	27.011	27.014	27.017
915	27.020	27.023	27.026	27.029	27.032	27.035	27.038	27.041	27.044	27.047
916	27.049	27.052	27.055	27.058	27.061	27.064	27.067	27.070	27.073	27.076
917	27.079	27.082	27.085	27.088	27.091	27.094	27.097	27.100	27.103	27.106
918	27.109	27.111	27.114	27.117	27.120	27.123	27.126	27.129	27.132	27.135
919	27.138	27.141	27.144	27.147	27.150	27.153	27.156	27.159	27.162	27.165
920	27.168	27.171	27.173	27.176	27.179	27.182	27.185	27.188	27.191	27.194
921	27.197	27.200	27.203	27.206	27.209	27.212	27.215	27.218	27.221	27.224
922	27.227	27.230	27.233	27.236	27.238	27.241	27.244	27.247	27.250	27.253
923	27.256	27.259	27.262	27.265	27.268	27.271	27.274	27.277	27.280	27.283
924	27.286	27.289	27.292	27.295	27.298	27.300	27.303	27.306	27.309	27.312
925	27.315	27.318	27.321	27.324	27.327	27.330	27.333	27.336	27.339	27.342
926	27.345	27.348	27.351	27.354	27.357	27.360	27.362	27.365	27.368	27.371
927	27.374	27.377	27.380	27.383	27.386	27.389	27.392	27.395	27.398	27.401
928	27.404	27.407	27.410	27.413	27.416	27.419	27.422	27.424	27.427	27.430
929	27.433	27.436	27.439	27.442	27.445	27.448	27.451	27.454	27.457	27.460
930	27.463	27.466	27.469	27.472	27.475	27.478	27.481	27.484	27.487	27.489
931	27.492	27.495	27.498	27.501	27.504	27.507	27.510	27.513	27.516	27.519
932	27.522	27.525	27.528	27.531	27.534	27.537	27.540	27.543	27.546	27.549
933	27.551	27.554	27.557	27.560	27.563	27.566	27.569	27.572	27.575	27.578
934	27.581	27.584	27.587	27.590	27.593	27.596	27.599	27.602	27.605	27.608
935	27.611	27.613	27.616	27.619	27.622	27.625	27.628	27.631	27.634	27.637
936	27.640	27.643	27.646	27.649	27.652	27.655	27.658	27.661	27.664	27.667
937	27.670	27.673	27.675	27.678	27.681	27.684	27.687	27.690	27.693	27.696
938	27.699	27.702	27.705	27.708	27.711	27.714	27.717	27.720	27.723	27.726
939	27.729	27.732	27.735	27.738	27.740	27.743	27.746	27.749	27.752	27.755
940	27.758	27.761	27.764	27.767	27.770	27.773	27.776	27.779	27.782	27.785
941	27.788	27.791	27.794	27.797	27.800	27.802	27.805	27.808	27.811	27.814
942	27.817	27.820	27.823	27.826	27.829	27.832	27.835	27.838	27.841	27.844
943	27.847	27.850	27.853	27.856	27.859	27.862	27.864	27.867	27.870	27.873
944	27.876	27.879	27.882	27.885	27.888	27.891	27.894	27.897	27.900	27.903
945	27.906	27.909	27.912	27.915	27.918	27.921	27.924	27.927	27.929	27.932
946	27.935	27.938	27.941	27.944	27.947	27.950	27.953	27.956	27.959	27.962
947	27.965	27.968	27.971	27.974	27.977	27.980	27.983	27.986	27.989	27.991
948	27.994	27.997	28.000	28.003	28.006	28.009	28.012	28.015	28.018	28.021
949	28.024	28.027	28.030	28.033	28.036	28.039	28.042	28.045	28.048	28.051
950	28.053	28.056	28.059	28.062	28.065	28.068	28.071	28.074	28.077	28.080

(*continued*)

Proportional parts	mb.	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in. Hg	.000	.001	.001	.001	.001	.002	.002	.002	.003

TABLE 1.4.2 (CONTINUED)

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Milli-bars	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
950	28.053	28.056	28.059	28.062	28.065	28.068	28.071	28.074	28.077	28.080
951	28.083	28.086	28.089	28.092	28.095	28.098	28.101	28.104	28.107	28.110
952	28.113	28.115	28.118	28.121	28.124	28.127	28.130	28.133	28.136	28.139
953	28.142	28.145	28.148	28.151	28.154	28.157	28.160	28.163	28.166	28.169
954	28.172	28.175	28.178	28.180	28.183	28.186	28.189	28.192	28.195	28.198
955	28.201	28.204	28.207	28.210	28.213	28.216	28.219	28.222	28.225	28.228
956	28.231	28.234	28.237	28.240	28.242	28.245	28.248	28.251	28.254	28.257
957	28.260	28.263	28.266	28.269	28.272	28.275	28.278	28.281	28.284	28.287
958	28.290	28.293	28.296	28.299	28.302	28.304	28.307	28.310	28.313	28.316
959	28.319	28.322	28.325	28.328	28.331	28.334	28.337	28.340	28.343	28.346
960	28.349	28.352	28.355	28.358	28.361	28.364	28.366	28.369	28.372	28.375
961	28.378	28.381	28.384	28.387	28.390	28.393	28.396	28.399	28.402	28.405
962	28.408	28.411	28.414	28.417	28.420	28.423	28.426	28.429	28.431	28.434
963	28.437	28.440	28.443	28.446	28.449	28.452	28.455	28.458	28.461	28.464
964	28.467	28.470	28.473	28.476	28.479	28.482	28.485	28.488	28.491	28.493
965	28.496	28.499	28.502	28.505	28.508	28.511	28.514	28.517	28.520	28.523
966	28.526	28.529	28.532	28.535	28.538	28.541	28.544	28.547	28.550	28.553
967	28.555	28.558	28.561	28.564	28.567	28.570	28.573	28.576	28.579	28.582
968	28.585	28.588	28.591	28.594	28.597	28.600	28.603	28.606	28.609	28.612
969	28.615	28.618	28.620	28.623	28.626	28.629	28.632	28.635	28.638	28.641
970	28.644	28.647	28.650	28.653	28.656	28.659	28.662	28.665	28.668	28.671
971	28.674	28.677	28.680	28.682	28.685	28.688	28.691	28.694	28.697	28.700
972	28.703	28.706	28.709	28.712	28.715	28.718	28.721	28.724	28.727	28.730
973	28.733	28.736	28.739	28.742	28.744	28.747	28.750	28.753	28.756	28.759
974	28.762	28.765	28.768	28.771	28.774	28.777	28.780	28.783	28.786	28.789
975	28.792	28.795	28.798	28.801	28.804	28.806	28.809	28.812	28.815	28.818
976	28.821	28.824	28.827	28.830	28.833	28.836	28.839	28.842	28.845	28.848
977	28.851	28.854	28.857	28.860	28.863	28.866	28.869	28.871	28.874	28.877
978	28.880	28.883	28.886	28.889	28.892	28.895	28.898	28.901	28.904	28.907
979	28.910	28.913	28.916	28.919	28.922	28.925	28.928	28.931	28.933	28.936
980	28.939	28.942	28.945	28.948	28.951	28.954	28.957	28.960	28.963	28.966
981	28.969	28.972	28.975	28.978	28.981	28.984	28.987	28.990	28.993	28.995
982	28.998	29.001	29.004	29.007	29.010	29.013	29.016	29.019	29.022	29.025
983	29.028	29.031	29.034	29.037	29.040	29.043	29.046	29.049	29.052	29.055
984	29.058	29.060	29.063	29.066	29.069	29.072	29.075	29.078	29.081	29.084
985	29.087	29.090	29.093	29.096	29.099	29.102	29.105	29.108	29.111	29.114
986	29.117	29.120	29.122	29.125	29.128	29.131	29.134	29.137	29.140	29.143
987	29.146	29.149	29.152	29.155	29.158	29.161	29.164	29.167	29.170	29.173
988	29.176	29.179	29.182	29.184	29.187	29.190	29.193	29.196	29.199	29.202
989	29.205	29.208	29.211	29.214	29.217	29.220	29.223	29.226	29.229	29.232
990	29.235	29.238	29.241	29.244	29.246	29.249	29.252	29.255	29.258	29.261
991	29.264	29.267	29.270	29.273	29.276	29.279	29.282	29.285	29.288	29.291
992	29.294	29.297	29.300	29.303	29.306	29.309	29.311	29.314	29.317	29.320
993	29.323	29.326	29.329	29.332	29.335	29.338	29.341	29.344	29.347	29.350
994	29.353	29.356	29.359	29.362	29.365	29.368	29.371	29.373	29.376	29.379
995	29.382	29.385	29.388	29.391	29.394	29.397	29.400	29.403	29.406	29.409
996	29.412	29.415	29.418	29.421	29.424	29.427	29.430	29.433	29.435	29.438
997	29.441	29.444	29.447	29.450	29.453	29.456	29.459	29.462	29.465	29.468
998	29.471	29.474	29.477	29.480	29.483	29.486	29.489	29.492	29.495	29.497
999	29.500	29.503	29.506	29.509	29.512	29.515	29.518	29.521	29.524	29.527
1000	29.530	29.533	29.536	29.539	29.542	29.545	29.548	29.551	29.554	29.557

(continued)

Proportional parts	mb.	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in. Hg	.000	.001	.001	.001	.001	.002	.002	.002	.003

TABLE 1.4.2 (CONTINUED)

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Millibars	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
1000	29.530	29.533	29.536	29.539	29.542	29.545	29.548	29.551	29.554	29.557
1001	29.560	29.562	29.565	29.568	29.571	29.574	29.577	29.580	29.583	29.586
1002	29.589	29.592	29.595	29.598	29.601	29.604	29.607	29.610	29.613	29.616
1003	29.619	29.622	29.624	29.627	29.630	29.633	29.636	29.639	29.642	29.645
1004	29.648	29.651	29.654	29.657	29.660	29.663	29.666	29.669	29.672	29.675
1005	29.678	29.681	29.684	29.686	29.689	29.692	29.695	29.698	29.701	29.704
1006	29.707	29.710	29.713	29.716	29.719	29.722	29.725	29.728	29.731	29.734
1007	29.737	29.740	29.743	29.746	29.749	29.751	29.754	29.757	29.760	29.763
1008	29.766	29.769	29.772	29.775	29.778	29.781	29.784	29.787	29.790	29.793
1009	29.796	29.799	29.802	29.805	29.808	29.811	29.813	29.816	29.819	29.822
1010	29.825	29.828	29.831	29.834	29.837	29.840	29.843	29.846	29.849	29.852
1011	29.855	29.858	29.861	29.864	29.867	29.870	29.873	29.875	29.878	29.881
1012	29.884	29.887	29.890	29.893	29.896	29.899	29.902	29.905	29.908	29.911
1013	29.914	29.917	29.920	29.923	29.926	29.929	29.932	29.935	29.937	29.940
1014	29.943	29.946	29.949	29.952	29.955	29.958	29.961	29.964	29.967	29.970
1015	29.973	29.976	29.979	29.982	29.985	29.988	29.991	29.994	29.997	30.000
1016	30.002	30.005	30.008	30.011	30.014	30.017	30.020	30.023	30.026	30.029
1017	30.032	30.035	30.038	30.041	30.044	30.047	30.050	30.053	30.056	30.059
1018	30.062	30.064	30.067	30.070	30.073	30.076	30.079	30.082	30.085	30.088
1019	30.091	30.094	30.097	30.100	30.103	30.106	30.109	30.112	30.115	30.118
1020	30.121	30.124	30.126	30.129	30.132	30.135	30.138	30.141	30.144	30.147
1021	30.150	30.153	30.156	30.159	30.162	30.165	30.168	30.171	30.174	30.177
1022	30.180	30.183	30.186	30.188	30.191	30.194	30.197	30.200	30.203	30.206
1023	30.209	30.212	30.215	30.218	30.221	30.224	30.227	30.230	30.233	30.236
1024	30.239	30.242	30.245	30.248	30.251	30.253	30.256	30.259	30.262	30.265
1025	30.268	30.271	30.274	30.277	30.280	30.283	30.286	30.289	30.292	30.295
1026	30.298	30.301	30.304	30.307	30.310	30.313	30.315	30.318	30.321	30.324
1027	30.327	30.330	30.333	30.336	30.339	30.342	30.345	30.348	30.351	30.354
1028	30.357	30.360	30.363	30.366	30.369	30.372	30.375	30.377	30.380	30.383
1029	30.386	30.389	30.392	30.395	30.398	30.401	30.404	30.407	30.410	30.413
1030	30.416	30.419	30.422	30.425	30.428	30.431	30.434	30.437	30.440	30.442
1031	30.445	30.448	30.451	30.454	30.457	30.460	30.463	30.466	30.469	30.472
1032	30.475	30.478	30.481	30.484	30.487	30.490	30.493	30.496	30.499	30.502
1033	30.504	30.507	30.510	30.513	30.516	30.519	30.522	30.525	30.528	30.531
1034	30.534	30.537	30.540	30.543	30.546	30.549	30.552	30.555	30.558	30.561
1035	30.564	30.566	30.569	30.572	30.575	30.578	30.581	30.584	30.587	30.590
1036	30.593	30.596	30.599	30.602	30.605	30.608	30.611	30.614	30.617	30.620
1037	30.623	30.626	30.628	30.631	30.634	30.637	30.640	30.643	30.646	30.649
1038	30.652	30.655	30.658	30.661	30.664	30.667	30.670	30.673	30.676	30.679
1039	30.682	30.685	30.688	30.691	30.693	30.696	30.699	30.702	30.705	30.708
1040	30.711	30.714	30.717	30.720	30.723	30.726	30.729	30.732	30.735	30.738
1041	30.741	30.744	30.747	30.750	30.753	30.755	30.758	30.761	30.764	30.767
1042	30.770	30.773	30.776	30.779	30.782	30.785	30.788	30.791	30.794	30.797
1043	30.800	30.803	30.806	30.809	30.812	30.815	30.817	30.820	30.823	30.826
1044	30.829	30.832	30.835	30.838	30.841	30.844	30.847	30.850	30.853	30.856
1045	30.859	30.862	30.865	30.868	30.871	30.874	30.877	30.880	30.882	30.885
1046	30.888	30.891	30.894	30.897	30.900	30.903	30.906	30.909	30.912	30.915
1047	30.918	30.921	30.924	30.927	30.930	30.933	30.936	30.939	30.942	30.944
1048	30.947	30.950	30.953	30.956	30.959	30.962	30.965	30.968	30.971	30.974
1049	30.977	30.980	30.983	30.986	30.989	30.992	30.995	30.998	31.001	31.004
1050	31.006	31.009	31.012	31.015	31.018	31.021	31.024	31.027	31.030	31.033

(continued)

Proportional parts	mb.	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in. Hg	.000	.001	.001	.001	.001	.002	.002	.002	.003

TABLE 1.4.2 (CONTINUED)

Millibars to Inches of Mercury

[1 millibar = 0.02952998 inch of mercury.]

Milli-bars	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg	In. Hg
1050	31.006	31.009	31.012	31.015	31.018	31.021	31.024	31.027	31.030	31.033
1051	31.036	31.039	31.042	31.045	31.048	31.051	31.054	31.057	31.060	31.063
1052	31.066	31.068	31.071	31.074	31.077	31.080	31.083	31.086	31.089	31.092
1053	31.095	31.098	31.101	31.104	31.107	31.110	31.113	31.116	31.119	31.122
1054	31.125	31.128	31.131	31.133	31.136	31.139	31.142	31.145	31.148	31.151
1055	31.154	31.157	31.160	31.163	31.166	31.169	31.172	31.175	31.178	31.181
1056	31.184	31.187	31.190	31.193	31.195	31.198	31.201	31.204	31.207	31.210
1057	31.213	31.216	31.219	31.222	31.225	31.228	31.231	31.234	31.237	31.240
1058	31.243	31.246	31.249	31.252	31.255	31.257	31.260	31.263	31.266	31.269
1059	31.272	31.275	31.278	31.281	31.284	31.287	31.290	31.293	31.296	31.299
1060	31.302	31.305	31.308	31.311	31.314	31.317	31.319	31.322	31.325	31.328
1061	31.331	31.334	31.337	31.340	31.343	31.346	31.349	31.352	31.355	31.358
1062	31.361	31.364	31.367	31.370	31.373	31.376	31.379	31.382	31.384	31.387
1063	31.390	31.393	31.396	31.399	31.402	31.405	31.408	31.411	31.414	31.417
1064	31.420	31.423	41.426	31.429	31.432	31.435	31.438	31.441	31.444	31.446
1065	31.449	31.452	31.455	31.458	31.461	31.464	31.467	31.470	31.473	31.476
1066	31.479	31.482	31.485	31.488	31.491	31.494	31.497	31.500	31.503	31.506
1067	31.508	31.511	31.514	31.517	31.520	31.523	31.526	31.529	31.532	31.535
1068	31.538	31.541	31.544	31.547	31.550	31.553	31.556	31.559	31.562	31.565
1069	31.568	31.571	31.573	31.576	31.579	31.582	31.585	31.588	31.591	31.594
1070	31.597	31.600	31.603	31.606	31.609	31.612	31.615	31.618	31.621	31.624
1071	31.627	31.630	31.633	31.635	31.638	31.641	31.644	31.647	31.650	31.653
1072	31.656	31.659	31.662	31.665	31.668	31.671	31.674	31.677	31.680	31.683
1073	31.686	31.689	31.692	31.695	31.697	31.700	31.703	31.706	31.709	31.712
1074	31.715	31.718	31.721	31.724	31.727	31.730	31.733	31.736	31.739	31.742
1075	31.745	31.748	31.751	31.754	31.757	31.759	31.762	31.765	31.768	31.771
1076	31.774	31.777	31.780	31.783	31.786	31.789	31.792	31.795	31.798	31.801
1077	31.804	31.807	31.810	31.813	31.816	31.819	31.822	31.824	31.827	31.830
1078	31.833	31.836	31.839	31.842	31.845	31.848	31.851	31.854	31.857	31.860
1079	31.863	31.866	31.869	31.872	31.875	31.878	31.881	31.884	31.886	31.889
1080	31.892	31.895	31.898	31.901	31.904	31.907	31.910	31.913	31.916	31.919
1081	31.922	31.925	31.928	31.931	31.934	31.937	31.940	31.943	31.946	31.948
1082	31.951	31.954	31.957	31.960	31.963	31.966	31.969	31.972	31.975	31.978
1083	31.981	31.984	31.987	31.990	31.993	31.996	31.999	32.002	32.005	32.008
1084	32.010	32.013	32.016	32.019	32.022	32.025	32.028	32.031	32.034	32.037
1085	32.040	32.043	32.046	32.049	32.052	32.055	32.058	32.061	32.064	32.067
1086	32.070	32.073	32.075	32.078	32.081	32.084	32.087	32.090	32.093	32.096
1087	32.099	32.102	32.105	32.108	32.111	32.114	32.117	32.120	32.123	32.126
1088	32.129	32.132	32.135	32.137	32.140	32.143	32.146	32.149	32.152	32.155
1089	32.158	32.161	32.164	32.167	32.170	32.173	32.176	32.179	32.182	32.185
1090	32.188	32.191	32.194	32.197	32.199	32.202	32.205	32.208	32.211	32.214
1091	32.217	32.220	32.223	32.226	32.229	32.232	32.235	32.238	32.241	32.244
1092	32.247	32.250	32.253	32.256	32.259	32.262	32.264	32.267	32.270	32.273
1093	32.276	32.279	32.282	32.285	32.288	32.291	32.294	32.297	32.300	32.303
1094	32.306	32.309	32.312	32.315	32.318	32.321	32.324	32.326	32.329	32.332
1095	32.335	32.338	32.341	32.344	32.347	32.350	32.353	32.356	32.359	32.362
1096	32.365	32.368	32.371	32.374	32.377	32.380	32.383	32.386	32.388	32.391
1097	32.394	32.397	32.400	32.403	32.406	32.409	32.412	32.415	32.418	32.421
1098	32.424	32.427	32.430	32.433	32.436	32.439	32.442	32.445	32.448	32.450
1099	32.453	32.456	32.459	32.462	32.465	32.468	32.471	32.474	32.477	32.480
1100	32.483	32.486	32.489	32.492	32.495	32.498	32.501	32.504	32.507	32.510

(*end*)

Proportional parts										
	mb.	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in. Hg	.000	.001	.001	.001	.001	.002	.002	.002	.003

TABLE 3.1.1

*Corrections to Reduce Mercurial Barometer Readings to Standard Gravity for Ships at Sea Level Where Readings Are in Inches**

Tabular values of $\frac{g_{\phi,o} - g_o}{g_o} B$ *in inches where*

$g_{\phi,o}$ = *acceleration of gravity at latitude* ϕ *at sea level, in cm/sec*^{2}
g_o = *standard acceleration of gravity, 980.665 cm/sec*^{2}
B = *height of mercury column, in inches*
[Apply corrections according to algebraic sign indicated.]

Latitude ϕ	Height of mercury column, inches							
	25	26	27	28	29	30	31	32
	in.	in.	in.	in	in.	in.	in	in.
90°	+0.065	+0.067	+0.070	+0.073	+0.075	+0.078	+0.080	+0.083
89°	.065	.067	.070	.073	.075	.078	.080	.083
88°	.065	.067	.070	.072	.075	.078	.080	.083
87°	.064	.067	.070	.072	.075	.077	.080	.083
86°	.064	.067	.069	.072	.074	.077	.080	.082
85°	+.064	+.066	+.069	+.071	+.074	+.077	+.079	+.082
84°	.063	.066	.068	.071	.074	.076	.079	.081
83°	.063	.065	.068	.070	.073	.075	.078	.080
82°	.062	.065	.067	.070	.072	.075	.077	.080
81°	.062	.064	.067	.069	.071	.074	.076	.079
80°	+.061	+.063	+.066	+.068	+.071	+.073	+.075	+.078
79°	.060	.062	.065	.067	.070	.072	.074	.076
78°	.059	.061	.064	.066	.069	.071	.073	.076
77°	.058	.060	.063	.065	.067	.070	.072	.074
76°	.057	.059	.062	.064	.066	.068	.071	.073
75°	+.056	+.058	+.060	+.063	+.065	+.067	+.069	+.072
74°	.055	.057	.059	.061	.064	.066	.068	.070
73°	.054	.056	.058	.060	.062	.064	.066	.068
72°	.052	.054	.056	.058	.061	.063	.065	.067
71°	.051	.053	.055	.057	.059	.061	.063	.065
70°	+.049	+.051	+.053	+.055	+.057	+.059	+.061	+.063
69°	.048	.050	.052	.054	.055	.057	.059	.061
68°	.046	.048	.050	.052	.054	.056	.057	.059
67°	.045	.046	.048	.050	.052	.054	.055	.057
66°	.043	.045	.046	.048	.050	.052	.053	.055
65°	+.041	+.043	+.044	+.046	+.048	+.049	+.051	+.053
64°	.039	.041	.043	.044	.046	.047	.049	.050
63°	.038	.039	.041	.042	.044	.045	.047	.048
62°	.036	.037	.039	.040	.041	.043	.044	.046
61°	.034	.035	.036	.038	.039	.040	.042	.043
60°	+.032	+.033	+.034	+.036	+.037	+.038	+.039	+.041
59°	.030	.031	.032	.033	.034	.036	.037	.038
58°	.028	.029	.030	.031	.032	.033	.034	.035
57°	.026	.027	.028	.029	.030	.031	.032	.033
56°	.023	.024	.025	.026	.027	.028	.029	.030
55°	+.021	+.022	+.023	+.024	+.025	+.026	+.026	+.027
54°	.019	.020	.021	.021	.022	.023	.024	.025
53°	.017	.018	.018	.019	.020	.020	.021	.022
52°	.015	.015	.016	.016	.017	.018	.018	.019
51°	.012	.013	.013	.014	.014	.015	.015	.016
50°	+.010	+.011	+.011	+.011	+.012	+.012	+.013	+.013
49°	.008	.008	.009	.009	.009	.010	.010	.010
48°	.006	.006	.006	.006	.007	.007	.007	.007
47°	.003	.003	.004	.004	.004	.004	.004	.004
46°	+.001	+.001	+.001	+.001	+.001	+.001	+.001	+.001
45°32′40″	.000	.000	.000	.000	.000	.000	.000	.000

* These corrections should *not* be applied to aneroid barometer readings.

TABLE 3.1.1 (CONTINUED)

*Corrections to Reduce Mercurial Barometer Readings to Standard Gravity for Ships at Sea Level Where Readings Are in Inches**

Tabular values of $\frac{g_{\phi,0} - g_0}{g_0} B$ *in inches where*

$g_{\phi,0}$ = *acceleration of gravity at latitude* ϕ *at sea level, in* cm/sec^2
g_0 = *standard acceleration of gravity, 980.665* cm/sec^2
B = *height of mercury column, in inches*

[Apply corrections according to algebraic sign indicated.]

Latitude ϕ	Height of mercury column, inches							
	25	26	27	28	29	30	31	32
	in.	in.	in.	in.	in.	in.	in.	in.
45°	—.001	—.001	—.001	—.001	—.001	—.002	—.002	—.002
44°	—.004	—.004	—.004	—.004	—.004	—.004	—.004	—.005
43°	—.006	—.006	—.006	—.007	—.007	—.007	—.007	—.007
42°	—.008	—.008	—.009	—.009	—.009	—.010	—.010	—.010
41°	—.010	—.011	—.011	—.012	—.012	—.013	—.013	—.013
40°	—.013	—.013	—.014	—.014	—.015	—.015	—.016	—.016
39°	—.015	—.016	—.016	—.017	—.017	—.018	—.019	—.019
38°	—.017	—.018	—.019	—.019	—.020	—.021	—.021	—.022
37°	—.019	—.020	—.021	—.022	—.023	—.023	—.024	—.025
36°	—.022	—.022	—.023	—.024	—.025	—.026	—.027	—.028
35°	—.024	—.025	—.026	—.027	—.028	—.029	—.029	—.030
34°	—.025	—.027	—.028	—.029	—.030	—.031	—.032	—.033
33°	—.028	—.029	—.030	—.031	—.033	—.034	—.035	—.036
32°	—.030	—.031	—.033	—.034	—.035	—.036	—.037	—.039
31°	—.032	—.033	—.035	—.036	—.037	—.039	—.040	—.041
30°	—.034	—.036	—.037	—.038	—.040	—.041	—.042	—.044
29°	—.036	—.038	—.039	—.040	—.042	—.043	—.045	—.046
28°	—.038	—.040	—.041	—.043	—.044	—.046	—.047	—.049
27°	—.040	—.042	—.043	—.045	—.046	—.048	—.050	—.051
26°	—.042	—.043	—.045	—.047	—.048	—.050	—.052	—.053
25°	—.044	—.045	—.047	—.049	—.051	—.052	—.054	—.056
24°	—.045	—.047	—.049	—.051	—.053	—.054	—.056	—.058
23°	—.047	—.049	—.051	—.053	—.054	—.056	—.058	—.060
22°	—.049	—.050	—.052	—.054	—.056	—.058	—.060	—.062
21°	—.050	—.052	—.054	—.056	—.058	—.060	—.062	—.064
20°	—.052	—.054	—.056	—.058	—.060	—.062	—.064	—.066
19°	—.053	—.055	—.057	—.059	—.062	—.064	—.066	—.068
18°	—.054	—.057	—.059	—.061	—.063	—.065	—.068	—.070
17°	—.056	—.058	—.060	—.062	—.064	—.067	—.069	—.071
16°	—.057	—.059	—.062	—.064	—.066	—.068	—.071	—.073
15°	—.058	—.061	—.063	—.065	—.068	—.070	—.072	—.075
14°	—.059	—.062	—.064	—.066	—.069	—.071	—.074	—.076
13°	—.060	—.063	—.065	—.068	—.070	—.072	—.075	—.077
12°	—.061	—.064	—.066	—.069	—.071	—.074	—.076	—.079
11°	—.062	—.065	—.067	—.070	—.072	—.075	—.077	—.080
10°	—.063	—.066	—.068	—.071	—.073	—.076	—.078	—.081
9°	—.064	—.066	—.069	—.071	—.074	—.077	—.079	—.082
8°	—.065	—.067	—.070	—.072	—.075	—.077	—.080	—.083
7°	—.065	—.068	—.070	—.073	—.075	—.078	—.081	—.083
6°	—.066	—.068	—.071	—.073	—.076	—.079	—.081	—.084
5°	—.066	—.068	—.071	—.074	—.077	—.079	—.082	—.085
4°	—.066	—.069	—.072	—.074	—.077	—.080	—.082	—.085
3°	—.067	—.069	—.072	—.075	—.077	—.080	—.083	—.085
2°	—.067	—.070	—.072	—.075	—.078	—.080	—.083	—.086
1°	—.067	—.070	—.072	—.075	—.078	—.080	—.083	—.086
0°	—.067	—.070	—.072	—.075	—.078	—.080	—.083	—.086

* These corrections should *not* be applied to aneroid barometer readings.

TABLE 3.1.2

*Corrections to Reduce Mercurial Barometer Readings to Standard Gravity for Ships at Sea Level Where Readings Are in Millibars or Millimeters**

Tabular values of $\frac{g_{\phi,o} - g_o}{g_o}B$, *in millibars or millimeters where*

$g_{\phi,o}$ = *acceleration of gravity at latitude* ϕ *at sea level, in cm/sec*^{2}

g_o = *standard acceleration of gravity at sea level, 980.665 cm/sec*^{2}

B = *height of mercury column, in millibars or millimeters.*

[Apply corrections according to algebraic sign indicated.]

Latitude ϕ	Height of mercury column, millibars or millimeters					
	600	700	800	900	1000	1100
	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.
90°	+1.56	+1.82	+2.07	+2.33	+2.59	+2.85
89°	1.55	1.81	2.07	2.33	2.59	2.85
88°	1.55	1.81	2.07	2.33	2.59	2.85
87°	1.55	1.81	2.06	2.32	2.58	2.84
86°	1.54	1.80	2.05	2.31	2.57	2.82
85°	+1.53	+1.79	+2.04	+2.30	+2.55	+2.81
84°	1.52	1.77	2.03	2.28	2.54	2.79
83°	1.51	1.76	2.01	2.26	2.52	2.77
82°	1.49	1.74	1.99	2.24	2.49	2.74
81°	1.48	1.72	1.97	2.22	2.46	2.71
80°	+1.46	+1.70	+1.95	+2.19	+2.43	+2.68
79°	1.44	1.68	1.92	2.16	2.40	2.64
78°	1.42	1.65	1.89	2.13	2.36	2.60
77°	1.40	1.63	1.86	2.09	2.33	2.56
76°	1.37	1.60	1.83	2.05	2.28	2.51
75°	+1.34	+1.57	+1.79	+2.01	+2.24	+2.46
74°	1.31	1.53	1.75	1.97	2.19	2.41
73°	1.28	1.50	1.71	1.93	2.14	2.35
72°	1.25	1.46	1.67	1.88	2.09	2.30
71°	1.22	1.42	1.63	1.83	2.03	2.24
70°	+1.18	+1.38	+1.58	+1.78	+1.97	+2.17
69°	1.15	1.34	1.53	1.72	1.91	2.10
68°	1.11	1.30	1.48	1.67	1.85	2.04
67°	1.07	1.25	1.43	1.61	1.79	1.96
66°	1.03	1.20	1.37	1.55	1.72	1.89
65°	+0.99	+1.15	+1.32	+1.48	+1.65	+1.81
64°	0.95	1.10	1.26	1.42	1.58	1.73
63°	0.90	1.05	1.20	1.35	1.50	1.65
62°	0.86	1.00	1.14	1.28	1.43	1.57
61°	0.81	0.94	1.08	1.21	1.35	1.48
60°	+0.76	+0.89	+1.02	+1.14	+1.27	+1.40
59°	0.71	0.83	0.95	1.07	1.19	1.31
58°	0.66	0.77	0.89	1.00	1.11	1.22
57°	0.61	0.72	0.82	0.92	1.02	1.13
56°	0.56	0.66	0.75	0.85	0.94	1.03
55°	+0.51	+0.60	+0.68	+0.77	+0.85	+0.94
54°	0.46	0.54	0.61	0.69	0.77	0.84
53°	0.41	0.47	0.54	0.61	0.68	0.74
52°	0.35	0.41	0.47	0.53	0.59	0.65
51°	0.30	0.35	0.40	0.45	0.50	0.55
50°	+0.24	+0.29	+0.33	+0.37	+0.41	+0.45
49°	0.19	0.22	0.25	0.29	0.32	0.35
48°	0.14	0.16	0.18	0.20	0.23	0.25
47°	0.08	0.09	0.11	0.12	0.13	0.15
46°	+0.03	+0.03	+0.03	+0.04	+0.04	+0.05
45°32′40″	0.00	0.00	0.00	0.00	0.00	0.00

*These corrections should *not* be applied to aneroid barometer readings.

TABLE 3.1.2 (CONTINUED)

*Corrections to Reduce Mercurial Barometer Readings to Standard Gravity for Ships at Sea Level Where Readings Are in Millibars or Millimeters**

Tabular values of $\frac{g_{\phi,0} - g_0}{g_0}B$, *in millibars or millimeters where*

$g_{\phi,0}$ = *acceleration of gravity at latitude* ϕ *at sea level, in cm/sec*^{2}
g_0 = *standard acceleration of gravity at sea level, 980.665 cm/sec*^{2}
B = *height of mercury column, in millibars or millimeters.*

[Apply corrections according to algebraic sign indicated.]

Latitude ϕ	Height of mercury column, millibars or millimeters					
	600	700	800	900	1000	1100
	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.
45°	−0.03	−0.04	−0.04	−0.05	−0.05	−0.06
44°	−0.09	−0.10	−0.11	−0.13	−0.14	−0.16
43°	−0.14	−0.16	−0.19	−0.21	−0.23	−0.26
42°	−0.20	−0.23	−0.26	−0.29	−0.33	−0.36
41°	−0.25	−0.29	−0.33	−0.38	−0.42	−0.46
40°	−0.30	−0.36	−0.41	−0.46	−0.51	−0.56
39°	−0.36	−0.42	−0.48	−0.54	−0.60	−0.66
38°	−0.41	−0.48	−0.55	−0.62	−0.69	−0.76
37°	−0.46	−0.54	−0.62	−0.69	−0.78	−0.85
36°	−0.52	−0.61	−0.69	−0.78	−0.87	−0.95
35°	−0.57	−0.67	−0.76	−0.86	−0.95	−1.05
34°	−0.62	−0.73	−0.83	−0.93	−1.04	−1.14
33°	−0.67	−0.79	−0.90	−1.01	−1.12	−1.23
32°	−0.72	−0.84	−0.96	−1.08	−1.21	−1.33
31°	−0.77	−0.90	−1.03	−1.16	−1.29	−1.42
30°	−0.82	−0.96	−1.09	−1.23	−1.37	−1.50
29°	−0.87	−1.01	−1.16	−1.30	−1.45	−1.59
28°	−0.91	−1.07	−1.22	−1.37	−1.52	−1.67
27°	−0.96	−1.12	−1.28	−1.44	−1.60	−1.76
26°	−1.00	−1.17	−1.34	−1.50	−1.67	−1.84
25°	−1.05	−1.22	−1.39	−1.57	−1.74	−1.92
24°	−1.09	−1.27	−1.45	−1.63	−1.81	−1.99
23°	−1.13	−1.32	−1.50	−1.69	−1.88	−2.07
22°	−1.17	−1.36	−1.56	−1.75	−1.94	−2.14
21°	−1.20	−1.40	−1.61	−1.81	−2.01	−2.21
20°	−1.24	−1.45	−1.65	−1.86	−2.07	−2.27
19°	−1.27	−1.49	−1.70	−1.91	−2.12	−2.34
18°	−1.31	−1.53	−1.74	−1.96	−2.18	−2.40
17°	−1.34	−1.56	−1.79	−2.01	−2.23	−2.46
16°	−1.37	−1.60	−1.83	−2.05	−2.28	−2.51
15°	−1.40	−1.63	−1.86	−2.10	−2.33	−2.56
14°	−1.42	−1.66	−1.90	−2.14	−2.37	−2.61
13°	−1.45	−1.69	−1.93	−2.17	−2.42	−2.66
12°	−1.47	−1.72	−1.96	−2.21	−2.45	−2.70
11°	−1.49	−1.74	−1.99	−2.24	−2.49	−2.74
10°	−1.51	−1.77	−2.02	−2.27	−2.52	−2.78
9°	−1.53	−1.79	−2.04	−2.30	−2.55	−2.81
8°	−1.55	−1.81	−2.06	−2.32	−2.58	−2.84
7°	−1.56	−1.82	−2.08	−2.34	−2.60	−2.86
6°	−1.57	−1.84	−2.10	−2.36	−2.62	−2.89
5°	−1.58	−1.85	−2.11	−2.38	−2.64	−2.91
4°	−1.59	−1.86	−2.12	−2.39	−2.66	−2.92
3°	−1.60	−1.87	−2.13	−2.40	−2.67	−2.93
2°	−1.61	−1.87	−2.14	−2.41	−2.68	−2.94
1°	−1.61	−1.88	−2.14	−2.41	−2.68	−2.95
0°	−1.61	−1.88	−2.14	−2.41	−2.68	−2.95

*These corrections should *not* be applied to aneroid barometer readings.

TABLE 3.2.1

Acceleration of Gravity at Sea Level ($g_{\phi,0}$)

$g_{\phi,0} = 980.6160\ (1 - 0.0026373 \cos 2\phi + 0.0000059 \cos^2 2\phi)$ *in cm/sec²*.

Latitude ϕ	Minutes of latitude					
	0′	10′	20′	30′	40′	50′
	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²
0°	978.036	978.036	978.036	978.036	978.036	978.037
1°	978.037	978.038	978.038	978.039	978.040	978.041
2°	978.042	978.043	978.044	978.045	978.047	978.048
3°	978.050	978.051	978.053	978.055	978.057	978.059
4°	978.061	978.063	978.065	978.067	978.070	978.072
5°	978.075	978.077	978.080	978.083	978.086	978.089
6°	978.092	978.095	978.098	978.102	978.105	978.109
7°	978.112	978.116	978.120	978.123	978.127	978.131
8°	978.135	978.140	978.144	978.148	978.153	978.157
9°	978.162	978.166	978.171	978.176	978.181	978.186
10°	978.191	978.196	978.201	978.207	978.212	978.218
11°	978.223	978.229	978.234	978.240	978.246	978.252
12°	978.258	978.264	978.271	978.277	978.283	978.290
13°	978.296	978.303	978.310	978.316	978.323	978.330
14°	978.337	978.344	978.351	978.358	978.366	978.373
15°	978.381	978.388	978.396	978.403	978.411	978.419
16°	978.427	978.435	978.443	978.451	978.459	978.468
17°	978.476	978.484	978.493	978.501	978.510	978.519
18°	978.528	978.536	978.545	978.554	978.563	978.572
19°	978.582	978.591	978.600	978.610	978.619	978.629
20°	978.638	978.648	978.658	978.667	978.677	978.687
21°	978.697	978.707	978.717	978.728	978.738	978.748
22°	978.759	978.769	978.780	978.790	978.801	978.812
23°	978.822	978.833	978.844	978.855	978.866	978.877
24°	978.888	978.899	978.911	978.922	978.933	978.945
25°	978.956	978.968	978.979	978.991	979.002	979.014
26°	979.026	979.038	979.050	979.062	979.074	979.086
27°	979.098	979.110	979.122	979.135	979.147	979.159
28°	979.172	979.184	979.197	979.209	979.222	979.234
29°	979.247	979.260	979.273	979.286	979.298	979.311
30°	979.324	979.337	979.350	979.364	979.377	979.390
31°	979.403	979.416	979.430	979.443	979.456	979.470
32°	979.483	979.497	979.510	979.524	979.538	979.551
33°	979.565	979.579	979.593	979.606	979.620	979.634
34°	979.648	979.662	979.676	979.690	979.704	979.718
35°	979.732	979.746	979.760	979.775	979.789	979.803
36°	979.817	979.832	979.846	979.860	979.875	979.889
37°	979.904	979.918	979.933	979.947	979.962	979.976
38°	979.991	980.005	980.020	980.035	980.049	980.064
39°	980.079	980.093	980.108	980.123	980.138	980.152
40°	980.167	980.182	980.197	980.212	980.226	980.241
41°	980.256	980.271	980.286	980.301	980.316	980.331
42°	980.346	980.361	980.376	980.391	980.406	980.421
43°	980.436	980.451	980.466	980.481	980.496	980.511
44°	980.526	980.541	980.556	980.571	980.586	980.601

TABLE 3.2.1 (CONTINUED)

Acceleration of Gravity at Sea Level ($g_{\phi,o}$)

$$g_{\phi,o} = 980.6160\ (1 - 0.0026373 \cos 2\phi + 0.0000059 \cos^2 2\phi) \text{ in cm/sec}^2.$$

Latitude ϕ	Minutes of latitude					
	0′	10′	20′	30′	40′	50′
	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²	cm/sec²
45°	980.616	980.631	980.646	980.661	980.676	980.691
46°	980.706	980.721	980.736	980.751	980.766	980.781
47°	980.796	980.811	980.826	980.841	980.856	980.871
48°	980.886	980.901	980.916	980.931	980.946	980.961
49°	980.976	980.991	981.006	981.021	981.036	981.050
50°	981.065	981.080	981.095	981.110	981.124	981.139
51°	981.154	981.169	981.183	981.198	981.213	981.227
52°	981.242	981.257	981.271	981.286	981.300	981.315
53°	981.329	981.344	981.358	981.373	981.387	981.401
54°	981.416	981.430	981.444	981.459	981.473	981.487
55°	981.501	981.515	981.529	981.544	981.558	981.572
56°	981.586	981.600	981.613	981.627	981.641	981.655
57°	981.669	981.683	981.696	981.710	981.724	981.737
58°	981.751	981.764	981.778	981.791	981.805	981.818
59°	981.831	981.845	981.858	981.871	981.884	981.897
60°	981.911	981.924	981.937	981.950	981.962	981.975
61°	981.988	982.001	982.014	982.026	982.039	982.051
62°	982.064	982.076	982.089	982.101	982.114	982.126
63°	982.138	982.150	982.162	982.175	982.187	982.198
64°	982.210	982.222	982.234	982.246	982.258	982.269
65°	982.281	982.292	982.304	982.315	982.327	982.338
66°	982.349	982.360	982.371	982.382	982.393	982.404
67°	982.415	982.426	982.437	982.448	982.458	982.469
68°	982.479	982.490	982.500	982.511	982.521	982.531
69°	982.541	982.551	982.561	982.571	982.581	982.591
70°	982.601	982.610	982.620	982.629	982.639	982.648
71°	982.658	982.667	982.676	982.685	982.694	982.703
72°	982.712	982.721	982.730	982.738	982.747	982.756
73°	982.764	982.772	982.781	982.789	982.797	982.805
74°	982.813	982.821	982.829	982.837	982.845	982.852
75°	982.860	982.868	982.875	982.882	982.890	982.897
76°	982.904	982.911	982.918	982.925	982.932	982.938
77°	982.945	982.952	982.958	982.965	982.971	982.977
78°	982.983	982.990	982.996	983.001	983.007	983.013
79°	983.019	983.024	983.030	983.035	983.041	983.046
80°	983.051	983.056	983.061	983.066	983.071	983.076
81°	983.081	983.085	983.090	983.094	983.099	983.103
82°	983.107	983.111	983.116	983.119	983.123	983.127
83°	983.131	983.134	983.138	983.141	983.145	983.148
84°	983.151	983.154	983.157	983.160	983.163	983.166
85°	983.168	983.171	983.174	983.176	983.178	983.181
86°	983.183	983.185	983.187	983.189	983.190	983.192
87°	983.194	983.195	983.197	983.198	983.199	983.201
88°	983.202	983.203	983.204	983.204	983.205	983.206
89°	983.206	983.207	983.207	983.208	983.208	983.208
90°	983.208	------------	------------	------------	------------	------------

TABLE 3.2.2

Free-Air Gravity Correction

Tabular values represent C_f, in cm/sec², a correction to be subtracted algebraically from $g_{\phi,0}$, the acceleration of gravity at sea level, in cm/sec².

$C_f = 0.00009406 H_s$, in cm/sec² where H_s = barometer elevation, in feet.

Barometer elevation H_s (feet)	0	100	200	300	400	500	600	700	800	900
					Units cm/sec²					
−1,000	−0.094	--------	--------	--------	--------	--------	--------	--------	--------	--------
0	0	0.009	0.019	0.028	0.038	0.047	0.056	0.066	0.075	0.085
1,000	.094	.103	.113	.122	.132	.141	.150	.160	.169	.179
2,000	.188	.198	.207	.216	.226	.235	.245	.254	.263	.273
3,000	.282	.292	.301	.310	.320	.329	.339	.348	.357	.367
4,000	.376	.386	.395	.404	.414	.423	.433	.442	.451	.461
5,000	.470	.480	.489	.499	.508	.517	.527	.536	.546	.555
6,000	.564	.574	.583	.593	.602	.611	.621	.630	.640	.649
7,000	.658	.668	.677	.687	.696	.705	.715	.724	.734	.743
8,000	.752	.762	.771	.781	.790	.800	.809	.818	.828	.837
9,000	.847	.856	.865	.875	.884	.895	.903	.912	.922	.931
10,000	.941	.950	.959	.969	.978	.988	.997	1.006	1.016	1.025
11,000	1.035	1.044	1.053	1.063	1.072	1.082	1.091	1.101	1.110	1.119
12,000	1.129	1.138	1.148	1.157	1.166	1.176	1.185	1.195	1.204	1.213
13,000	1.223	1.232	1.242	1.251	1.260	1.270	1.279	1.289	1.298	1.307
14,000	1.317	1.326	1.336	1.345	1.354	1.364	1.373	1.383	1.392	1.401
15,000	1.411	1.420	1.430	1.439	1.449	1.458	1.467	1.477	1.486	1.496
16,000	1.505	1.514	1.524	1.533	1.543	1.552	1.562	1.571	1.580	1.590
17,000	1.599	1.608	1.618	1.627	1.637	1.646	1.655	1.665	1.674	1.684
18,000	1.693	1.702	1.712	1.721	1.731	1.740	1.750	1.758	1.768	1.778
19,000	1.788	1.797	1.806	1.815	1.825	1.834	1.844	1.853	1.862	1.872
20,000	1.881	1.891	1.900	1.909	1.919	1.928	1.938	1.947	1.956	1.966
21,000	1.975	1.985	1.994	2.003	2.013	2.022	2.032	2.041	2.051	2.060
22,000	2.069	2.079	2.088	2.098	2.107	2.116	2.126	2.135	2.145	2.154
23,000	2.163	2.173	2.182	2.192	2.201	2.210	2.220	2.229	2.239	2.248
24,000	2.257	2.267	2.276	2.286	2.295	2.304	2.314	2.323	2.333	2.342
25,000	2.352	2.361	2.370	2.380	2.389	2.399	2.408	2.417	2.427	2.436
26,000	2.446	2.455	2.464	2.474	2.483	2.493	2.502	2.511	2.521	2.530
27,000	2.540	2.549	2.558	2.568	2.577	2.587	2.596	2.605	2.615	2.624
28,000	2.634	2.643	2.652	2.662	2.671	2.681	2.690	2.700	2.709	2.718
29,000	2.728	2.737	2.747	2.756	2.765	2.775	2.784	2.794	2.803	2.812
30,000	2.822	2.831	2.841	2.850	2.859	2.869	2.878	2.888	2.897	2.906

TABLE 3.2.3

Free Air-Bouguer Correction

Tabular values represent C_b, in cm/sec², a correction to be added algebraically to the value of $(g_{\phi,o} - C_f)$.

$C_b = 0.00003408\ (H_z - H')$, *in cm/sec² where*
H_z = *Barometer elevation, in feet*
H' = *elevation, in feet, of the general terrain for a radius of 100 miles.*

[Apply C_b to $(g_{\phi,o} - C_f)$ according to the algebraic sign of $(H_z - H')$. Note $g_{\phi,o}$ = acceleration of gravity at sea level, and C_f = free-air gravity correction in cm/sec²]

$(H_z - H')$ (feet)	0	100	200	300	400	500	600	700	800	900
					Units cm/sec²					
0	0	0.003	0.007	0.010	0.014	0.017	0.020	0.024	0.027	0.031
1,000	.034	.037	.041	.044	.048	.051	.055	.058	.061	.065
2,000	.068	.072	.075	.078	.082	.085	.089	.092	.095	.099
3,000	.102	.106	.109	.112	.116	.119	.123	.126	.130	.133
4,000	.136	.140	.143	.147	.150	.153	.157	.160	.164	.167
5,000	.170	.174	.177	.181	.184	.187	.191	.194	.198	.201
6,000	.204	.208	.211	.215	.218	.222	.225	.228	.232	.235
7,000	.239	.242	.245	.249	.252	.256	.259	.262	.266	.269
8,000	.273	.276	.279	.283	.286	.290	.293	.296	.300	.303
9,000	.307	.310	.314	.317	.320	.324	.327	.331	.334	.337
10,000	.341	.344	.348	.351	.354	.358	.361	.365	.368	.371
11,000	.375	.378	.382	.385	.389	.392	.395	.399	.402	.406
12,000	.409	.412	.416	.419	.423	.426	.429	.433	.436	.440
13,000	.443	.446	.450	.453	.457	.460	.463	.467	.470	.474
14,000	.477	.481	.484	.488	.491	.494	.498	.501	.504	.508
15,000	.511	.514	.518	.521	.525	.528	.532	.535	.538	.542
16,000	.545	.549	.552	.556	.559	.562	.566	.569	.573	.576
17,000	.579	.583	.586	.590	.593	.596	.600	.603	.607	.610
18,000	.613	.617	.620	.624	.627	.630	.634	.637	.641	.644
19,000	.648	.651	.654	.658	.661	.665	.668	.671	.675	.678
20,000	.682	.685	.688	.692	.695	.698	.702	.705	.709	.712

TABLE 3.3.1

Corrections to Reduce Barometric Readings to Standard Gravity for English Readings of Barometer

Tabular values of $\frac{g_l - g_o}{g_o}B$ *in inches where*

g_l = *local acceleration of gravity, in cm/sec²*

g_o = *standard acceleration of gravity, 980.665 cm/sec²*

B = *height of mercury column, in inches*

[Apply correction in accordance with algebraic sign of the actual difference $(g_l - g_o)$.]

$(g_l - g_o)$ (*cm/sec²*)	Height of Mercury Column, *B*, inches											
	1	2	3	4	5	6	7	8	9	10	11	12
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
0.1	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009	0.0010	0.0011	0.0012
.2	.0002	.0004	.0006	.0008	.0010	.0012	.0014	.0016	.0018	.0020	.0022	.0024
.3	.0003	.0006	.0009	.0012	.0015	.0018	.0021	.0024	.0028	.0031	.0034	.0037
.4	.0004	.0008	.0012	.0016	.0020	.0024	.0029	.0033	.0037	.0041	.0045	.0049
.5	.0005	.0010	.0015	.0020	.0025	.0031	.0036	.0041	.0046	.0051	.0056	.0061
.6	.0006	.0012	.0018	.0024	.0031	.0037	.0043	.0049	.0055	.0061	.0067	.0073
.7	.0007	.0014	.0021	.0029	.0036	.0043	.0050	.0057	.0064	.0071	.0079	.0086
.8	.0008	.0016	.0024	.0033	.0041	.0049	.0057	.0065	.0073	.0082	.0090	.0098
.9	.0009	.0018	.0028	.0037	.0046	.0055	.0064	.0073	.0083	.0092	.0101	.0110
1.0	.0010	.0020	.0031	.0041	.0051	.0061	.0071	.0082	.0092	.0102	.0112	.0122
1.1	.0011	.0022	.0034	.0045	.0056	.0067	.0079	.0090	.0101	.0112	.0123	.0135
1.2	.0012	.0024	.0037	.0049	.0061	.0073	.0086	.0098	.0110	.0122	.0135	.0147
1.3	.0013	.0027	.0040	.0053	.0066	.0080	.0093	.0106	.0119	.0133	.0146	.0159
1.4	.0014	.0029	.0043	.0057	.0071	.0086	.0100	.0114	.0128	.0143	.0157	.0171
1.5	.0015	.0031	.0046	.0061	.0076	.0092	.0107	.0122	.0138	.0153	.0168	.0184
1.6	.0016	.0033	.0049	.0065	.0082	.0098	.0114	.0131	.0147	.0163	.0179	.0196
1.7	.0017	.0035	.0052	.0069	.0087	.0104	.0121	.0139	.0156	.0173	.0191	.0208
1.8	.0018	.0037	.0055	.0073	.0092	.0110	.0128	.0147	.0165	.0184	.0202	.0220
1.9	.0019	.0039	.0058	.0077	.0097	.0116	.0136	.0155	.0174	.0194	.0213	.0232
2.0	.0020	.0041	.0061	.0082	.0102	.0122	.0143	.0163	.0184	.0204	.0224	.0245
2.1	.0021	.0043	.0064	.0086	.0107	.0128	.0150	.0171	.0193	.0214	.0236	.0257
2.2	.0022	.0045	.0067	.0090	.0112	.0135	.0157	.0179	.0202	.0224	.0247	.0269
2.3	.0023	.0047	.0070	.0094	.0117	.0141	.0164	.0188	.0211	.0235	.0258	.0281
2.4	.0024	.0049	.0073	.0098	.0122	.0147	.0171	.0196	.0220	.0245	.0269	.0294
2.5	.0025	.0051	.0076	.0102	.0127	.0153	.0178	.0204	.0229	.0255	.0280	.0306
2.6	.0027	.0053	.0080	.0106	.0133	.0159	.0186	.0212	.0239	.0265	.0292	.0318
2.7	.0028	.0055	.0083	.0110	.0138	.0165	.0193	.0220	.0248	.0275	.0303	.0330
2.8	.0029	.0057	.0086	.0114	.0143	.0171	.0200	.0228	.0257	.0286	.0314	.0343
2.9	.0030	.0059	.0089	.0118	.0148	.0177	.0207	.0237	.0266	.0296	.0325	.0355
3.0	.0031	.0061	.0092	.0122	.0153	.0184	.0214	.0245	.0275	.0306	.0337	.0367
3.1	.0032	.0063	.0095	.0126	.0158	.0190	.0221	.0253	.0285	.0316	.0348	.0379
3.2	.0033	.0065	.0098	.0131	.0163	.0196	.0228	.0261	.0294	.0326	.0359	.0392
3.3	.0034	.0067	.0101	.0135	.0168	.0202	.0236	.0269	.0303	.0337	.0370	.0404
3.4	.0035	.0069	.0104	.0139	.0173	.0208	.0243	.0277	.0312	.0347	.0381	.0416
3.5	.0036	.0071	.0107	.0143	.0178	.0214	.0250	.0286	.0321	.0357	.0393	.0428
3.6	.0037	.0073	.0110	.0147	.0184	.0220	.0257	.0294	.0330	.0367	.0404	.0441
3.7	.0038	.0075	.0113	.0151	.0189	.0226	.0264	.0302	.0340	.0377	.0415	.0453
3.8	.0039	.0077	.0116	.0155	.0194	.0232	.0271	.0310	.0349	.0387	.0426	.0465
3.9	.0040	.0080	.0119	.0159	.0199	.0239	.0278	.0318	.0358	.0398	.0437	.0477
4.0	.0041	.0082	.0122	.0163	.0204	.0245	.0286	.0326	.0367	.0408	.0449	.0489
4.1	.0042	.0084	.0125	.0167	.0209	.0251	.0293	.0334	.0376	.0418	.0460	.0502
4.2	.0043	.0086	.0128	.0171	.0214	.0257	.0300	.0343	.0385	.0428	.0471	.0514
4.3	.0044	.0088	.0132	.0175	.0219	.0263	.0307	.0351	.0395	.0438	.0482	.0526
4.4	.0045	.0090	.0135	.0179	.0224	.0269	.0314	.0359	.0404	.0449	.0494	.0538
4.5	.0046	.0092	.0138	.0184	.0229	.0275	.0321	.0367	.0413	.0459	.0505	.0551
4.6	.0047	.0094	.0141	.0188	.0235	.0281	.0328	.0375	.0422	.0469	.0516	.0563
4.7	.0048	.0096	.0144	.0192	.0240	.0288	.0335	.0383	.0431	.0479	.0527	.0575
4.8	.0049	.0098	.0147	.0196	.0245	.0294	.0343	.0392	.0441	.0489	.0538	.0587
4.9	.0050	.0100	.0150	.0200	.0250	.0300	.0350	.0400	.0450	.0500	.0550	.0600
5.0	.0051	.0102	.0153	.0204	.0255	.0306	.0357	.0408	.0459	.0510	.0561	.0612

TABLE 3.3.1 (CONTINUED)

Corrections to Reduce Barometric Readings to Standard Gravity for English Readings of Barometer

Tabular values of $\frac{g_l - g_o}{g_o} B$ *in inches where*

g_l = *local acceleration of gravity, in cm/sec²*

g_o = *standard acceleration of gravity, 980.665 cm/sec²*

B = *height of mercury column, in inches*

[Apply correction in accordance with algebraic sign of the actual difference $(g_l - g_o)$.]

$(g_l - g_o)$ (cm/sec^2)	Height of Mercury Column, *B*, inches										
	12	13	14	15	16	17	18	19	20	21	22
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
0.1	0.0012	0.0013	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019	0.0020	0.0021	0.0022
.2	.0024	.0027	.0029	.0031	.0033	.0035	.0037	.0039	.0041	.0043	.0045
.3	.0037	.0040	.0043	.0046	.0049	.0052	.0055	.0058	.0061	.0064	.0067
.4	.0049	.0053	.0057	.0061	.0065	.0069	.0073	.0077	.0082	.0086	.0090
.5	.0061	.0066	.0071	.0076	.0082	.0087	.0092	.0097	.0102	.0107	.0112
.6	.0073	.0080	.0086	.0092	.0098	.0104	.0110	.0116	.0122	.0128	.0135
.7	.0086	.0093	.0100	.0107	.0114	.0121	.0128	.0136	.0143	.0150	.0157
.8	.0098	.0106	.0114	.0122	.0131	.0139	.0147	.0155	.0163	.0171	.0179
.9	.0110	.0119	.0128	.0138	.0147	.0156	.0165	.0174	.0184	.0193	.0202
1.0	.0122	.0133	.0143	.0153	.0163	.0173	.0184	.0194	.0204	.0214	.0224
1.1	.0135	.0146	.0157	.0168	.0179	.0191	.0202	.0213	.0224	.0236	.0247
1.2	.0147	.0159	.0171	.0184	.0196	.0208	.0220	.0232	.0245	.0257	.0269
1.3	.0159	.0172	.0186	.0199	.0212	.0225	.0239	.0252	.0265	.0278	.0292
1.4	.0171	.0186	.0200	.0214	.0228	.0243	.0257	.0271	.0286	.0300	.0314
1.5	.0184	.0199	.0214	.0229	.0245	.0260	.0275	.0291	.0306	.0321	.0337
1.6	.0196	.0212	.0228	.0245	.0261	.0277	.0294	.0310	.0326	.0343	.0359
1.7	.0208	.0225	.0243	.0260	.0277	.0295	.0312	.0329	.0347	.0364	.0381
1.8	.0220	.0239	.0257	.0275	.0294	.0312	.0330	.0349	.0367	.0385	.0405
1.9	.0232	.0252	.0271	.0291	.0310	.0329	.0349	.0368	.0387	.0407	.0426
2.0	.0245	.0265	.0286	.0306	.0326	.0347	.0367	.0387	.0408	.0428	.0449
2.1	.0257	.0278	.0300	.0321	.0343	.0364	.0385	.0407	.0428	.0450	.0471
2.2	.0269	.0292	.0314	.0337	.0359	.0381	.0404	.0426	.0449	.0471	.0494
2.3	.0281	.0305	.0328	.0352	.0375	.0399	.0422	.0446	.0469	.0493	.0516
2.4	.0294	.0318	.0343	.0367	.0392	.0416	.0441	.0465	.0489	.0514	.0538
2.5	.0306	.0331	.0357	.0382	.0408	.0433	.0459	.0484	.0510	.0535	.0561
2.6	.0318	.0345	.0371	.0398	.0424	.0451	.0477	.0504	.0530	.0557	.0583
2.7	.0330	.0358	.0385	.0413	.0441	.0468	.0496	.0523	.0551	.0578	.0606
2.8	.0343	.0371	.0400	.0428	.0457	.0485	.0514	.0542	.0571	.0600	.0628
2.9	.0355	.0384	.0414	.0444	.0473	.0503	.0532	.0562	.0591	.0621	.0651
3.0	.0367	.0398	.0428	.0459	.0489	.0520	.0551	.0581	.0612	.0642	.0673
3.1	.0379	.0411	.0443	.0474	.0506	.0537	.0569	.0601	.0632	.0664	.0695
3.2	.0392	.0424	.0457	.0489	.0522	.0555	.0587	.0620	.0653	.0685	.0718
3.3	.0404	.0437	.0471	.0505	.0538	.0572	.0606	.0639	.0673	.0707	.0740
3.4	.0416	.0451	.0485	.0520	.0555	.0589	.0624	.0659	.0693	.0728	.0763
3.5	.0428	.0464	.0500	.0535	.0571	.0607	.0642	.0678	.0714	.0749	.0785
3.6	.0441	.0477	.0514	.0551	.0587	.0624	.0661	.0697	.0734	.0771	.0808
3.7	.0453	.0490	.0528	.0566	.0604	.0641	.0679	.0717	.0755	.0792	.0830
3.8	.0465	.0504	.0542	.0581	.0620	.0659	.0697	.0736	.0775	.0814	.0852
3.9	.0477	.0517	.0557	.0597	.0636	.0676	.0716	.0756	.0795	.0835	.0875
4.0	.0489	.0531	.0571	.0612	.0653	.0693	.0734	.0775	.0816	.0856	.0897
4.1	.0502	.0544	.0585	.0627	.0669	.0711	.0753	.0794	.0836	.0878	.0920
4.2	.0514	.0557	.0600	.0642	.0685	.0728	.0771	.0814	.0857	.0899	.0942
4.3	.0526	.0570	.0614	.0658	.0702	.0745	.0789	.0833	.0877	.0921	.0965
4.4	.0538	.0583	.0628	.0673	.0718	.0763	.0808	.0852	.0897	.0942	.0987
4.5	.0551	.0597	.0642	.0688	.0734	.0780	.0826	.0872	.0918	.0964	.1010
4.6	.0563	.0610	.0657	.0704	.0751	.0797	.0844	.0891	.0938	.0985	.1032
4.7	.0575	.0623	.0671	.0719	.0767	.0815	.0863	.0911	.0959	.1006	.1054
4.8	.0587	.0636	.0685	.0734	.0783	.0832	.0881	.0930	.0979	.1028	.1077
4.9	.0600	.0650	.0700	.0749	.0799	.0849	.0899	.0949	.0999	.1049	.1099
5.0	.0612	.0663	.0714	.0765	.0816	.0867	.0918	.0969	.1020	.1071	.1122

TABLE 3.3.1 (CONTINUED)

Corrections to Reduce Barometric Readings to Standard Gravity for English Readings of Barometer

Tabular values of $\frac{g_l - g_o}{g_o} B$ *in inches where*

g_l = *local acceleration of gravity, in cm/sec*^{2}

g_o = *standard acceleration of gravity, 980.665 cm/sec*^{2}

B = *height of mercury column, in inches*

[Apply correction in accordance with algebraic sign of the actual difference $(g_l - g_o)$.]

$(g_l - g_o)$ (cm/sec^2)	Height of Mercury Column, *B*, inches										
	22	23	24	25	26	27	28	29	30	31	32
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
0.1	0.0022	0.0023	0.0024	0.0025	0.0027	0.0028	0.0029	0.0030	0.0031	0.0032	0.0033
.2	.0045	.0047	.0049	.0051	.0053	.0055	.0057	.0059	.0061	.0063	.0065
.3	.0067	.0070	.0073	.0076	.0080	.0083	.0086	.0089	.0092	.0095	.0098
.4	.0090	.0094	.0098	.0102	.0106	.0110	.0114	.0118	.0122	.0126	.0131
.5	.0112	.0117	.0122	.0127	.0133	.0138	.0143	.0148	.0153	.0158	.0163
.6	.0135	.0141	.0147	.0153	.0159	.0165	.0171	.0177	.0184	.0190	.0196
.7	.0157	.0164	.0171	.0178	.0186	.0193	.0200	.0207	.0214	.0221	.0228
.8	.0179	.0188	.0196	.0205	.0212	.0220	.0228	.0237	.0245	.0253	.0261
.9	.0202	.0211	.0220	.0229	.0239	.0248	.0257	.0266	.0275	.0285	.0294
1.0	.0224	.0235	.0245	.0255	.0265	.0275	.0286	.0296	.0306	.0316	.0326
1.1	.0247	.0258	.0269	.0280	.0292	.0303	.0314	.0325	.0337	.0348	.0359
1.2	.0269	.0281	.0294	.0306	.0318	.0330	.0343	.0355	.0367	.0379	.0392
1.3	.0292	.0305	.0318	.0331	.0345	.0358	.0371	.0384	.0398	.0411	.0424
1.4	.0314	.0328	.0343	.0357	.0371	.0385	.0400	.0414	.0428	.0443	.0457
1.5	.0337	.0352	.0367	.0382	.0398	.0413	.0428	.0444	.0459	.0474	.0489
1.6	.0359	.0375	.0392	.0408	.0424	.0441	.0457	.0473	.0489	.0506	.0522
1.7	.0381	.0399	.0416	.0433	.0451	.0468	.0485	.0503	.0520	.0537	.0555
1.8	.0405	.0422	.0441	.0459	.0477	.0496	.0514	.0532	.0551	.0569	.0587
1.9	.0426	.0446	.0465	.0484	.0504	.0523	.0542	.0562	.0581	.0601	.0620
2.0	.0449	.0469	.0489	.0510	.0530	.0551	.0571	.0591	.0612	.0632	.0653
2.1	.0471	.0493	.0514	.0535	.0557	.0578	.0600	.0621	.0642	.0664	.0685
2.2	.0494	.0516	.0538	.0561	.0583	.0606	.0628	.0651	.0673	.0695	.0718
2.3	.0516	.0539	.0563	.0586	.0610	.0633	.0657	.0680	.0704	.0727	.0751
2.4	.0538	.0563	.0587	.0612	.0636	.0661	.0685	.0710	.0734	.0759	.0783
2.5	.0561	.0586	.0612	.0637	.0663	.0688	.0714	.0739	.0765	.0790	.0816
2.6	.0583	.0610	.0636	.0663	.0689	.0716	.0742	.0769	.0795	.0822	.0848
2.7	.0606	.0633	.0661	.0688	.0716	.0743	.0771	.0798	.0826	.0854	.0881
2.8	.0628	.0657	.0685	.0714	.0742	.0771	.0799	.0828	.0857	.0885	.0914
2.9	.0651	.0680	.0710	.0739	.0769	.0798	.0828	.0858	.0887	.0917	.0946
3.0	.0673	.0704	.0734	.0765	.0795	.0826	.0857	.0887	.0918	.0948	.0979
3.1	.0695	.0727	.0759	.0790	.0822	.0854	.0885	.0917	.0948	.0980	.1012
3.2	.0718	.0751	.0783	.0816	.0848	.0881	.0914	.0946	.0979	.1012	.1044
3.3	.0740	.0774	.0808	.0841	.0875	.0909	.0942	.0976	.1010	.1043	.1077
3.4	.0763	.0797	.0832	.0867	.0901	.0936	.0971	.1005	.1040	.1075	.1109
3.5	.0785	.0821	.0857	.0892	.0928	.0964	.0999	.1035	.1071	.1106	.1142
3.6	.0808	.0844	.0881	.0918	.0954	.0991	.1028	.1065	.1101	.1138	.1175
3.7	.0830	.0868	.0906	.0943	.0981	.1019	.1056	.1094	.1132	.1170	.1207
3.8	.0852	.0891	.0930	.0969	.1007	.1046	.1085	.1124	.1162	.1201	.1240
3.9	.0875	.0915	.0954	.0994	.1034	.1074	.1114	.1153	.1193	.1233	.1273
4.0	.0897	.0938	.0979	.1020	.1061	.1101	.1142	.1183	.1224	.1264	.1305
4.1	.0920	.0962	.1003	.1045	.1087	.1129	.1171	.1212	.1254	.1296	.1338
4.2	.0942	.0985	.1028	.1071	.1114	.1156	.1199	.1242	.1285	.1328	.1370
4.3	.0965	.1008	.1052	.1096	.1140	.1184	.1228	.1272	.1315	.1359	.1403
4.4	.0987	.1032	.1077	.1122	.1167	.1211	.1256	.1301	.1346	.1391	.1436
4.5	.1010	.1055	.1101	.1147	.1193	.1239	.1285	.1331	.1377	.1423	.1468
4.6	.1032	.1079	.1126	.1173	.1220	.1266	.1313	.1360	.1407	.1454	.1501
4.7	.1054	.1102	.1150	.1198	.1246	.1294	.1342	.1390	.1438	.1486	.1534
4.8	.1077	.1126	.1175	.1224	.1273	.1322	.1370	.1419	.1468	.1517	.1566
4.9	.1099	.1149	.1199	.1249	.1299	.1349	.1399	.1449	.1499	.1549	.1599
5.0	.1122	.1173	.1224	.1275	.1326	.1377	.1428	.1479	.1530	.1581	.1632

TABLE 3.3.2

Corrections to Reduce Barometric Readings to Standard Gravity for Millibar or Millimeter Readings

Tabular values of $\frac{g_l - g_o}{g_o}B$ *in mb. or mm. where*

g_l = *local acceleration of gravity, in cm/sec²*

g_o = *standard acceleration of gravity, 980.665 cm/sec²*

B = *height of mercury column, in mb. or mm.*

[Apply correction in accordance with algebraic sign of the actual difference $(g_l - g_o)$.]

$(g_l - g_o)$ (cm/sec²)	Height of Mercury Column, B, in mb. or mm.					
	600	700	800	900	1000	1100
	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.
0.1	0.061	0.071	0.082	0.092	0.102	0.112
.2	.122	.143	.163	.184	.204	.224
.3	.184	.214	.245	.275	.306	.337
.4	.245	.286	.326	.367	.408	.449
.5	.306	.357	.408	.459	.510	.561
.6	.367	.428	.489	.551	.612	.673
.7	.428	.500	.571	.642	.714	.785
.8	.489	.571	.653	.734	.816	.897
.9	.551	.642	.734	.826	.918	1.010
1.0	.612	.714	.816	.918	1.020	1.122
1.1	.673	.785	.897	1.010	1.122	1.234
1.2	.734	.857	.979	1.101	1.224	1.346
1.3	.795	.928	1.061	1.193	1.326	1.458
1.4	.857	.999	1.142	1.285	1.428	1.570
1.5	.918	1.071	1.224	1.377	1.530	1.683
1.6	.979	1.142	1.305	1.468	1.632	1.795
1.7	1.040	1.213	1.387	1.560	1.734	1.907
1.8	1.101	1.285	1.468	1.652	1.835	2.019
1.9	1.162	1.356	1.550	1.744	1.937	2.131
2.0	1.224	1.428	1.632	1.835	2.039	2.243
2.1	1.285	1.499	1.713	1.927	2.141	2.356
2.2	1.346	1.570	1.794	2.019	2.243	2.468
2.3	1.407	1.642	1.876	2.111	2.345	2.580
2.4	1.468	1.713	1.958	2.203	2.447	2.692
2.5	1.530	1.785	2.039	2.294	2.549	2.804
2.6	1.591	1.856	2.121	2.386	2.651	2.916
2.7	1.652	1.927	2.203	2.478	2.753	3.029
2.8	1.713	1.999	2.284	2.570	2.855	3.141
2.9	1.774	2.070	2.366	2.661	2.957	3.253
3.0	1.835	2.141	2.447	2.753	3.059	3.365
3.1	1.897	2.213	2.529	2.845	3.161	3.477
3.2	1.958	2.284	2.610	2.937	3.263	3.589
3.3	2.019	2.356	2.692	3.029	3.365	3.702
3.4	2.080	2.427	2.774	3.120	3.467	3.814
3.5	2.141	2.498	2.855	3.212	3.569	3.926
3.6	2.203	2.570	2.937	3.304	3.671	4.038
3.7	2.264	2.641	3.018	3.396	3.773	4.150
3.8	2.325	2.712	3.100	3.487	3.875	4.262
3.9	2.386	2.784	3.182	3.579	3.977	4.375
4.0	2.447	2.855	3.263	3.671	4.079	4.487
4.1	2.509	2.927	3.345	3.763	4.181	4.599
4.2	2.570	2.998	3.426	3.855	4.283	4.711
4.3	2.631	3.069	3.508	3.946	4.385	4.823
4.4	2.692	3.141	3.589	4.038	4.487	4.935
4.5	2.753	3.212	3.671	4.130	4.589	5.048
4.6	2.814	3.283	3.753	4.222	4.691	5.160
4.7	2.876	3.355	3.834	4.313	4.793	5.272
4.8	2.937	3.426	3.916	4.405	4.895	5.384
4.9	2.998	3.498	3.997	4.497	4.997	5.496
5.0	3.059	3.569	4.079	4.589	5.099	5.608

TABLE 3.3.3

*Annual Mean Station Pressure Over Period of Record**

State and station	Elevation above mean sea level (feet)	Annual mean station pressure		Period of record (mo./yr.)
		(in. Hg)	(mb.)	
ALABAMA				
Birmingham	700	29.33	993.2	9/03—8/50
Montgomery	218	29.82	1009.8	1/74—11/50
ALASKA				
Anchorage	132	29.64	1003.7	2/43—10/50
Annette	110	29.80	1009.1	1/48—11/50
Bethel	38	29.74	1007.1	1/43—11/50
Cordova	48	29.74	1007.1	9/42—11/50
Fairbanks	454	29.34	993.6	1/30—12/50
Galena	123	29.73	1006.8	1/47—11/50
Gambell	27	29.80	1009.1	1/43—12/50
Juneau	24	29.84	1010.5	1/48—11/50
Kotzebue	16	29.84	1010.5	1/43—11/50
McGrath	338	29.43	996.6	10/42—11/50
Northway	1721	27.99	947.9	1/45—11/50
ARIZONA				
Flagstaff	6907	23.35	790.7	1/44—10/50
Phoenix	1107	28.75	973.6	8/95—11/50
Prescott	5022	25.02	847.3	1/43—11/50
Tucson	2555	27.31	924.8	1/42—12/49
Yuma	142	29.88	1011.9	5/01—8/50
ARKANSAS				
Little Rock	357	29.69	1005.4	7/88—10/50
Fort Smith	463	29.54	1000.3	6/82—11/50
Texarkana	368	29.63	1003.4	1/46—10/51
CALIFORNIA				
Bakersfield	492	29.45	997.3	2/39—7/39 1/40—4/40 10/40—11/50
Eureka	60	30.02	1016.6	1/00—8/50
Fresno	327	29.63	1003.4	1/88—11/50
Los Angeles	512	29.44	997.0	1/01—12/47
Oakland	7	30.01	1016.3	1/31—11/50
Red Bluff	353	29.62	1003.0	8/44—11/50
Sacramento	66	29.92	1013.2	7/77—3/49
San Bruno	18	30.01	1016.3	8/42—8/50
San Diego	87	29.89	1012.2	1/73—11/50
San Francisco	155	29.86	1011.2	1/73—12/42
Santa Maria	238	29.77	1008.1	3/43—11/50
COLORADO				
Denver	5292	24.71	836.8	1/73—12/50
Grand Junction	4602	25.39	859.8	–/79——/50
Pueblo	4690	25.28	856.1	1/89—11/50
CONNECTICUT				
Hartford	159	29.84	1010.5	1/05—11/50
New Haven	107	29.91	1012.9	1/73—11/50
DIST. OF COLUMBIA				
Washington	112	29.93	1013.5	1/73—12/50

*See reference notes at end of table.

TABLE 3.3.3 (CONTINUED)

*Annual Mean Station Pressure Over Period of Record**

State and station	Elevation above mean sea level (feet)	Annual mean station pressure (in. Hg)	Annual mean station pressure (mb.)	Period of record (mo./yr.)
FLORIDA				
Apalachicola	35	30.02	1016.6	7/22—10/50
Daytona Beach	41	30.02	1016.6	1/42—11/50
Fort Myers	12	30.02	1016.6	1/27—12/37 1/48—12/50
Jacksonville	43	30.01	1016.3	1/73—12/50
Key West (CO)	21	30.00	1015.9	1/73—12/50
Key West (AP)	11	30.01	1016.3	7/39—12/50
Miami	25	30.01	1016.3	7/11—8/50
Tampa	35	30.01	1016.3	4/90—12/50
GEORGIA				
Atlanta	1173	28.83	976.3	1/79—11/50
Augusta	182	29.88	1011.9	1/73—10/50
Macon	370	29.67	1004.7	4/99—12/50
Savannah	65	29.99	1015.6	1/73—11/50
HAWAII				
Honolulu	38	29.96	1014.6	1/05—10/50
IDAHO				
Boise	2739	27.18	920.4	1/99—11/50
Lewiston	1436	28.48	964.4	1/47—12/50
ILLINOIS				
Cairo	357	29.67	1004.7	1/73—11/50
Chicago	673	29.30	992.2	1/26—11/50
Moline	594	29.38	994.9	1/43—10/50
Peoria	609	29.38	994.9	–/05——/49
Springfield	636	29.35	993.9	1/80—10/50
INDIANA				
Evansville	431	29.59	1002.0	1/98—11/50
Fort Wayne	857	29.11	985.8	6/11—11/50
Indianapolis	823	29.16	987.5	3/71—8/50
South Bend	773	29.19	988.5	1/46—11/50
Terre Haute	575	29.42	996.3	8/12—11/50
IOWA				
Burlington	702	29.27	991.2	1/42—11/50
Charles City	1015	28.93	979.7	11/04—10/50
Davenport	606	29.37	994.6	1/73—11/50
Des Moines	860	29.10	985.4	8/79—10/50
Dubuque	699	29.27	991.2	1/05—11/50
Sioux City	1138	28.79	974.9	1/90—8/50
KANSAS				
Concordia	1392	28.54	966.5	1/86—12/49
Dodge City	2509	27.39	927.5	1/75—11/50
Goodland	3688	26.22	887.9	1/44—11/50
Topeka	986	28.95	980.4	10/36—10/50
Wichita	1358	28.57	967.5	1/89—12/40
KENTUCKY				
Lexington	989	29.00	982.1	11/87—11/50
Louisville	525	29.48	998.3	1/72—10/50

*See reference notes at end of table.

TABLE 3.3.3 (CONTINUED)

*Annual Mean Station Pressure Over Period of Record**

State and station	Elevation above mean sea level (feet)	Annual mean station pressure		Period of record (mo./yr.)
		(in. Hg)	(mb.)	
LOUISIANA				
Lake Charles	32	30.00	1015.9	1/40—8/50
New Orleans	53	29.99	1015.6	–/71——/49
Shreveport	249	29.77	1008.1	9/71—10/50
MAINE				
Eastport	75	29.90	1012.5	1/87—11/50
Portland	63	29.93	1013.5	2/71—11/50
MARYLAND				
Baltimore	123	29.92	1013.2	1/73—11/50
MASSACHUSETTS				
Boston	124	29.87	1011.5	1/71—10/50
Nantucket	12	29.99	1015.6	1/87—10/50
MICHIGAN				
Alpena	609	29.34	993.6	1/73—10/50
Detroit	730	29.23	989.8	1/73—12/50
Escanaba	612	29.34	993.6	–/73——/87 –/99——/50
Grand Rapids	689	29.25	990.5	7/03—10/50
Lansing	878	29.07	984.4	5/10—10/50
Marquette	734	29.19	988.5	1/73—10/50
Saulte Ste. Marie	614	29.31	992.6	7/88—12/50
MINNESOTA				
Duluth	1133	28.76	973.9	1/73—10/50
Minneapolis	919	28.99	981.7	1/15—11/50
St. Paul	837	29.09	985.1	1/73—6/33
MISSISSIPPI				
Jackson	331	29.68	1005.1	1/46—12/50
Meridian	375	29.67	1004.7	9/89—9/96 1/99—10/50
Vicksburg	247	29.79	1008.8	1/73—10/50
MISSOURI				
Columbia	784	29.19	988.5	9/89—10/50
Kansas City	963	28.99	981.7	7/89—12/50
St. Louis	568	29.43	996.6	1/73—12/48
Springfield	1324	28.63	969.5	1/87—11/50
MONTANA				
Billings	3570	26.30	890.6	———11/50
Butte	5533	24.48	829.0	1/42—10/50
Glasgow	2086	27.76	940.1	10/43—12/48
Havre	2507	27.33	925.5	6/92—8/50
Helena	4123	25.79	873.3	4/80—8/50
Kalispell	2973	26.93	912.0	1/00—11/50
Missoula	3189	26.71	904.5	7/39—10/50

*See reference notes at end of table.

TABLE 3.3.3 (CONTINUED)

*Annual Mean Station Pressure Over Period of Record**

State and station	Elevation above mean sea level (feet)	Annual mean station pressure (in. Hg)	Annual mean station pressure (mb.)	Period of record (mo./yr.)
NEBRASKA				
Lincoln	1189	28.74	973.2	1/97—11/50
Norfolk	1551	28.35	960.0	10/45—11/50
North Platte	2787	27.07	916.7	10/74—11/50
Omaha	1105	28.83	976.3	1/00—11/50
Valentine	2598	27.28	923.8	1/89—10/50
NEW HAMPSHIRE				
Concord	289	29.68	1005.1	1/03—11/50
NEVADA				
Ely	6262	23.88	808.7	10/38—10/50
Las Vegas	1869	27.97	947.2	1/41—12/48
NEW JERSEY				
Atlantic City	52	29.98	1015.2	1/74—11/50
Newark	30	30.01	1016.3	1/46—11/50
Trenton	190	29.83	1010.2	4/13—11/50
NEW MEXICO				
Albuquerque	4972	25.05	848.3	4/31—10/50
Clayton	5052	24.96	845.2	9/46—11/50
Roswell	3566	26.36	892.7	–/05——/49
NEW YORK				
Albany	97	29.92	1013.2	1/74—12/49
Binghamton	871	29.09	985.1	10/96—8/50
Buffalo	706	29.25	990.5	1/73—12/49
Canton	448	29.51	999.3	–/07——/49
Oswego	335	29.64	1003.7	1/73—11/50
Rochester	523	29.44	997.0	1/73—12/30
Syracuse	596	29.38	994.9	9/02—3/50
NORTH CAROLINA				
Charlotte	779	29.23	989.8	10/78—11/50
Greensboro	886	29.13	986.5	11/28—12/50
Hatteras	11	30.04	1017.3	1/92—11/50
Raleigh (AP)	441	29.60	1002.4	5/44—11/50
Raleigh (CO)	376	29.66	1004.4	1/87—12/48
Winston-Salem	978	29.03	983.1	12/45—12/50
NORTH DAKOTA				
Bismarck	1677	28.21	955.3	–/75—11/50
Devils Lake	1478	28.40	961.7	1/05—12/50
Fargo	940	28.98	981.4	1/81—12/50
Williston	1878	27.99	947.9	1/94—8/50

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*See reference notes at end of table.

TABLE 3.3.3 (CONTINUED)

*Annual Mean Station Pressure Over Period of Record**

State and station	Elevation above mean sea level (feet)	Annual mean station pressure (in. Hg)	Annual mean station pressure (mb.)	Period of record (mo./yr.)
OHIO				
Cincinnati	627	29.38	994.9	–/74——/50
Cleveland	762	29.21	989.2	1/91—11/50
Dayton	900	29.08	984.8	8/11—6/33 2/35—11/50
Sandusky	629	29.35	993.9	8/77—12/50
Toledo	628	29.35	993.9	1/73—11/50
Youngstown	1186	28.77	974.3	3/47—11/50
OKLAHOMA				
Oklahoma City	1214	28.73	972.9	1/90—10/50
Tulsa (AP)	676	29.29	991.9	9/42—11/50
OREGON				
Baker	3471	26.43	895.0	7/89—11/50
Burns	4170	25.79	873.3	1/44—10/50
Eugene	373	29.66	1004.4	1/45—11/50
Meacham	4056	25.89	876.7	1/45—11/50
Medford	1329	28.62	969.2	7/27—11/50
Pendleton	1495	28.44	963.1	1/49—10/50
Portland	154	29.89	1012.2	1/73—11/50
Roseburg	510	29.51	999.3	1/70—11/50
Salem	201	29.84	1010.5	1/45—11/50
PENNSYLVANIA				
Allentown	385	29.64	1003.7	3/45—11/50
Erie	714	29.25	990.5	6/73—8/49
Harrisburg	378	29.65	1004.1	1/89—12/50
Philadelphia	114	29.93	1013.5	1/73—10/50
Reading	323	29.70	1005.8	1/13—10/50
Scranton	805	29.17	987.8	1/01—12/50
RHODE ISLAND				
Block Island	26	29.98	1015.2	1/81—8/50
Providence	159	29.84	1010.5	11/04—8/50
SOUTH CAROLINA				
Charleston	48	30.02	1016.6	1/73—11/50
Columbia	347	29.68	1005.1	6/01—8/50
Greenville	1040	28.96	980.7	9/17—11/50
SOUTH DAKOTA				
Huron	1301	28.61	968.8	7/81—10/50
Rapid City	3259	26.60	900.8	1/88—11/50
Sioux Falls	1427	28.48	964.4	8/49—11/50
TENNESSEE				
Chattanooga	762	29.27	991.2	1/79—11/50
Knoxville	995	29.02	982.7	1/73—12/50
Memphis	399	29.64	1003.7	1/96—12/50
Nashville	546	29.49	998.6	–/73——/50

*See reference notes at end of table.

TABLE 3.3.3 (CONTINUED)

*Annual Mean Station Pressure Over Period of Record**

State and station	Elevation above mean sea level (feet)	Annual mean station pressure		Period of record (mo./yr.)
		(in. Hg)	(mb.)	
TEXAS				
Abilene	1738	28.20	955.0	10/85—10/50
Amarillo	3676	26.27	889.6	1/92—11/50
Austin	605	29.35	993.9	11/26—11/50
Brownsville	57	29.94	1013.9	10/22—12/50
Corpus Christi	20	29.97	1014.9	2/87—11/50
Dallas	512	29.47	998.0	10/13—8/50
Del Rio	960	28.98	981.4	1/06—11/50
El Paso	3778	26.17	886.2	2/79—11/50
Ft. Worth	679	29.30	992.2	9/98—8/50
Galveston	54	29.98	1015.2	–/73——/50
Houston	138	29.88	1011.9	10/09—11/50
Laredo	512	29.48	998.3	1/44—12/50
Lubbock	3241	26.67	903.1	12/46—12/50
Palestine	510	29.50	999.0	1/82—10/50
Port Arthur (AP)	22	29.99	1015.6	3/44—11/50
Port Arthur (CO)	34	29.99	1015.6	2/17—10/50
San Antonio	693	29.28	991.5	1/86—10/50
Victoria	117	29.87	1011.5	1/47—11/50
Waco	508	29.44	997.0	1/42—12/50
UTAH				
Salt Lake City (AP)	4227	25.73	871.3	5/28—1/50
Salt Lake City (CO)	4357	25.62	867.6	–/75——/41
VERMONT				
Burlington	403	29.55	1000.7	4/06—8/50
VIRGINIA				
Cape Henry	18	30.03	1016.9	1/11—10/50
Norfolk	91	29.96	1014.6	1/73—11/50
Richmond	164	29.90	1012.5	11/97—10/50
Roanoke	1176	28.73	972.9	–/49——/50
WASHINGTON				
Ellensburg	1735	28.17	953.9	1/45—11/50
North Head	211	29.83	1010.2	9/83—10/90 8/02—10/50
Olympia	200	29.82	1009.8	1/45—11/50
Port Angeles	29	30.02	1016.6	1/47—8/50
Seattle-Tacoma (AP)	388	29.62	1003.0	1/45—11/50
Spokane	1929	27.97	947.1	1/93—12/49
Tacoma	194	29.83	1010.2	1/08—11/50
Tatoosh Island	86	29.93	1013.5	10/83—3/89 8/91—6/98 12/02—11/50
Walla Walla	991	28.96	980.7	1/86—10/50
WEST VIRGINIA				
Elkins	1947	27.96	946.8	12/00—11/50
Parkersburg	637	29.38	994.9	1/89—4/48

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*See reference notes at end of table.

TABLE 3.3.3 (CONTINUED)

*Annual Mean Station Pressure Over Period of Record**

State and station	Elevation above mean sea level (feet)	Annual mean station pressure		Period of record (mo./yr.)
		(in. Hg)	(mb.)	
WISCONSIN				
Green Bay	617	29.33	993.2	1/87—8/50
La Crosse	714	29.23	989.8	1/73—12/42
Madison	974	28.97	981.0	10/78—8/50
Milwaukee	681	29.27	991.2	1/73—10/50
WYOMING				
Casper	5290	24.69	836.1	4/43—10/50
Cheyenne	6141	23.96	811.4	9/35—10/50
Lander	5352	24.64	834.4	8/91—11/50
Sheridan	3790	26.09	883.5	5/07—11/50
VIRGIN ISLANDS				
Christiansted (St. Croix Island)	55	29.92	1013.2	9/47—11/50
PACIFIC AREA				
Canton	12	29.79	1008.8	1/47—11/50
Wake Island	12	29.96	1014.6	1/49—12/50
See also Hawaii				

Annual Mean Station Pressure Over Period of Record

1. Geographical coordinates for most of the stations will be found in Table 7.1.2.
2. Coordinates for Christiansted, Virgin Islands, are: 17°45′ N.; 64°42′ W.
3. (AP) indicates data pertain to Weather Bureau Airport Station.
4. (CO) indicates data pertain to Weather Bureau City Office.
5. In cases where elevation changes have occurred during the period of record, and/or the observational program was transferred from City Office to Airport, the pressures have been adjusted to the station elevation (H_p) adopted on January 1, 1900, for the City Office, or the first station elevation adopted after 1900, in order to provide a continuous record at the same elevation.

TABLE 4.1.1

Tabular Values Showing the Change in Pressure (Inches of Mercury) Corresponding to a Change in Height of One Geopotential Foot

Temperature (° F.)	Pressure (inches of mercury)				
	31.00	30.00	29.00	28.00	27.00
	in. Hg	in. Hg	in. Hg	in. Hg	in. Hg
−90	0.0015707	0.0015201	0.0014694	0.0014187	0.0013680
−80	.0015293	.0014800	.0014307	.0013813	.0013320
−70	.0014901	.0014421	.0013940	.0013459	.0012978
−60	.0014528	.0014059	.0013591	.0013122	.0012654
−50	.0014174	.0013717	.0013259	.0012802	.0012345
−40	0.0013836	0.0013390	0.0012943	0.0012497	0.0012051
−30	.0013514	.0013078	.0012642	.0012206	.0011770
−20	.0013207	.0012781	.0012355	.0011929	.0011502
−10	.0012913	.0012496	.0012080	.0011663	.0011246
0	.0012632	.0012225	.0011817	.0011410	.0011002
10	0.0012363	0.0011964	0.0011565	0.0011166	0.0010768
20	.0012105	.0011715	.0011324	.0010934	.0010543
30	.0011858	.0011475	.0011093	.0010710	.0010328
40	.0011621	.0011246	.0010871	.0010496	.0010121
50	.0011393	.0011025	.0010658	.0010290	.0009923
60	0.0011173	0.0010813	0.0010452	0.0010092	0.0009732
70	.0010963	.0010609	.0010255	.0009902	.0009548
80	.0010759	.0010412	.0010065	.0009718	.0009371
90	.0010564	.0010223	.0009882	.0009541	.0009201
100	.0010375	.0010040	.0009706	.0009371	.0009036
110	0.0010193	0.0009864	0.0009535	0.0009207	0.0008878
120	.0010017	.0009694	.0009371	.0009048	.0008724
130	.0009847	.0009530	.0009212	.0008894	.0008577
140	.0009683	.0009371	.0009058	.0008746	.0008434

TABLE 4.1.1 (CONTINUED)

Tabular Values Showing the Change in Pressure (Inches of Mercury) Corresponding to a Change in Height of One Geopotential Foot

Temperature (° F.)	Pressure (inches of mercury)					
	27.00	26.00	25.00	24.00	23.00	22.00
	in. Hg	in. Hg	in. Hg	in. Hg	in. Hg	in. Hg
−90	0.0013680	0.0013174	0.0012667	0.0012160	0.0011654	0.0011147
−80	.0013320	.0012827	.0012333	.0011840	.0011347	.0010853
−70	.0012978	.0012498	.0012017	.0011536	.0011056	.0010575
−60	.0012654	.0012185	.0011716	.0011247	.0010779	.0010310
−50	.0012345	.0011888	.0011431	.0010973	.0010516	.0010059
−40	0.0012051	0.0011604	0.0011158	0.0010712	0.0010265	0.0009819
−30	.0011770	.0011334	.0010898	.0010462	.0010026	.0009590
−20	.0011502	.0011076	.0010650	.0010224	.0009798	.0009372
−10	.0011246	.0010830	.0010413	.0009997	.0009580	.0009164
0	.0011002	.0010595	.0010187	.0009780	.0009372	.0008965
10	0.0010768	0.0010369	0.0009970	0.0009571	0.0009172	0.0008774
20	.0010543	.0010153	.0009762	.0009372	.0008981	.0008591
30	.0010328	.0009945	.0009563	.0009180	.0008798	.0008415
40	.0010121	.0009747	.0009372	.0008997	.0008622	.0008247
50	.0009923	.0009555	.0009188	.0008820	.0008453	.0008085
60	0.0009732	0.0009371	0.0009011	0.0008650	0.0008290	0.0007929
70	.0009548	.0009194	.0008841	.0008487	.0008134	.0007780
80	.0009371	.0009024	.0008677	.0008330	.0007983	.0007636
90	.0009201	.0008860	.0008519	.0008178	.0007838	.0007497
100	.0009036	.0008702	.0008367	.0008032	.0007697	.0007363
110	0.0008878	0.0008549	0.0008220	0.0007891	0.0007563	0.0007234
120	.0008724	.0008401	.0008078	.0007755	.0007432	.0007109
130	.0008577	.0008259	—	—	—	—
140	.0008434	.0008121	—	—	—	—

Temperature (° F.)	Pressure (inches of mercury)					
	22.00	21.00	20.00	18.00	16.00	14.00
	in. Hg	in. Hg	in. Hg	in. Hg	in. Hg	in. Hg
−90	0.0011147	0.0010640	0.0010134	0.0009120	0.0008107	0.0007094
−80	.0010853	.0010360	.0009867	.0008880	.0007893	.0006907
−70	.0010575	.0010094	.0009614	.0008652	.0007691	.0006730
−60	.0010310	.0009842	.0009373	.0008436	.0007498	.0006561
−50	.0010059	.0009602	.0009144	.0008230	.0007316	.0006401
−40	0.0009819	0.0009373	0.0008926	0.0008034	0.0007141	0.0006248
−30	.0009590	.0009154	.0008718	.0007847	.0006975	.0006103
−20	.0009372	.0008946	.0008520	.0007668	.0006816	.0005964
−10	.0009164	.0008747	.0008331	.0007498	.0006665	.0005832
0	.0008965	.0008557	.0008150	.0007335	.0006520	.0005705
10	0.0008774	0.0008375	0.0007976	0.0007178	0.0006381	0.0005583
20	.0008591	.0008200	.0007810	.0007029	.0006248	.0005467
30	.0008415	.0008033	.0007650	.0006885	.0006120	.0005355
40	.0008247	.0007872	.0007497	.0006748	.0005998	.0005248
50	.0008085	.0007718	.0007350	.0006615	.0005880	.0005145
60	0.0007929	0.0007569	0.0007209	0.0006488	0.0005767	0.0005046
70	.0007780	.0007426	.0007073	.0006365	.0005658	.0004951
80	.0007636	.0007289	.0006942	.0006247	.0005553	.0004859
90	.0007497	.0007156	.0006815	.0006135	.0005452	.0004771
100	.0007363	.0007028	.0006693	.0006024	.0005355	.0004685
110	0.0007234	0.0006905	0.0006576	—	—	—
120	.0007109	.0006786	.0006463	—	—	—

TABLE 5.2.1

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
−20.0	+0.069	+0.071	+0.073	+0.075	+0.078	+0.080	+0.082	+0.084	+0.087
−19.5	+0.068	+0.070	+0.072	+0.075	+0.077	+0.079	+0.081	+0.083	+0.086
−19.0	.067	.070	.072	.074	.076	.078	.080	.083	.085
−18.5	.067	.069	.071	.073	.075	.077	.080	.082	.084
−18.0	.066	.068	.070	.072	.074	.077	.079	.081	.083
−17.5	.065	.067	.069	.072	.074	.076	.078	.080	.082
−17.0	+0.065	+0.067	+0.069	+0.071	+0.073	+0.075	+0.077	+0.079	+0.081
−16.5	.064	.066	.068	.070	.072	.074	.076	.078	.080
−16.0	.063	.065	.067	.069	.071	.073	.075	.077	.079
−15.5	.062	.064	.066	.068	.070	.072	.074	.077	.079
−15.0	.062	.064	.066	.068	.070	.072	.074	.076	.078
−14.5	+0.061	+0.063	+0.065	+0.067	+0.069	+0.071	+0.073	+0.075	+0.077
−14.0	.060	.062	.064	.066	.068	.070	.072	.074	.076
−13.5	.060	.061	.063	.065	.067	.069	.071	.073	.075
−13.0	.059	.061	.063	.065	.066	.068	.070	.072	.074
−12.5	.058	.060	.062	.064	.066	.068	.069	.071	.073
−12.0	+0.057	+0.059	+0.061	+0.063	+0.065	+0.067	+0.069	+0.070	+0.072
−11.5	.057	.059	.060	.062	.064	.066	.068	.070	.071
−11.0	.056	.058	.060	.061	.063	.065	.067	.069	.070
−10.5	.055	.057	.059	.061	.062	.064	.066	.068	.070
−10.0	.055	.056	.058	.060	.062	.063	.065	.067	.069
− 9.5	+0.054	+0.056	+0.057	+0.059	+0.061	+0.063	+0.064	+0.066	+0.068
− 9.0	.053	.055	.057	.058	.060	.062	.063	.065	.067
− 8.5	.052	.054	.056	.058	.059	.061	.063	.064	.066
− 8.0	.052	.053	.055	.057	.058	.060	.062	.063	.065
− 7.5	.051	.053	.054	.056	.058	.059	.061	.063	.064
− 7.0	+0.050	+0.052	+0.054	+0.055	+0.057	+0.058	+0.060	+0.062	+0.063
− 6.5	.050	.051	.053	.054	.056	.058	.059	.061	.062
− 6.0	.049	.051	.052	.054	.055	.057	.058	.060	.062
− 5.5	.048	.050	.051	.053	.054	.056	.058	.059	.061
− 5.0	.048	.049	.051	.052	.054	.055	.057	.058	.060
− 4.5	+0.047	+0.048	+0.050	+0.051	+0.053	+0.054	+0.056	+0.057	+0.059
− 4.0	.046	.048	.049	.051	.052	.054	.055	.056	.058
− 3.5	.045	.047	.048	.050	.051	.053	.054	.056	.057
− 3.0	.045	.046	.048	.049	.050	.052	.053	.055	.056
− 2.5	.044	.045	.047	.048	.050	.051	.052	.054	.055
− 2.0	+0.043	+0.045	+0.046	+0.047	+0.049	+0.050	+0.052	+0.053	+0.054
− 1.5	.043	.044	.045	.047	.048	.049	.051	.052	.054
− 1.0	.042	.043	.045	.046	.047	.049	.050	.051	.053
− 0.5	.041	.042	.044	.045	.046	.048	.049	.050	.052
0.0	.040	.042	.043	.044	.046	.047	.048	.050	.051

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
0.0	+0.040	+0.042	+0.043	+0.044	+0.046	+0.047	+0.048	+0.050	+0.051
0.5	+0.040	+0.041	+0.042	+0.044	+0.045	+0.046	+0.047	+0.049	+0.050
1.0	.039	.040	.042	.043	.044	.045	.047	.048	.049
1.5	.038	.040	.041	.042	.043	.044	.046	.047	.048
2.0	.038	.039	.040	.041	.042	.044	.045	.046	.047
2.5	.037	.038	.039	.040	.042	.043	.044	.045	.046
3.0	+0.036	+0.037	+0.039	+0.040	+0.041	+0.042	+0.043	+0.044	+0.046
3.5	.035	.037	.038	.039	.040	.041	.042	.043	.045
4.0	.035	.036	.037	.038	.039	.040	.041	.043	.044
4.5	.034	.035	.036	.037	.038	.040	.041	.042	.043
5.0	.033	.034	.035	.037	.038	.039	.040	.041	.042
5.5	+0.033	+0.034	+0.035	+0.036	+0.037	+0.038	+0.039	+0.040	+0.041
6.0	.032	.033	.034	.035	.036	.037	.038	.039	.040
6.5	.031	.032	.033	.034	.035	.036	.037	.038	.039
7.0	.031	.032	.032	.033	.034	.035	.036	.037	.038
7.5	.030	.031	.032	.033	.034	.035	.036	.037	.038
8.0	+0.029	+0.030	+0.031	+0.032	+0.033	+0.034	+0.035	+0.036	+0.037
8.5	.028	.029	.030	.031	.032	.033	.034	.035	.036
9.0	.028	.029	.029	.030	.031	.032	.033	.034	.035
9.5	.027	.028	.029	.030	.030	.031	.032	.033	.034
10.0	.026	.027	.028	.029	.030	.031	.031	.032	.033
10.5	+0.026	+0.026	+0.027	+0.028	+0.029	+0.030	+0.031	+0.031	+0.032
11.0	.025	.026	.026	.027	.028	.029	.030	.030	.031
11.5	.024	.025	.026	.026	.027	.028	.029	.030	.030
12.0	.023	.024	.025	.026	.026	.027	.028	.029	.030
12.5	.023	.023	.024	.025	.026	.026	.027	.028	.029
13.0	+0.022	+0.023	+0.023	+0.024	+0.025	+0.026	+0.026	+0.027	+0.028
13.5	.021	.022	.023	.023	.024	.025	.025	.026	.027
14.0	.021	.021	.022	.023	.023	.024	.025	.025	.026
14.5	.020	.021	.021	.022	.022	.023	.024	.024	.025
15.0	.019	.020	.020	.021	.022	.022	.023	.024	.024
15.5	+0.019	+0.019	+0.020	+0.020	+0.021	+0.021	+0.022	+0.023	+0.023
16.0	.018	.018	.019	.020	.020	.021	.021	.022	.023
16.5	.017	.018	.018	.019	.019	.020	.020	.021	.022
17.0	.016	.017	.017	.018	.019	.019	.020	.020	.021
17.5	.016	.016	.017	.017	.018	.018	.019	.019	.020
18.0	+0.015	+0.015	+0.016	+0.016	+0.017	+0.017	+0.018	+0.018	+0.019
18.5	.014	.015	.015	.016	.016	.017	.017	.017	.018
19.0	.014	.014	.014	.015	.015	.016	.016	.017	.017
19.5	.013	.013	.014	.014	.015	.015	.015	.016	.016
20.0	.012	.013	.013	.013	.014	.014	.015	.015	.015
20.5	+0.011	+0.012	+0.012	+0.013	+0.013	+0.013	+0.014	+0.014	+0.014
21.0	.011	.011	.011	.012	.012	.012	.013	.013	.014
21.5	.010	.010	.011	.011	.011	.012	.012	.012	.013
22.0	.009	.010	.010	.010	.011	.011	.011	.011	.012
22.5	.009	.009	.009	.009	.010	.010	.010	.011	.011
23.0	+0.008	+0.008	+0.008	+0.009	+0.009	+0.009	+0.009	+0.010	+0.010
23.5	.007	.007	.008	.008	.008	.008	.009	.009	.009
24.0	.007	.007	.007	.007	.007	.008	.008	.008	.008
24.5	.006	.006	.006	.006	.007	.007	.007	.007	.007
25.0	.005	.005	.005	.006	.006	.006	.006	.006	.006

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached ther- mometer (° F.)	Height of mercury column, inches								
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
25.5	+0.004	+0.005	+0.005	+0.005	+0.005	+0.005	+0.005	+0.005	+0.006
26.0	.004	.004	.004	.004	.004	.004	.004	.005	.005
26.5	.003	.003	.003	.003	.003	.003	.004	.004	.004
27.0	.002	.002	.002	.003	.003	.003	.003	.003	.003
27.5	.002	.002	.002	.002	.002	.002	.002	.002	.002
28.0	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001
28.5	.000	.000	.000	.000	.000	.000	.000	.000	.000
29.0	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
29.5	− .001	− .001	− .001	− .001	− .001	− .001	− .001	− .002	− .002
30.0	− .002	− .002	− .002	− .002	− .002	− .002	− .002	− .002	− .002
30.5	−0.003	−0.003	−0.003	−0.003	−0.003	−0.003	−0.003	−0.003	−0.003
31.0	− .003	− .003	− .004	− .004	− .004	− .004	− .004	− .004	− .004
31.5	− .004	− .004	− .004	− .004	− .005	− .005	− .005	− .005	− .005
32.0	− .005	− .005	− .005	− .005	− .005	− .006	− .006	− .006	− .006
32.5	− .005	− .006	− .006	− .006	− .006	− .006	− .007	− .007	− .007
33.0	−0.006	−0.006	−0.007	−0.007	−0.007	−0.007	−0.007	−0.008	−0.008
33.5	− .007	− .007	− .007	− .008	− .008	− .008	− .008	− .008	− .009
34.0	− .008	− .008	− .008	− .008	− .009	− .009	− .009	− .009	− .010
34.5	− .008	− .009	− .009	− .009	− .009	− .010	− .010	− .010	− .010
35.0	− .009	− .009	− .010	− .010	− .010	− .010	− .011	− .011	− .011
35.5	−0.010	−0.010	−0.010	−0.011	−0.011	−0.011	−0.012	−0.012	−0.012
36.0	− .010	− .011	− .011	− .011	− .012	− .012	− .012	− .013	− .013
36.5	− .011	− .011	− .012	− .012	− .012	− .013	− .013	− .014	− .014
37.0	− .012	− .012	− .013	− .013	− .013	− .014	− .014	− .014	− .015
37.5	− .012	− .013	− .013	− .014	− .014	− .014	− .015	− .015	− .016
38.0	−0.013	−0.014	−0.014	−0.014	−0.015	−0.015	−0.016	−0.016	−0.017
38.5	− .014	− .014	− .015	− .015	− .016	− .016	− .017	− .017	− .017
39.0	− .015	− .015	− .016	− .016	− .016	− .017	− .017	− .018	− .018
39.5	− .015	− .016	− .016	− .017	− .017	− .018	− .018	− .019	− .019
40.0	− .016	− .017	− .017	− .018	− .018	− .019	− .019	− .020	− .020
40.5	−0.017	−0.017	−0.018	−0.018	−0.019	−0.019	−0.020	−0.020	−0.021
41.0	− .017	− .018	− .019	− .019	− .020	− .020	− .021	− .021	− .022
41.5	− .018	− .019	− .019	− .020	− .020	− .021	− .022	− .022	− .023
42.0	− .019	− .019	− .020	− .021	− .021	− .022	− .022	− .023	− .024
42.5	− .020	− .020	− .021	− .021	− .022	− .023	− .023	− .024	− .025
43.0	−0.020	−0.021	−0.022	−0.022	−0.023	−0.023	−0.024	−0.025	−0.025
43.5	− .021	− .022	− .022	− .023	− .024	− .024	− .025	− .026	− .026
44.0	− .022	− .022	− .023	− .024	− .024	− .025	− .026	− .026	− .027
44.5	− .022	− .023	− .024	− .024	− .025	− .026	− .027	− .027	− .028
45.0	− .023	− .024	− .024	− .025	− .026	− .027	− .027	− .028	− .029
45.5	−0.024	−0.024	−0.025	−0.026	−0.027	−0.028	−0.028	−0.029	−0.030
46.0	− .024	− .025	− .026	− .027	− .028	− .028	− .029	− .030	− .031
46.5	− .025	− .026	− .027	− .028	− .028	− .029	− .030	− .031	− .032
47.0	− .026	− .027	− .027	− .028	− .029	− .030	− .031	− .032	− .032
47.5	− .027	− .027	− .028	− .029	− .030	− .031	− .032	− .033	− .033
48.0	−0.027	−0.028	−0.029	−0.030	−0.031	−0.032	−0.032	−0.033	−0.034
48.5	− .028	− .029	− .030	− .031	− .032	− .032	− .033	− .034	− .035
49.0	− .029	− .030	− .030	− .031	− .032	− .033	− .034	− .035	− .036
49.5	− .029	− .030	− .031	− .032	− .033	− .034	− .035	− .036	− .037
50.0	− .030	− .031	− .032	− .033	− .034	− .035	− .036	− .037	− .038

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
50.5	—0.031	—0.032	—0.033	—0.034	—0.035	—0.036	—0.037	—0.038	—0.039
51.0	— .031	— .032	— .033	— .034	— .035	— .036	— .038	— .039	— .040
51.5	— .032	— .033	— .034	— .035	— .036	— .037	— .038	— .039	— .040
52.0	— .033	— .034	— .035	— .036	— .037	— .038	— .039	— .040	— .041
52.5	— .034	— .035	— .036	— .037	— .038	— .039	— .040	— .041	— .042
53.0	—0.034	—0.035	—0.036	—0.038	—0.039	—0.040	—0.041	—0.042	—0.043
53.5	— .035	— .036	— .037	— .038	— .039	— .041	— .042	— .043	— .044
54.0	— .036	— .037	— .038	— .039	— .040	— .041	— .043	— .044	— .045
54.5	— .036	— .037	— .039	— .040	— .041	— .042	— .043	— .045	— .046
55.0	— .037	— .038	— .039	— .041	— .042	— .043	— .044	— .045	— .047
55.5	—0.038	—0.039	—0.040	—0.041	—0.043	—0.044	—0.045	—0.046	—0.047
56.0	— .038	— .040	— .041	— .042	— .043	— .045	— .046	— .047	— .048
56.5	— .039	— .040	— .042	— .043	— .044	— .045	— .047	— .048	— .049
57.0	— .040	— .041	— .042	— .044	— .045	— .046	— .048	— .049	— .050
57.5	— .041	— .042	— .043	— .044	— .046	— .047	— .048	— .050	— .051
58.0	—0.041	—0.043	—0.044	—0.045	—0.047	—0.048	—0.049	—0.051	—0.052
58.5	— .042	— .043	— .045	— .046	— .048	— .049	— .050	— .051	— .053
59.0	— .043	— .044	— .045	— .047	— .048	— .050	— .051	— .052	— .054
59.5	— .043	— .045	— .046	— .048	— .049	— .050	— .052	— .053	— .055
60.0	— .044	— .045	— .047	— .048	— .050	— .051	— .053	— .054	— .055
60.5	—0.045	—0.046	—0.047	—0.049	—0.050	—0.052	—0.053	—0.055	—0.056
61.0	— .045	— .047	— .048	— .050	— .051	— .053	— .054	— .056	— .057
61.5	— .046	— .048	— .049	— .051	— .052	— .054	— .055	— .057	— .058
62.0	— .047	— .048	— .050	— .051	— .053	— .054	— .056	— .057	— .059
62.5	— .048	— .049	— .051	— .052	— .054	— .055	— .057	— .058	— .060
63.0	—0.048	—0.050	—0.051	—0.053	—0.054	—0.056	—0.058	—0.059	—0.061
63.5	— .049	— .050	— .052	— .054	— .055	— .057	— .058	— .060	— .062
64.0	— .050	— .051	— .053	— .054	— .056	— .058	— .059	— .061	— .062
64.5	— .050	— .052	— .054	— .055	— .057	— .058	— .060	— .062	— .063
65.0	— .051	— .053	— .054	— .056	— .058	— .059	— .061	— .063	— .064
65.5	—0.052	—0.053	—0.055	—0.057	—0.058	—0.060	—0.062	—0.063	—0.065
66.0	— .052	— .054	— .056	— .057	— .059	— .061	— .063	— .064	— .066
66.5	— .053	— .055	— .057	— .058	— .060	— .062	— .063	— .065	— .067
67.0	— .054	— .056	— .057	— .059	— .061	— .062	— .064	— .066	— .068
67.5	— .055	— .056	— .058	— .060	— .062	— .063	— .065	— .067	— .069
68.0	—0.055	—0.057	—0.059	—0.061	—0.062	—0.064	—0.066	—0.068	—0.069
68.5	— .056	— .058	— .060	— .061	— .063	— .065	— .067	— .069	— .070
69.0	— .057	— .058	— .060	— .062	— .064	— .066	— .068	— .069	— .071
69.5	— .057	— .059	— .061	— .063	— .065	— .067	— .068	— .070	— .072
70.0	— .058	— .060	— .062	— .064	— .065	— .067	— .069	— .071	— .073
70.5	—0.059	—0.061	—0.062	—0.064	—0.066	—0.068	—0.070	—0.072	—0.074
71.0	— .059	— .061	— .063	— .065	— .067	— .069	— .071	— .073	— .075
71.5	— .060	— .062	— .064	— .066	— .068	— .070	— .072	— .074	— .076
72.0	— .061	— .063	— .065	— .067	— .069	— .071	— .073	— .075	— .076
72.5	— .061	— .063	— .065	— .067	— .069	— .071	— .073	— .075	— .077
73.0	—0.062	—0.064	—0.066	—0.068	—0.070	—0.072	—0.074	—0.076	—0.078
73.5	— .063	— .065	— .067	— .069	— .071	— .073	— .075	— .077	— .079
74.0	— .064	— .066	— .068	— .070	— .072	— .074	— .076	— .078	— .080
74.5	— .064	— .066	— .068	— .070	— .073	— .075	— .077	— .079	— .081
75.0	— .065	— .067	— .069	— .071	— .073	— .075	— .078	— .080	— .082

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
75.5	—0.066	—0.068	—0.070	—0.072	—0.074	—0.076	—0.078	—0.081	—0.083
76.0	— .066	— .069	— .071	— .073	— .075	— .077	— .079	— .081	— .084
76.5	— .067	— .069	— .071	— .074	— .076	— .078	— .080	— .082	— .084
77.0	— .068	— .070	— .072	— .074	— .077	— .079	— .081	— .083	— .085
77.5	— .068	— .071	— .073	— .075	— .077	— .080	— .082	— .084	— .086
78.0	—0.069	—0.071	—0.074	—0.076	—0.078	—0.080	—0.083	—0.085	—0.087
78.5	— .070	— .072	— .074	— .077	— .079	— .081	— .083	— .086	— .088
79.0	— .071	— .073	— .075	— .077	— .080	— .082	— .084	— .086	— .089
79.5	— .071	— .074	— .076	— .078	— .080	— .083	— .085	— .087	— .090
80.0	— .072	— .074	— .077	— .079	— .081	— .084	— .086	— .088	— .091
80.5	—0.073	—0.075	—0.077	—0.080	—0.082	—0.084	—0.087	—0.089	—0.091
81.0	— .073	— .076	— .078	— .080	— .083	— .085	— .088	— .090	— .092
81.5	— .074	— .076	— .079	— .081	— .084	— .086	— .088	— .091	— .093
82.0	— .075	— .077	— .080	— .082	— .084	— .087	— .089	— .092	— .094
82.5	— .075	— .078	— .080	— .083	— .085	— .088	— .090	— .092	— .095
83.0	—0.076	—0.079	—0.081	—0.083	—0.086	—0.088	—0.091	—0.093	—0.096
83.5	— .077	— .079	— .082	— .084	— .087	— .089	— .092	— .094	— .097
84.0	— .078	— .080	— .083	— .085	— .088	— .090	— .093	— .095	— .098
84.5	— .078	— .081	— .083	— .086	— .088	— .091	— .093	— .096	— .098
85.0	— .079	— .081	— .084	— .087	— .089	— .092	— .094	— .097	— .099
85.5	—0.080	—0.082	—0.085	—0.087	—0.090	—0.092	—0.095	—0.098	—0.100
86.0	— .080	— .083	— .085	— .088	— .091	— .093	— .096	— .098	— .101
86.5	— .081	— .084	— .086	— .089	— .091	— .094	— .097	— .099	— .102
87.0	— .082	— .084	— .087	— .090	— .092	— .095	— .098	— .100	— .103
87.5	— .082	— .085	— .088	— .090	— .093	— .096	— .098	— .101	— .104
88.0	—0.083	—0.086	—0.088	—0.091	—0.094	—0.096	—0.099	—0.102	—0.105
88.5	— .084	— .086	— .089	— .092	— .095	— .097	— .100	— .103	— .105
89.0	— .084	— .087	— .090	— .093	— .095	— .098	— .101	— .104	— .106
89.5	— .085	— .088	— .091	— .093	— .096	— .099	— .102	— .104	— .107
90.0	— .086	— .089	— .091	— .094	— .097	— .100	— .102	— .105	— .108
90.5	—0.086	—0.089	—0.092	—0.095	—0.098	—0.101	—0.103	—0.106	—0.109
91.0	— .087	— .090	— .093	— .096	— .099	— .101	— .104	— .107	— .110
91.5	— .088	— .091	— .094	— .096	— .099	— .102	— .105	— .108	— .111
92.0	— .089	— .092	— .094	— .097	— .100	— .103	— .106	— .109	— .112
92.5	— .089	— .092	— .095	— .098	— .101	— .104	— .107	— .110	— .112
93.0	—0.090	—0.093	—0.096	—0.099	—0.102	—0.105	—0.107	—0.110	—0.113
93.5	— .091	— .094	— .097	— .100	— .102	— .105	— .108	— .111	— .114
94.0	— .091	— .094	— .097	— .100	— .103	— .106	— .109	— .112	— .115
94.5	— .092	— .095	— .098	— .101	— .104	— .107	— .110	— .113	— .116
95.0	— .093	— .096	— .099	— .102	— .105	— .108	— .111	— .114	— .117
95.5	—0.094	—0.097	—0.100	—0.103	—0.106	—0.109	—0.112	—0.115	—0.118
96.0	— .094	— .097	— .100	— .103	— .106	— .109	— .112	— .115	— .119
96.5	— .095	— .098	— .101	— .104	— .107	— .110	— .113	— .116	— .119
97.0	— .096	— .099	— .102	— .105	— .108	— .111	— .114	— .117	— .120
97.5	— .096	— .099	— .103	— .106	— .109	— .112	— .115	— .118	— .121
98.0	—0.097	—0.100	—0.103	—0.106	—0.109	—0.113	—0.116	—0.119	—0.122
98.5	— .098	— .101	— .104	— .107	— .110	— .113	— .117	— .120	— .123
99.0	— .098	— .102	— .105	— .108	— .111	— .114	— .117	— .121	— .124
99.5	— .099	— .102	— .105	— .109	— .112	— .115	— .118	— .121	— .125
100.0	— .100	— .103	— .106	— .109	— .113	— .116	— .119	— .122	— .126

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
−20.0	+0.087	+0.089	+0.091	+0.093	+0.095	+0.098	+0.100	+0.102	+0.104
−19.5	+0.086	+0.088	+0.090	+0.092	+0.094	+0.097	+0.099	+0.101	+0.103
−19.0	.085	.087	.089	.091	.093	.096	.098	.100	.102
−18.5	.084	.086	.088	.090	.092	.095	.097	.099	.101
−18.0	.083	.085	.087	.089	.091	.094	.096	.098	.100
−17.5	.082	.084	.086	.088	.091	.093	.095	.097	.099
−17.0	+0.081	+0.083	+0.085	+0.087	+0.090	+0.092	+0.094	+0.096	+0.098
−16.5	.080	.082	.084	.086	.089	.091	.093	.095	.097
−16.0	.079	.081	.083	.086	.088	.090	.092	.094	.096
−15.5	.079	.081	.083	.085	.087	.089	.091	.093	.095
−15.0	.078	.080	.082	.084	.086	.088	.090	.092	.094
−14.5	+0.077	+0.079	+0.081	+0.083	+0.085	+0.087	+0.089	+0.090	+0.092
−14.0	.076	.078	.080	.082	.084	.086	.087	.089	.091
−13.5	.075	.077	.079	.081	.083	.085	.086	.088	.090
−13.0	.074	.076	.078	.080	.082	.084	.085	.087	.089
−12.5	.073	.075	.077	.079	.081	.083	.084	.086	.088
−12.0	+0.072	+0.074	+0.076	+0.078	+0.080	+0.082	+0.083	+0.085	+0.087
−11.5	.071	.073	.075	.077	.079	.081	.082	.084	.086
−11.0	.070	.072	.074	.076	.078	.080	.081	.083	.085
−10.5	.070	.071	.073	.075	.077	.079	.080	.082	.084
−10.0	.069	.070	.072	.074	.076	.077	.079	.081	.083
− 9.5	+0.068	+0.070	+0.071	+0.073	+0.075	+0.076	+0.078	+0.080	+0.082
− 9.0	.067	.069	.070	.072	.074	.075	.077	.079	.081
− 8.5	.066	.068	.069	.071	.073	.074	.076	.078	.080
− 8.0	.065	.067	.068	.070	.072	.073	.075	.077	.078
− 7.5	.064	.066	.068	.069	.071	.072	.074	.076	.077
− 7.0	+0.063	+0.065	+0.067	+0.068	+0.070	+0.071	+0.073	+0.075	+0.076
− 6.5	.062	.064	.066	.067	.069	.070	.072	.074	.075
− 6.0	.062	.063	.065	.066	.068	.069	.071	.073	.074
− 5.5	.061	.062	.064	.065	.067	.068	.070	.072	.073
− 5.0	.060	.061	.063	.064	.066	.067	.069	.071	.072
− 4.5	+0.059	+0.060	+0.062	+0.063	+0.065	+0.066	+0.068	+0.069	+0.071
− 4.0	.058	.059	.061	.062	.064	.065	.067	.068	.070
− 3.5	.057	.059	.060	.061	.063	.064	.066	.067	.069
− 3.0	.056	.058	.059	.061	.062	.063	.065	.066	.068
− 2.5	.055	.057	.058	.060	.061	.062	.064	.065	.067
− 2.0	+0.054	+0.056	+0.057	+0.059	+0.060	+0.061	+0.063	+0.064	+0.066
− 1.5	.054	.055	.056	.058	.059	.060	.062	.063	.065
− 1.0	.053	.054	.055	.057	.058	.059	.061	.062	.063
− 0.5	.052	.053	.054	.056	.057	.058	.060	.061	.062
0.0	.051	.052	.053	.055	.056	.057	.059	.060	.061

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
0.5	+0.050	+0.051	+0.053	+0.054	+0.055	+0.056	+0.058	+0.059	+0.060
1.0	.049	.050	.052	.053	.054	.055	.057	.058	.059
1.5	.048	.049	.051	.052	.053	.054	.056	.057	.058
2.0	.047	.049	.050	.051	.052	.053	.055	.056	.057
2.5	.046	.048	.049	.050	.051	.052	.054	.055	.056
3.0	+0.046	+0.047	+0.048	+0.049	+0.050	+0.051	+0.053	+0.054	+0.055
3.5	.045	.046	.047	.048	.049	.050	.051	.053	.054
4.0	.044	.045	.046	.047	.048	.049	.050	.052	.053
4.5	.043	.044	.045	.046	.047	.048	.049	.051	.052
5.0	.042	.043	.044	.045	.046	.047	.048	.049	.051
5.5	+0.041	+0.042	+0.043	+0.044	+0.045	+0.046	+0.047	+0.048	+0.049
6.0	.040	.041	.042	.043	.044	.045	.046	.047	.048
6.5	.039	.040	.041	.042	.043	.044	.045	.046	.047
7.0	.038	.039	.040	.041	.042	.043	.044	.045	.046
7.5	.038	.038	.039	.040	.041	.042	.043	.044	.045
8.0	+0.037	+0.038	+0.038	+0.039	+0.040	+0.041	+0.042	+0.043	+0.044
8.5	.036	.037	.038	.038	.039	.040	.041	.042	.043
9.0	.035	.036	.037	.038	.038	.039	.040	.041	.042
9.5	.034	.035	.036	.037	.037	.038	.039	.040	.041
10.0	.033	.034	.035	.036	.036	.037	.038	.039	.040
10.5	+0.032	+0.033	+0.034	+0.035	+0.035	+0.036	+0.037	+0.038	+0.039
11.0	.031	.032	.033	.034	.034	.035	.036	.037	.038
11.5	.030	.031	.032	.033	.034	.034	.035	.036	.037
12.0	.030	.030	.031	.032	.033	.033	.034	.035	.036
12.5	.029	.029	.030	.031	.032	.032	.033	.034	.034
13.0	+0.028	+0.028	+0.029	+0.030	+0.031	+0.031	+0.032	+0.033	+0.033
13.5	.027	.028	.028	.029	.030	.030	.031	.032	.032
14.0	.026	.027	.027	.028	.029	.029	.030	.031	.031
14.5	.025	.026	.026	.027	.028	.028	.029	.030	.030
15.0	.024	.025	.025	.026	.027	.027	.028	.029	.029
15.5	+0.023	+0.024	+0.024	+0.025	+0.026	+0.026	+0.027	+0.027	+0.028
16.0	.023	.023	.024	.024	.025	.025	.026	.026	.027
16.5	.022	.022	.023	.023	.024	.024	.025	.025	.026
17.0	.021	.021	.022	.022	.023	.023	.024	.024	.025
17.5	.020	.020	.021	.021	.022	.022	.023	.023	.024
18.0	+0.019	+0.019	+0.020	+0.020	+0.021	+0.021	+0.022	+0.022	+0.023
18.5	.018	.018	.019	.019	.020	.020	.021	.021	.022
19.0	.017	.018	.018	.018	.019	.019	.020	.020	.021
19.5	.016	.017	.017	.017	.018	.018	.019	.019	.020
20.0	.015	.016	.016	.016	.017	.017	.018	.018	.018
20.5	+0.014	+0.015	+0.015	+0.016	+0.016	+0.016	+0.017	+0.017	+0.017
21.0	.014	.014	.014	.015	.015	.015	.016	.016	.016
21.5	.013	.013	.013	.014	.014	.014	.015	.015	.015
22.0	.012	.012	.012	.013	.013	.013	.014	.014	.014
22.5	.011	.011	.011	.012	.012	.012	.013	.013	.013
23.0	+0.010	+0.010	+0.010	+0.011	+0.011	+0.011	+0.012	+0.012	+0.012
23.5	.009	.009	.010	.010	.010	.010	.011	.011	.011
24.0	.008	.008	.009	.009	.009	.009	.010	.010	.010
24.5	.007	.008	.008	.008	.008	.008	.009	.009	.009
25.0	.006	.007	.007	.007	.007	.007	.007	.008	.008

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
25.5	+0.006	+0.006	+0.006	+0.006	+0.006	+0.006	+0.006	+0.007	+0.007
26.0	.005	.005	.005	.005	.005	.005	.005	.005	.006
26.5	.004	.004	.004	.004	.004	.004	.004	.004	.005
27.0	.003	.003	.003	.003	.003	.003	.003	.003	.003
27.5	.002	.002	.002	.002	.002	.002	.002	.002	.002
28.0	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001
28.5	.000	.000	.000	.000	.000	.000	.000	.000	.000
29.0	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
29.5	− .002	− .002	− .002	− .002	− .002	− .002	− .002	− .002	− .002
30.0	− .002	− .002	− .003	− .003	− .003	− .003	− .003	− .003	− .003
30.5	−0.003	−0.003	−0.003	−0.004	−0.004	−0.004	−0.004	−0.004	−0.004
31.0	− .004	− .004	− .004	− .005	− .005	− .005	− .005	− .005	− .005
31.5	− .005	− .005	− .005	− .005	− .006	− .006	− .006	− .006	− .006
32.0	− .006	− .006	− .006	− .006	− .007	− .007	− .007	− .007	− .007
32.5	− .007	− .007	− .007	− .007	− .008	− .008	− .008	− .008	− .008
33.0	−0.008	−0.008	−0.008	−0.008	−0.009	−0.009	−0.009	−0.009	−0.009
33.5	− .009	− .009	− .009	− .009	− .010	− .010	− .010	− .010	− .010
34.0	− .010	− .010	− .010	− .010	− .010	− .011	− .011	− .011	− .011
34.5	− .010	− .011	− .011	− .011	− .011	− .012	− .012	− .012	− .013
35.0	− .011	− .012	− .012	− .012	− .012	− .013	− .013	− .013	− .014
35.5	−0.012	−0.012	−0.013	−0.013	−0.013	−0.014	−0.014	−0.014	−0.015
36.0	− .013	− .013	− .014	− .014	− .014	− .015	− .015	− .015	− .016
36.5	− .014	− .014	− .015	− .015	− .015	− .016	− .016	− .016	− .017
37.0	− .015	− .015	− .016	− .016	− .016	− .017	− .017	− .017	− .018
37.5	− .016	− .016	− .017	− .017	− .017	− .018	− .018	− .019	− .019
38.0	−0.017	−0.017	−0.017	−0.018	−0.018	−0.019	−0.019	−0.020	−0.020
38.5	− .017	− .018	− .018	− .019	− .019	− .020	− .020	− .021	− .021
39.0	− .018	− .019	− .019	− .020	− .020	− .021	− .021	− .022	− .022
39.5	− .019	− .020	− .020	− .021	− .021	− .022	− .022	− .023	− .023
40.0	− .020	− .021	− .021	− .022	− .022	− .023	− .023	− .024	− .024
40.5	−0.021	−0.022	−0.022	−0.023	−0.023	−0.024	−0.024	−0.025	−0.025
41.0	− .022	− .022	− .023	− .024	− .024	− .025	− .025	− .026	− .026
41.5	− .023	− .023	− .024	− .025	− .025	− .026	− .026	− .027	− .027
42.0	− .024	− .024	− .025	− .025	− .026	− .027	− .027	− .028	− .029
42.5	− .025	− .025	− .026	− .026	− .027	− .028	− .028	− .029	− .030
43.0	−0.025	−0.026	−0.027	−0.027	−0.028	−0.029	−0.029	−0.030	−0.031
43.5	− .026	− .027	− .028	− .028	− .029	− .030	− .030	− .031	− .032
44.0	− .027	− .028	− .029	− .029	− .030	− .031	− .031	− .032	− .033
44.5	− .028	− .029	− .030	− .030	− .031	− .032	− .032	− .033	− .034
45.0	− .029	− .030	− .030	− .031	− .032	− .033	− .033	− .034	− .035
45.5	−0.030	−0.031	−0.031	−0.032	−0.033	−0.034	−0.034	−0.035	−0.036
46.0	− .031	− .031	− .032	− .033	− .034	− .035	− .035	− .036	− .037
46.5	− .032	− .032	− .033	− .034	− .035	− .036	− .036	− .037	− .038
47.0	− .032	− .033	− .034	− .035	− .036	− .037	− .037	− .038	− .039
47.5	− .033	− .034	− .035	− .036	− .037	− .038	− .038	− .039	− .040
48.0	−0.034	−0.035	−0.036	−0.037	−0.038	−0.039	−0.040	−0.040	−0.041
48.5	− .035	− .036	− .037	− .038	− .039	− .040	− .041	− .041	− .042
49.0	− .036	− .037	− .038	− .039	− .040	− .041	− .042	− .042	− .043
49.5	− .037	− .038	− .039	− .040	− .041	− .042	− .043	− .044	− .044
50.0	− .038	− .039	− .040	− .041	− .042	− .043	− .044	− .045	− .046

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
50.5	−0.039	−0.040	−0.041	−0.042	−0.043	−0.044	−0.045	−0.046	−0.047
51.0	− .040	− .041	− .042	− .043	− .044	− .045	− .046	− .047	− .048
51.5	− .040	− .041	− .042	− .044	− .045	− .046	− .047	− .048	− .049
52.0	− .041	− .042	− .043	− .044	− .046	− .047	− .048	− .049	− .050
52.5	− .042	− .043	− .044	− .045	− .047	− .048	− .049	− .050	− .051
53.0	−0.043	−0.044	−0.045	−0.046	−0.047	−0.049	−0.050	−0.051	−0.052
53.5	− .044	− .045	− .046	− .047	− .048	− .050	− .051	− .052	− .053
54.0	− .045	− .046	− .047	− .048	− .049	− .051	− .052	− .053	− .054
54.5	− .046	− .047	− .048	− .049	− .050	− .052	− .053	− .054	− .055
55.0	− .047	− .048	− .049	− .050	− .051	− .053	− .054	− .055	− .056
55.5	−0.047	−0.049	−0.050	−0.051	−0.052	−0.054	−0.055	−0.056	−0.057
56.0	− .048	− .050	− .051	− .052	− .053	− .055	− .056	− .057	− .058
56.5	− .049	− .050	− .052	− .053	− .054	− .056	− .057	− .058	− .059
57.0	− .050	− .051	− .053	− .054	− .055	− .057	− .058	− .059	− .060
57.5	− .051	− .052	− .054	− .055	− .056	− .058	− .059	− .060	− .061
58.0	−0.052	−0.053	−0.055	−0.056	−0.057	−0.059	−0.060	−0.061	−0.063
58.5	− .053	− .054	− .055	− .057	− .058	− .060	− .061	− .062	− .064
59.0	− .054	− .055	− .056	− .058	− .059	− .061	− .062	− .063	− .065
59.5	− .055	− .056	− .057	− .059	− .060	− .061	− .063	− .064	− .066
60.0	− .055	− .057	− .058	− .060	− .061	− .062	− .064	− .065	− .067
60.5	−0.056	−0.058	−0.059	−0.061	−0.062	−0.063	−0.065	−0.066	−0.068
61.0	− .057	− .059	− .060	− .062	− .063	− .064	− .066	− .067	− .069
61.5	− .058	− .060	− .061	− .062	− .064	− .065	− .067	− .068	− .070
62.0	− .059	− .060	− .062	− .063	− .065	− .066	− .068	− .069	− .071
62.5	− .060	− .061	− .063	− .064	− .066	− .067	− .069	− .071	− .072
63.0	−0.061	−0.062	−0.064	−0.065	−0.067	−0.068	−0.070	−0.072	−0.073
63.5	− .062	− .063	− .065	− .066	− .068	− .069	− .071	− .073	− .074
64.0	− .062	− .064	− .066	− .067	− .069	− .070	− .072	− .074	− .075
64.5	− .063	− .065	− .067	− .068	− .070	− .071	− .073	− .075	− .076
65.0	− .064	− .066	− .067	− .069	− .071	− .072	− .074	− .076	− .077
65.5	−0.065	−0.067	−0.068	−0.070	−0.072	−0.073	−0.075	−0.077	−0.078
66.0	− .066	− .068	− .069	− .071	− .073	− .074	− .076	− .078	− .079
66.5	− .067	− .069	− .070	− .072	− .074	− .075	− .077	− .079	− .081
67.0	− .068	− .069	− .071	− .073	− .075	− .076	− .078	− .080	− .082
67.5	− .069	− .070	− .072	− .074	− .076	− .077	− .079	− .081	− .083
68.0	−0.069	−0.071	−0.073	−0.075	−0.077	−0.078	−0.080	−0.082	−0.084
68.5	− .070	− .072	− .074	− .076	− .078	− .079	− .081	− .083	− .085
69.0	− .071	− .073	− .075	− .077	− .079	− .080	− .082	− .084	− .086
69.5	− .072	− .074	− .076	− .078	− .079	− .081	− .083	− .085	− .087
70.0	− .073	− .075	− .077	− .079	− .080	− .082	− .084	− .086	− .088
70.5	−0.074	−0.076	−0.078	−0.080	−0.081	−0.083	−0.085	−0.087	−0.089
71.0	− .075	− .077	− .079	− .080	− .082	− .084	− .086	− .088	− .090
71.5	− .076	− .078	− .079	− .081	− .083	− .085	− .087	− .089	− .091
72.0	− .076	− .078	− .080	− .082	− .084	− .086	− .088	− .090	− .092
72.5	− .077	− .079	− .081	− .083	− .085	− .087	− .089	− .091	− .093
73.0	−0.078	−0.080	−0.082	−0.084	−0.086	−0.088	−0.090	−0.092	−0.094
73.5	− .079	− .081	− .083	− .085	− .087	− .089	− .091	− .093	− .095
74.0	− .080	− .082	− .084	− .086	− .088	− .090	− .092	− .094	− .096
74.5	− .081	− .083	− .085	− .087	− .089	− .091	− .093	− .095	− .097
75.0	− .082	− .084	− .086	− .088	− .090	− .092	− .094	− .096	− .099

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
75.5	−0.083	−0.085	−0.087	−0.089	−0.091	−0.093	−0.095	−0.097	−0.100
76.0	− .084	− .086	− .088	− .090	− .092	− .094	− .096	− .098	− .101
76.5	− 084	− .087	− .089	− .091	− .093	− .095	− .097	− .100	− .102
77.0	− .085	− .087	− .090	− .092	− .094	− .096	− .098	− .101	− .103
77.5	− .086	− .088	− .091	− .093	− .095	− .097	− .099	− .102	− .104
78.0	−0.087	−0.089	−0.091	−0.094	−0.096	−0.098	−0.100	−0.103	+0.105
78.5	− .088	− .090	− .092	− .095	− .097	− .099	− .101	− .104	− .106
79.0	− .089	− .091	− .093	− .096	− .098	− .100	− .102	− .105	− .107
79.5	− .090	− .092	− .094	− .097	− .099	− .101	− .103	− .106	− .108
80.0	− .091	− .093	− .095	− .097	− .100	− .102	− .104	− .107	− .109
80.5	−0.091	−0.094	−0.096	−0.098	−0.101	−0.103	−0.105	−0.108	−0.110
81.0	− .092	− .095	− .097	− .099	− .102	− .104	− .106	− .109	− .111
81.5	− .093	− .096	− .098	− .100	− .103	− .105	− .107	− .110	− .112
82.0	− .094	− .096	− .099	− .101	− .104	− .106	− .108	− .111	− .113
82.5	− .095	− .097	− .100	− .102	− .105	− .107	− .109	− .112	− .114
83.0	−0.096	−0.098	−0.101	−0.103	−0.106	−0.108	−0.111	−0.113	−0.115
83.5	− .097	− .099	− .102	− .104	− .107	− .109	− .112	− .114	− .117
84.0	− .098	− .100	− .103	− .105	− .108	− .110	− .113	− .115	− .118
84.5	− .098	− .101	− .103	− .106	− .108	− .111	− .114	− .116	− .119
85.0	− .099	− .102	− .104	− .107	− .109	− .112	− .115	− .117	− .120
85.5	−0.100	−0.103	−0.105	−0.108	−0.110	−0.113	−0.116	−0.118	−0.121
86.0	− .101	− .104	− .106	− .109	− .111	− .114	− .117	− .119	− .122
86.5	− .102	− .105	− .107	− .110	− .112	− .115	− .118	− .120	− .123
87.0	− .103	− .105	− .108	− .111	− .113	− .116	− .119	− .121	− .124
87.5	− .104	− .106	− .109	− .112	− .114	− .117	− .120	− .122	− .125
88.0	−0.105	−0.107	−0.110	−0.113	−0.115	−0.118	−0.121	−0.123	−0.126
88.5	− .105	− .108	− .111	− .114	− .116	− .119	− .122	− .124	− .127
89.0	− .106	− .109	− .112	− .114	− .117	− .120	− .123	− .125	− .128
89.5	− .107	− .110	− .113	− .115	− .118	− .121	− .124	− .126	− .129
90.0	− .108	− .111	− .114	− .116	− .119	− .122	− .125	− .127	− .130
90.5	−0.109	−0.112	−0.114	−0.117	−0.120	−0.123	−0.126	−0.128	−0.131
91.0	− .110	− .113	− .115	− .118	− .121	− .124	− .127	− .129	− .132
91.5	− .111	− .113	− .116	− .119	− .122	− .125	− .128	− .131	− .133
92.0	− .112	− .114	− .117	− .120	− .123	− .126	− .129	− .132	− .134
92.5	− .112	− .115	− .118	− .121	− .124	− .127	− .130	− .133	− .135
93.0	−0.113	−0.116	−0.119	−0.122	−0.125	−0.128	−0.131	−0.134	−0.137
93.5	− .114	− .117	− .120	− .123	− .126	− .129	− .132	− .135	− .138
94.0	− .115	− .118	− .121	− .124	− .127	− .130	− .133	− .136	− .139
94.5	− .116	− .119	− .122	− .125	− .128	− .131	− .134	− .137	− .140
95.0	− .117	− .120	− .123	− .126	− .129	− .132	− .135	− .138	− .141
95.5	−0.118	−0.121	−0.124	−0.127	−0.130	−0.133	−0.136	−0.139	−0.142
96.0	− .119	− .122	− .125	− .128	− .131	− .134	− .137	− .140	− .143
96.5	− .119	− .122	− .126	− .129	− .132	− .135	− .138	− .141	− .144
97.0	− .120	− .123	− .126	− .130	− .133	− .136	− .139	− .142	− .145
97.5	− .121	− .124	− .127	− .130	− .134	− .137	− .140	− .143	− .146
98.0	−0.122	−0.125	−0.128	−0.131	−0.135	−0.138	−0.141	−0.144	−0.147
98.5	− .123	− .126	− .129	− .132	− .135	− .139	− .142	− .145	− .148
99.0	− .124	− .127	− .130	− .133	− .136	− .140	− .143	− .146	− .149
99.5	− .125	− .128	− .131	− .134	− .137	− .141	− .144	− .147	− .150
100.0	− .126	− .129	− .132	− .135	− .138	− .142	− .145	− .148	− .151

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
−20.0	+0.104	+0.107	+0.109	+0.111	+0.113	+0.115	+0.118	+0.120	+0.122
−19.5	+0.103	+0.105	+0.108	+0.110	+0.112	+0.114	+0.116	+0.119	+0.121
−19.0	.102	.104	.107	.109	.111	.113	.115	.117	.120
−18.5	.101	.103	.105	.108	.110	.112	.114	.116	.118
−18.0	.100	.102	.104	.106	.109	.111	.113	.115	.117
−17.5	.099	.101	.103	.105	.107	.109	.112	.114	.116
−17.0	+0.098	+0.100	+0.102	+0.104	+0.106	+0.108	+0.110	+0.112	+0.115
−16.5	.097	.099	.101	.103	.105	.107	.109	.111	.113
−16.0	.096	.098	.100	.102	.104	.106	.108	.110	.112
−15.5	.095	.097	.099	.101	.103	.105	.107	.109	.111
−15.0	.094	.096	.098	.100	.102	.103	.105	.107	.109
−14.5	+0.092	+0.094	+0.096	+0.098	+0.100	+0.102	+0.104	+0.106	+0.108
−14.0	.091	.093	.095	.097	.099	.101	.103	.105	.107
−13.5	.090	.092	.094	.096	.098	.100	.102	.104	.106
−13.0	.089	.091	.093	.095	.097	.099	.101	.103	.104
−12.5	.088	.090	.092	.094	.096	.098	.099	.101	.103
−12.0	+0.087	+0.089	+0.091	+0.093	+0.094	+0.096	+0.098	+0.100	+0.102
−11.5	.086	.088	.090	.091	.093	.095	.097	.099	.101
−11.0	.085	.087	.089	.090	.092	.094	.096	.098	.099
−10.5	.084	.086	.087	.089	.091	.093	.095	.096	.098
−10.0	.083	.085	.086	.088	.090	.092	.093	.095	.097
− 9.5	+0.082	+0.083	+0.085	+0.087	+0.089	+0.090	+0.092	+0.094	+0.096
− 9.0	.081	.082	.084	.086	.087	.089	.091	.093	.094
− 8.5	.080	.081	.083	.085	.086	.088	.090	.091	.093
− 8.0	.078	.080	.082	.083	.085	.087	.088	.090	.092
− 7.5	.077	.079	.081	.082	.084	.086	.087	.089	.091
− 7.0	+0.076	+0.078	+0.080	+0.081	+0.083	+0.084	+0.086	+0.088	+0.089
− 6.5	.075	.077	.078	.080	.082	.083	.085	.086	.088
− 6.0	.074	.076	.077	.079	.080	.082	.084	.085	.087
− 5.5	.073	.075	.076	.078	.079	.081	.082	.084	.086
− 5.0	.072	.074	.075	.077	.078	.080	.081	.083	.084
− 4.5	+0.071	+0.072	+0.074	+0.075	+0.077	+0.079	+0.080	+0.082	+0.083
− 4.0	.070	.071	.073	.074	.076	.077	.079	.080	.082
− 3.5	.069	.070	.072	.073	.075	.076	.078	.079	.081
− 3.0	.068	.069	.071	.072	.073	.075	.076	.078	.079
− 2.5	.067	.068	.069	.071	.072	.074	.075	.077	.078
− 2.0	+0.066	+0.067	+0.068	+0.070	+0.071	+0.073	+0.074	+0.075	+0.077
− 1.5	.065	.066	.067	.069	.070	.071	.073	.074	.075
− 1.0	.063	.065	.066	.067	.069	.070	.072	.073	.074
− 0.5	.062	.064	.065	.066	.068	.069	.070	.072	.073
0.0	.061	.063	.064	.065	.067	.068	.069	.070	.072

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
0.0	+0.061	+0.063	+0.064	+0.065	+0.067	+0.068	+0.069	+0.070	+0.072
0.5	+0.060	+0.061	+0.063	+0.064	+0.065	+0.067	+0.068	+0.069	+0.070
1.0	.059	.060	.062	.063	.064	.065	.067	.068	.069
1.5	.058	.059	.061	.062	.063	.064	.065	.067	.068
2.0	.057	.058	.059	.061	.062	.063	.064	.065	.067
2.5	.056	.057	.058	.059	.061	.062	.063	.064	.065
3.0	+0.055	+0.056	+0.057	+0.058	+0.060	+0.061	+0.062	+0.063	+0.064
3.5	.054	.055	.056	.057	.058	.059	.061	.062	.063
4.0	.053	.054	.055	.056	.057	.058	.059	.061	.062
4.5	.052	.053	.054	.055	.056	.057	.058	.059	.060
5.0	.051	.052	.053	.054	.055	.056	.057	.058	.059
5.5	+0.049	+0.051	+0.052	+0.053	+0.054	+0.055	+0.056	+0.057	+0.058
6.0	.048	.049	.050	.052	.053	.054	.055	.056	.057
6.5	.047	.048	.049	.050	.051	.052	.053	.054	.055
7.0	.046	.047	.048	.049	.050	.051	.052	.053	.054
7.5	.045	.046	.047	.048	.049	.050	.051	.052	.053
8.0	+0.044	+0.045	+0.046	+0.047	+0.048	+0.049	+0.050	+0.051	+0.052
8.5	.043	.044	.045	.046	.047	.048	.049	.049	.050
9.0	.042	.043	.044	.045	.046	.046	.047	.048	.049
9.5	.041	.042	.043	.044	.044	.045	.046	.047	.048
10.0	.040	.041	.042	.042	.043	.044	.045	.046	.047
10.5	+0.039	+0.040	+0.040	+0.041	+0.042	+0.043	+0.044	+0.045	+0.045
11.0	.038	.039	.039	.040	.041	.042	.043	.043	.044
11.5	.037	.037	.038	.039	.040	.041	.041	.042	.043
12.0	.036	.036	.037	.038	.039	.039	.040	.041	.042
12.5	.034	.035	.036	.037	.037	.038	.039	.040	.040
13.0	+0.033	+0.034	+0.035	+0.036	+0.036	+0.037	+0.038	+0.038	+0.039
13.5	.032	.033	.034	.034	.035	.036	.036	.037	.038
14.0	.031	.032	.033	.033	.034	.035	.035	.036	.037
14.5	.030	.031	.031	.032	.033	.033	.034	.035	.035
15.0	.029	.030	.030	.031	.032	.032	.033	.033	.034
15.5	+0.028	+0.029	+0.029	+0.030	+0.030	+0.031	+0.032	+0.032	+0.033
16.0	.027	.028	.028	.029	.029	.030	.030	.031	.032
16.5	.026	.026	.027	.028	.028	.029	.029	.030	.030
17.0	.025	.025	.026	.026	.027	.027	.028	.029	.029
17.5	.024	.024	.025	.025	.026	.026	.027	.027	.028
18.0	+0.023	+0.023	+0.024	+0.024	+0.025	+0.025	+0.026	+0.026	+0.027
18.5	.022	.022	.023	.023	.023	.024	.024	.025	.025
19.0	.021	.021	.021	.022	.022	.023	.023	.024	.024
19.5	.020	.020	.020	.021	.021	.022	.022	.022	.023
20.0	.018	.019	.019	.020	.020	.020	.021	.021	.022
20.5	+0.017	+0.018	+0.018	+0.018	+0.019	+0.019	+0.020	+0.020	+0.020
21.0	.016	.017	.017	.017	.018	.018	.018	.019	.019
21.5	.015	.016	.016	.016	.017	.017	.017	.017	.018
22.0	.014	.014	.015	.015	.015	.016	.016	.016	.017
22.5	.013	.013	.014	.014	.014	.014	.015	.015	.015
23.0	+0.012	+0.012	+0.013	+0.013	+0.013	+0.013	+0.014	+0.014	+0.014
23.5	.011	.011	.011	.012	.012	.012	.012	.013	.013
24.0	.010	.010	.010	.011	.011	.011	.011	.011	.011
24.5	.009	.009	.009	.009	.010	.010	.010	.010	.010
25.0	.008	.008	.008	.008	.008	.009	.009	.009	.009

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
25.5	+0.007	+0.007	+0.007	+0.007	+0.007	+0.007	+0.007	+0.008	+0.008
26.0	.006	.006	.006	.006	.006	.006	.006	.006	.007
26.5	.005	.005	.005	.005	.005	.005	.005	.005	.005
27.0	.003	.004	.004	.004	.004	.004	.004	.004	.004
27.5	.002	.002	.003	.003	.003	.003	.003	.003	.003
28.0	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.002	+0.002	+0.002
28.5	.000	.000	.000	.000	.000	.000	.000	.000	.000
29.0	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
29.5	− .002	− .002	− .002	− .002	− .002	− .002	− .002	− .002	− .002
30.0	− .003	− .003	− .003	− .003	− .003	− .003	− .003	− .003	− .003
30.5	−0.004	−0.004	−0.004	−0.004	−0.004	−0.004	−0.005	−0.005	−0.005
31.0	− .005	− .005	− .005	− .005	− .005	− .006	− .006	− .006	− .006
31.5	− .006	− .006	− .006	− .007	− .007	− .007	− .007	− .007	− .007
32.0	− .007	− .007	− .007	− .008	− .008	− .008	− .008	− .008	− .008
32.5	− .008	− .008	− .009	− .009	− .009	− .009	− .009	− .009	− .010
33.0	−0.009	−0.010	−0.010	−0.010	−0.010	−0.010	−0.011	−0.011	−0.011
33.5	− .010	− .011	− .011	− .011	− .011	− .011	− .012	− .012	− .012
34.0	− .011	− .012	− .012	− .012	− .012	− .013	− .013	− .013	− .013
34.5	− .013	− .013	− .013	− .013	− .014	− .014	− .014	− .014	− .015
35.0	− .014	− .014	− .014	− .014	− .015	− .015	− .015	− .016	− .016
35.5	−0.015	−0.015	−0.015	−0.016	−0.016	−0.016	−0.017	−0.017	−0.017
36.0	− .016	− .016	− .016	− .017	− .017	− .017	− .018	− .018	− .018
36.5	− .017	− .017	− .017	− .018	− .018	− .019	− .019	− .019	− .020
37.0	− .018	− .018	− .019	− .019	− .019	− .020	− .020	− .021	− .021
37.5	− .019	− .019	− .020	− .020	− .021	− .021	− .021	− .022	− .022
38.0	−0.020	−0.020	−0.021	−0.021	−0.022	−0.022	−0.023	−0.023	−0.023
38.5	− .021	− .021	− .022	− .022	− .023	− .023	− .024	− .024	− .025
39.0	− .022	− .023	− .023	− .024	− .024	− .024	− .025	− .025	− .026
39.5	− .023	− .024	− .024	− .025	− .025	− .026	− .026	− .027	− .027
40.0	− .024	− .025	− .025	− .026	− .026	− .027	− .027	− .028	− .028
40.5	−0.025	−0.026	−0.026	−0.027	−0.027	−0.028	−0.029	−0.029	−0.030
41.0	− .026	− .027	− .027	− .028	− .029	− .029	− .030	− .030	− .031
41.5	− .027	− .028	− .029	− .029	− .030	− .030	− .031	− .032	− .032
42.0	− .029	− .029	− .030	− .030	− .031	− .032	− .032	− .033	− .033
42.5	− .030	− .030	− .031	− .031	− .032	− .033	− .033	− .034	− .035
43.0	−0.031	−0.031	−0.032	−0.033	−0.033	−0.034	−0.035	−0.035	−0.036
43.5	− .032	− .032	− .033	− .034	− .034	− .035	− .036	− .036	− .037
44.0	− .033	− .033	− .034	− .035	− .036	− .036	− .037	− .038	− .038
44.5	− .034	− .035	− .035	− .036	− .037	− .037	− .038	− .039	− .040
45.0	− .035	− .036	− .036	− .037	− .038	− .039	− .039	− .040	− .041
45.5	−0.036	−0.037	−0.037	−0.038	−0.039	−0.040	−0.041	−0.041	−0.042
46.0	− .037	− .038	− .039	− .039	− .040	− .041	− .042	− .043	− .043
46.5	− .038	− .039	− .040	− .041	− .041	− .042	− .043	− .044	− .045
47.0	− .039	− .040	− .041	− .042	− .042	− .043	− .044	− .045	− .046
47.5	− .040	− .041	− .042	− .043	− .044	− .045	− .045	− .046	− .047
48.0	−0.041	−0.042	−0.043	−0.044	−0.045	−0.046	−0.047	−0.047	−0.048
48.5	− .042	− .043	− .044	− .045	− .046	− .047	− .048	− .049	− .050
49.0	− .043	− .044	− .045	− .046	− .047	− .048	− .049	− .050	− .051
49.5	− .044	− .045	− .046	− .047	− .048	− .049	− .050	− .051	− .052
50.0	− .046	− .046	− .047	− .048	− .049	− .050	− .051	− .052	− .053

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
50.5	−0.047	−0.048	−0.049	−0.050	−0.051	−0.052	−0.053	−0.054	−0.055
51.0	− .048	− .049	− .050	− .051	− .052	− .053	− .054	− .055	− .056
51.5	− .049	− .050	− .051	− .052	− .053	− .054	− .055	− .056	− .057
52.0	− .050	− .051	− .052	− .053	− .054	− .055	− .056	− .057	− .058
52.5	− .051	− .052	− .053	− .054	− .055	− .056	− .057	− .058	− .059
53.0	−0.052	−0.053	−0.054	−0.055	−0.056	−0.057	−0.059	−0.060	−0.061
53.5	− .053	− .054	− .055	− .056	− .057	− .059	− .060	− .061	− .062
54.0	− .054	− .055	− .056	− .057	− .059	− .060	− .061	− .062	− .063
54.5	− .055	− .056	− .057	− .059	− .060	− .061	− .062	− .063	− .064
55.0	− .056	− .057	− .059	− .060	− .061	− .062	− .063	− .064	− .066
55.5	−0.057	−0.058	−0.060	−0.061	−0.062	−0.063	−0.065	−0.066	−0.067
56.0	− .058	− .060	− .061	− .062	− .063	− .064	− .066	− .067	− .068
56.5	− .059	− .061	− .062	− .063	− .064	− .066	− .067	− .068	− .069
57.0	− .060	− .062	− .063	− .064	− .066	− .067	− .068	− .069	− .071
57.5	− .061	− .063	− .064	− .065	− .067	− .068	− .069	− .071	− .072
58.0	−0.063	−0.064	−0.065	−0.066	−0.068	−0.069	−0.070	−0.072	−0.073
58.5	− .064	− .065	− .066	− .068	− .069	− .070	− .072	− .073	− .074
59.0	− .065	− .066	− .067	− .069	− .070	− .072	− .073	− .074	− .076
59.5	− .066	− .067	− .068	− .070	− .071	− .073	− .074	− .075	− .077
60.0	− .067	− .068	− .070	− .071	− .072	− .074	− .075	− .077	− .078
60.5	−0.068	−0.069	−0.071	−0.072	−0.074	−0.075	−0.076	−0.078	−0.079
61.0	− .069	− .070	− .072	− .073	− .075	− .076	− .078	− .079	− .081
61.5	− .070	− .071	− .073	− .074	− .076	− .077	− .079	− .080	− .082
62.0	− .071	− .073	− .074	− .076	− .077	− .079	− .080	− .082	− .083
62.5	− .072	− .074	− .075	− .077	− .078	− .080	− .081	− .083	− .084
63.0	−0.073	−0.075	−0.076	−0.078	−0.079	−0.081	−0.082	−0.084	−0.086
63.5	− .074	− .076	− .077	− .079	− .080	− .082	− .084	− .085	− .087
64.0	− .075	− .077	− .078	− .080	− .082	− .083	− .085	− .086	− .088
64.5	− .076	− .078	− .080	− .081	− .083	− .084	− .086	− .088	− .089
65.0	− .077	− .079	− .081	− .082	− .084	− .086	− .087	− .089	− .091
65.5	−0.078	−0.080	−0.082	−0.083	−0.085	−0.087	−0.088	−0.090	−0.092
66.0	− .079	− .081	− .083	− .085	− .086	− .088	− .090	− .091	− .093
66.5	− .081	− .082	− .084	− .086	− .087	− .089	− .091	− .093	− .094
67.0	− .082	− .083	− .085	− .087	− .089	− .090	− .092	− .094	− .095
67.5	− .083	− .084	− .086	− .088	− .090	− .092	− .093	− .095	− .097
68.0	−0.084	−0.085	−0.087	−0.089	−0.091	−0.093	−0.094	−0.096	−0.098
68.5	− .085	− .087	− .088	− .090	− .092	− .094	− .096	− .097	− .099
69.0	− .086	− .088	− .089	− .091	− .093	− .095	− .097	− .099	− .100
69.5	− .087	− .089	− .091	− .092	− .094	− .096	− .098	− .100	− .102
70.0	− .088	− .090	− .092	− .094	− .095	− .097	− .099	− .101	− .103
70.5	−0.089	−0.091	−0.093	−0.095	−0.097	−0.098	−0.100	−0.102	−0.104
71.0	− .090	− .092	− .094	− .096	− .098	− .100	− .102	− .103	− .105
71.5	− .091	− .093	− .095	− .097	− .099	− .101	− .103	− .105	− .107
72.0	− .092	− .094	− .096	− .098	− .100	− .102	− .104	− .106	− .108
72.5	− .093	− .095	− .097	− .099	− .101	− .103	− .105	− .107	− .109
73.0	−0.094	−0.096	−0.098	−0.100	−0.102	−0.104	−0.106	−0.108	−0.110
73.5	− .095	− .097	− .099	− .101	− .103	− .105	− .108	− .110	− .112
74.0	− .096	− .098	− .101	− .103	− .105	− .107	− .109	− .111	− .113
74.5	− .097	− .100	− .102	− .104	− .106	− .108	− .110	− .112	− .114
75.0	− .099	− .101	− .103	− .105	− .107	− .109	− .111	− .113	− .115

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
75.5	−0.100	−0.102	−0.104	−0.106	−0.108	−0.110	−0.112	−0.114	−0.117
76.0	− .101	− .103	− .105	− .107	− .109	− .111	− .113	− .116	− .118
76.5	− .102	− .104	− .106	− .108	− .111	− .113	− .115	− .117	− .119
77.0	− .103	− .105	− .107	− .109	− .112	− .114	− .116	− .118	− .120
77.5	− .104	− .106	− .108	− .110	− .113	− .115	− .117	− .119	− .121
78.0	−0.105	−0.107	−0.109	−0.112	−0.114	−0.116	−0.118	−0.120	−0.123
78.5	− .106	− .108	− .110	− .113	− .115	− .117	− .119	− .122	− .124
79.0	− .107	− .109	− .112	− .114	− .116	− .118	− .121	− .123	− .125
79.5	− .108	− .110	− .113	− .115	− .117	− .120	− .122	− .124	− .126
80.0	− .109	− .111	− .114	− .116	− .118	− .121	− .123	− .125	− .128
80.5	−0.110	−0.112	−0.115	−0.117	−0.120	−0.122	−0.124	−0.127	−0.129
81.0	− .111	− .114	− .116	− .118	− .121	− .123	− .125	− .128	− .130
81.5	− .112	− .115	− .117	− .119	− .122	− .124	− .127	− .129	− .131
82.0	− .113	− .116	− .118	− .121	− .123	− .125	− .128	− .130	− .133
82.5	− .114	− .117	− .119	− .122	− .124	− .127	− .129	− .131	− .134
83.0	−0.115	−0.118	−0.120	−0.123	−0.125	−0.128	−0.130	−0.133	−0.135
83.5	− .117	− .119	− .121	− .124	− .126	− .129	− .131	− .134	− .136
84.0	− .118	− .120	− .123	− .125	− .128	− .130	− .133	− .135	− .138
84.5	− .119	− .121	− .124	− .126	− .129	− .131	− .134	− .136	− .139
85.0	− .120	− .122	− .125	− .127	− .130	− .132	− .135	− .137	− .140
85.5	−0.121	−0.123	−0.126	−0.128	−0.131	−0.134	−0.136	−0.139	−0.141
86.0	− .122	− .124	− .127	− .130	− .132	− .135	− .137	− .140	− .142
86.5	− .123	− .125	− .128	− .131	− .133	− .136	− .138	− .141	− .144
87.0	− .124	− .126	− .129	− .132	− .134	− .137	− .140	− .142	− .145
87.5	− .125	− .128	− .130	− .133	− .136	− .138	− .141	− .144	− .146
88.0	−0.126	−0.129	−0.131	−0.134	−0.137	−0.139	−0.142	−0.145	−0.147
88.5	− .127	− .130	− .132	− .135	− .138	− .141	− .143	− .146	− .149
89.0	− .128	− .131	− .134	− .136	− .139	− .142	− .144	− .147	− .150
89.5	− .129	− .132	− .135	− .137	− .140	− .143	− .146	− .148	− .151
90.0	− .130	− .133	− .136	− .138	− .141	− .144	− .147	− .150	− .152
90.5	−0.131	−0.134	−0.137	−0.140	−0.142	−0.145	−0.148	−0.151	−0.154
91.0	− .132	− .135	− .138	− .141	− .144	− .146	− .149	− .152	− .155
91.5	− .133	− .136	− .139	− .142	− .145	− .148	− .150	− .153	− .156
92.0	− .134	− .137	− .140	− .143	− .146	− .149	− .152	− .154	− .157
92.5	− .135	− .138	− .141	− .144	− .147	− .150	− .153	− .156	− .159
93.0	−0.137	−0.139	−0.142	−0.145	−0.148	−0.151	−0.154	−0.157	−0.160
93.5	− .138	− .140	− .143	− .146	− .149	− .152	− .155	− .158	− .161
94.0	− .139	− .142	− .145	− .147	− .150	− .153	− .156	− .159	− .162
94.5	− .140	− .143	− .146	− .149	− .152	− .155	− .158	− .160	− .163
95.0	− .141	− .144	− .147	− .150	− .153	− .156	− .159	− .162	− .165
95.5	−0.142	−0.145	−0.148	−0.151	−0.154	−0.157	−0.160	−0.163	−0.166
96.0	− .143	− .146	− .149	− .152	− .155	− .158	− .161	− .164	− .167
96.5	− .144	− .147	− .150	− .153	− .156	− .159	− .162	− .165	− .168
97.0	− .145	− .148	− .151	− .154	− .157	− .160	− .163	− .167	− .170
97.5	− .146	− .149	− .152	− .155	− .158	− .162	− .165	− .168	− .171
98.0	−0.147	−0.150	−0.153	−0.156	−0.160	−0.163	−0.166	−0.169	−0.172
98.5	− .148	− .151	− .154	− .158	− .161	− .164	− .167	− .170	− .173
99.0	− .149	− .152	− .155	− .159	− .162	− .165	− .168	− .171	− .175
99.5	− .150	− .153	− .157	− .160	− .163	− .166	− .169	− .173	− .176
100.0	− .151	− .154	− .158	− .161	− .164	− .167	− .171	− .174	− .177

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (°F.)	Height of mercury column, inches								
	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
100.0	−0.151	−0.154	−0.158	−0.161	−0.164	−0.167	−0.171	−0.174	−0.177
100.5	−0.152	−0.156	−0.159	−0.162	−0.165	−0.169	−0.172	−0.175	−0.178
101.0	− .153	− .157	− .160	− .163	− .166	− .170	− .173	− .176	− .179
101.5	− .154	− .158	− .161	− .164	− .168	− .171	− .174	− .177	− .181
102.0	− .155	− .159	− .162	− .165	− .169	− .172	− .175	− .179	− .182
102.5	− .157	− .160	− .163	− .166	− .170	− .173	− .176	− .180	− .183
103.0	−0.158	−0.161	−0.164	−0.168	−0.171	−0.174	−0.178	−0.181	−0.184
103.5	− .159	− .162	− .165	− .169	− .172	− .175	− .179	− .182	− .186
104.0	− .160	− .163	− .166	− .170	− .173	− .177	− .180	− .183	− .187
104.5	− .161	− .164	− .168	− .171	− .174	− .178	− .181	− .185	− .188
105.0	− .162	− .165	− .169	− .172	− .176	− .179	− .182	− .186	− .189
105.5	−0.163	−0.166	−0.170	−0.173	−0.177	−0.180	−0.184	−0.187	−0.191
106.0	− .164	− .167	− .171	− .174	− .178	− .181	− .185	− .188	− .192
106.5	− .165	− .168	− .172	− .175	− .179	− .182	− .186	− .189	− .193
107.0	− .166	− .170	− .173	− .177	− .180	− .184	− .187	− .191	− .194
107.5	− .167	− .171	− .174	− .178	− .181	− .185	− .188	− .192	− .195
108.0	−0.168	−0.172	−0.175	−0.179	−0.182	−0.186	−0.190	−0.193	−0.197
108.5	− .169	− .173	− .176	− .180	− .184	− .187	− .191	− .194	− .198
109.0	− .170	− .174	− .177	− .181	− .185	− .188	− .192	− .196	− .199
109.5	− .171	− .175	− .179	− .182	− .186	− .189	− .193	− .197	− .200
110.0	− .172	− .176	− .180	− .183	− .187	− .191	− .194	− .198	− .202
110.5	−0.173	−0.177	−0.181	−0.184	−0.188	−0.192	−0.195	−0.199	−0.203
111.0	− .174	− .178	− .182	− .186	− .189	− .193	− .197	− .200	− .204
111.5	− .175	− .179	− .183	− .187	− .190	− .194	− .198	− .202	− .205
112.0	− .176	− .180	− .184	− .188	− .191	− .195	− .199	− .203	− .207
112.5	− .178	− .181	− .185	− .189	− .193	− .196	− .200	− .204	− .208
113.0	−0.179	−0.182	−0.186	−0.190	−0.194	−0.198	−0.201	−0.205	−0.209
113.5	− .180	− .183	− .187	− .191	− .195	− .199	− .203	− .206	− .210
114.0	− .181	− .185	− .188	− .192	− .196	− .200	− .204	− .208	− .211
114.5	− .182	− .186	− .189	− .193	− .197	− .201	− .205	− .209	− .213
115.0	− .183	− .187	− .191	− .194	− .198	− .202	− .206	− .210	− .214
115.5	−0.184	−0.188	−0.192	−0.196	−0.199	−0.203	−0.207	−0.211	−0.215
116.0	− .185	− .189	− .193	− .197	− .201	− .205	− .208	− .212	− .216
116.5	− .186	− .190	− .194	− .198	− .202	− .206	− .210	− .214	− .218
117.0	− .187	− .191	− .195	− .199	− .203	− .207	− .211	− .215	− .219
117.5	− .188	− .192	− .196	− .200	− .204	− .208	− .212	− .216	− .220
118.0	−0.189	−0.193	−0.197	−0.201	−0.205	−0.209	−0.213	−0.217	−0.221
118.5	− .190	− .194	− .198	− .202	− .206	− .210	− .214	− .218	− .222
119.0	− .191	− .195	− .199	− .203	− .207	− .211	− .216	− .220	− .224
119.5	− .192	− .196	− .200	− .204	− .209	− .213	− .217	− .221	− .225
120.0	− .193	− .197	− .201	− .206	− .210	− .214	− .218	− .222	− .226

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
−20.0	+0.122	+0.124	+0.127	+0.129	+0.131	+0.133	+0.135	+0.138	+0.140
−19.5	+0.121	+0.123	+0.125	+0.127	+0.130	+0.132	+0.134	+0.136	+0.138
−19.0	.120	.122	.124	.126	.128	.130	.133	.135	.137
−18.5	.118	.120	.123	.125	.127	.129	.131	.133	.135
−18.0	.117	.119	.121	.123	.126	.128	.130	.132	.134
−17.5	.116	.118	.120	.122	.124	.126	.128	.130	.133
−17.0	+0.115	+0.117	+0.119	+0.121	+0.123	+0.125	+0.127	+0.129	+0.131
−16.5	.113	.115	.117	.119	.121	.124	.126	.128	.130
−16.0	.112	.114	.116	.118	.120	.122	.124	.126	.128
−15.5	.111	.113	.115	.117	.119	.121	.123	.125	.127
−15.0	.109	.111	.113	.115	.117	.119	.121	.123	.125
−14.5	+0.108	+0.110	+0.112	+0.114	+0.116	+0.118	+0.120	+0.122	+0.124
−14.0	.107	.109	.111	.113	.115	.117	.119	.121	.122
−13.5	.106	.108	.110	.111	.113	.115	.117	.119	.121
−13.0	.104	.106	.108	.110	.112	.114	.116	.118	.120
−12.5	.103	.105	.107	.109	.111	.113	.114	.116	.118
−12.0	+0.102	+0.104	+0.106	+0.107	+0.109	+0.111	+0.113	+0.115	+0.117
−11.5	.101	.102	.104	.106	.108	.110	.112	.113	.115
−11.0	.099	.101	.103	.105	.107	.108	.110	.112	.114
−10.5	.098	.100	.102	.103	.105	.107	.109	.111	.112
−10.0	.097	.099	.100	.102	.104	.106	.107	.109	.111
− 9.5	+0.096	+0.097	+0.099	+0.101	+0.103	+0.104	+0.106	+0.108	+0.110
− 9.0	.094	.096	.098	.099	.101	.103	.105	.106	.108
− 8.5	.093	.095	.096	.098	.100	.102	.103	.105	.107
− 8.0	.092	.094	.095	.097	.099	.100	.102	.104	.105
− 7.5	.091	.092	.094	.096	.097	.099	.100	.102	.104
− 7.0	+0.089	+0.091	+0.093	+0.094	+0.096	+0.097	+0.099	+0.101	+0.102
− 6.5	.088	.090	.091	.093	.094	.096	.098	.099	.101
− 6.0	.087	.088	.090	.092	.093	.095	.096	.098	.099
− 5.5	.086	.087	.089	.090	.092	.093	.095	.096	.098
− 5.0	.084	.086	.087	.089	.090	.092	.094	.095	.097
− 4.5	+0.083	+0.085	+0.086	+0.088	+0.089	+0.091	+0.092	+0.094	+0.095
− 4.0	.082	.083	.085	.086	.088	.089	.091	.092	.094
− 3.5	.081	.082	.083	.085	.086	.088	.089	.091	.092
− 3.0	.079	.081	.082	.084	.085	.086	.088	.089	.091
− 2.5	.078	.079	.081	.082	.084	.085	.087	.088	.089
− 2.0	+0.077	+0.078	+0.080	+0.081	+0.082	+0.084	+0.085	+0.087	+0.088
− 1.5	.075	.077	.078	.080	.081	.082	.084	.085	.086
− 1.0	.074	.076	.077	.078	.080	.081	.082	.084	.085
− 0.5	.073	.074	.076	.077	.078	.080	.081	.082	.084
0.0	.072	.073	.074	.076	.077	.078	.080	.081	.082

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
0.0	+0.072	+0.073	+0.074	+0.076	+0.077	+0.078	+0.080	+0.081	+0.082
0.5	+0.070	+0.072	+0.073	+0.074	+0.076	+0.077	+0.078	+0.079	+0.081
1.0	.069	.070	.072	.073	.074	.076	.077	.078	.079
1.5	.068	.069	.070	.072	.073	.074	.075	.077	.078
2.0	.067	.068	.069	.070	.072	.073	.074	.075	.076
2.5	.065	.067	.068	.069	.070	.071	.073	.074	.075
3.0	+0.064	+0.065	+0.067	+0.068	+0.069	+0.070	+0.071	+0.072	+0.074
3.5	.063	.064	.065	.066	.068	.069	.070	.071	.072
4.0	.062	.063	.064	.065	.066	.067	.068	.070	.071
4.5	.060	.062	.063	.064	.065	.066	.067	.068	.069
5.0	.059	.060	.061	.062	.063	.065	.066	.067	.068
5.5	+0.058	+0.059	+0.060	+0.061	+0.062	+0.063	+0.064	+0.065	+0.066
6.0	.057	.058	.059	.060	.061	.062	.063	.064	.065
6.5	.055	.056	.057	.058	.059	.060	.061	.062	.063
7.0	.054	.055	.056	.057	.058	.059	.060	.061	.062
7.5	.053	.054	.055	.056	.057	.058	.059	.060	.061
8.0	+0.052	+0.053	+0.054	+0.054	+0.055	+0.056	+0.057	+0.058	+0.059
8.5	.050	.051	.052	.053	.054	.055	.056	.057	.058
9.0	.049	.050	.051	.052	.053	.054	.054	.055	.056
9.5	.048	.049	.050	.050	.051	.052	.053	.054	.055
10.0	.047	.047	.048	.049	.050	.051	.052	.053	.053
10.5	+0.045	+0.046	+0.047	+0.048	+0.049	+0.049	+0.050	+0.051	+0.052
11.0	.044	.045	.046	.047	.047	.048	.049	.050	.051
11.5	.043	.044	.044	.045	.046	.047	.048	.048	.049
12.0	.042	.042	.043	.044	.045	.045	.046	.047	.048
12.5	.040	.041	.042	.043	.043	.044	.045	.045	.046
13.0	+0.039	+0.040	+0.041	+0.041	+0.042	+0.043	+0.043	+0.044	+0.045
13.5	.038	.039	.039	.040	.041	.041	.042	.043	.043
14.0	.037	.037	.038	.039	.039	.040	.041	.041	.042
14.5	.035	.036	.037	.037	.038	.039	.039	.040	.040
15.0	.034	.035	.035	.036	.037	.037	.038	.038	.039
15.5	+0.033	+0.033	+0.034	+0.035	+0.035	+0.036	+0.036	+0.037	+0.038
16.0	.032	.032	.033	.033	.034	.034	.035	.036	.036
16.5	.030	.031	.031	.032	.033	.033	.034	.034	.035
17.0	.029	.030	.030	.031	.031	.032	.032	.033	.033
17.5	.028	.028	.029	.029	.030	.030	.031	.031	.032
18.0	+0.027	+0.027	+0.028	+0.028	+0.029	+0.029	+0.029	+0.030	+0.030
18.5	.025	.026	.026	.027	.027	.028	.028	.029	.029
19.0	.024	.025	.025	.025	.026	.026	.027	.027	.028
19.5	.023	.023	.024	.024	.024	.025	.025	.026	.026
20.0	.022	.022	.022	.023	.023	.024	.024	.024	.025
20.5	+0.020	+0.021	+0.021	+0.021	+0.022	+0.022	+0.023	+0.023	+0.023
21.0	.019	.019	.020	.020	.020	.021	.021	.022	.022
21.5	.018	.018	.018	.019	.019	.019	.020	.020	.020
22.0	.017	.017	.017	.017	.018	.018	.018	.019	.019
22.5	.015	.016	.016	.016	.016	.017	.017	.017	.018
23.0	+0.014	+0.014	+0.015	+0.015	+0.015	+0.015	+0.016	+0.016	+0.016
23.5	.013	.013	.013	.014	.014	.014	.014	.014	.015
24.0	.011	.012	.012	.012	.012	.013	.013	.013	.013
24.5	.010	.011	.011	.011	.011	.011	.011	.012	.012
25.0	.009	.009	.009	.010	.010	.010	.010	.010	.010

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
25.5	+0.008	+0.008	+0.008	+0.008	+0.008	+0.009	+0.009	+0.009	+0.009
26.0	.007	.007	.007	.007	.007	.007	.007	.007	.008
26.5	.005	.005	.006	.006	.006	.006	.006	.006	.006
27.0	.004	.004	.004	.004	.004	.004	.005	.005	.005
27.5	.003	.003	.003	.003	.003	.003	.003	.003	.003
28.0	+0.002	+0.002	+0.002	+0.002	+0.002	+0.002	+0.002	+0.002	+0.002
28.5	.000	.000	.000	.000	.000	.000	.000	.000	.000
29.0	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
29.5	− .002	− .002	− .002	− .002	− .002	− .002	− .002	− .002	− .002
30.0	− .003	− .003	− .004	− .004	− .004	− .004	− .004	− .004	− .004
30.5	−0.005	−0.005	−0.005	−0.005	−0.005	−0.005	−0.005	−0.005	−0.005
31.0	− .006	− .006	− .006	− .006	− .006	− .006	− .007	− .007	− .007
31.5	− .007	− .007	− .007	− .008	− .008	− .008	− .008	− .008	− .008
32.0	− .008	− .009	− .009	− .009	− .009	− .009	− .009	− .009	− .010
32.5	− .010	− .010	− .010	− .010	− .010	− .011	− .011	− .011	− .011
33.0	−0.011	−0.011	−0.011	−0.012	−0.012	−0.012	−0.012	−0.012	−0.012
33.5	− .012	− .012	− .013	− .013	− .013	− .013	− .013	− .014	− .014
34.0	− .013	− .014	− .014	− .014	− .014	− .015	− .015	− .015	− .015
34.5	− .015	− .015	− .015	− .015	− .016	− .016	− .016	− .017	− .017
35.0	− .016	− .016	− .016	− .017	− .017	− .017	− .018	− .018	− .018
35.5	−0.017	−0.017	−0.018	−0.018	−0.018	−0.019	−0.019	−0.019	−0.020
36.0	− .018	− .019	− .019	− .019	− .020	− .020	− .020	− .021	− .021
36.5	− .020	− .020	− .020	− .021	− .021	− .021	− .022	− .022	− .022
37.0	− .021	− .021	− .022	− .022	− .022	− .023	− .023	− .024	− .024
37.5	− .022	− .023	− .023	− .023	− .024	− .024	− .025	− .025	− .025
38.0	−0.023	−0.024	−0.024	−0.025	−0.025	−0.026	−0.026	−0.026	−0.027
38.5	− .025	− .025	− .026	− .026	− .026	− .027	− .027	− .028	− .028
39.0	− .026	− .026	− .027	− .027	− .028	− .028	− .029	− .029	− .030
39.5	− .027	− .028	− .028	− .029	− .029	− .030	− .030	− .031	− .031
40.0	− .028	− .029	− .029	− .030	− .030	− .031	− .031	− .032	− .032
40.5	−0.030	−0.030	−0.031	−0.031	−0.032	−0.032	−0.033	−0.033	−0.034
41.0	− .031	− .031	− .032	− .033	− .033	− .034	− .034	− .035	− .035
41.5	− .032	− .033	− .033	− .034	− .034	− .035	− .036	− .036	− .037
42.0	− .033	− .034	− .035	− .035	− .036	− .036	− .037	− .038	− .038
42.5	− .035	− .035	− .036	− .036	− .037	− .038	− .038	− .039	− .040
43.0	−0.036	−0.036	−0.037	−0.038	−0.038	−0.039	−0.040	−0.040	−0.041
43.5	− .037	− .038	− .038	− .039	− .040	− .040	− .041	− .042	− .042
44.0	− .038	− .039	− .040	− .040	− .041	− .042	− .042	− .043	− .044
44.5	− .040	− .040	− .041	− .042	− .042	− .043	− .044	− .045	− .045
45.0	− .041	− .042	− .042	− .043	− .044	− .045	− .045	− .046	− .047
45.5	−0.042	−0.043	−0.044	−0.044	−0.045	−0.046	−0.047	−0.047	−0.048
46.0	− .043	− .044	− .045	− .046	− .046	− .047	− .048	− .049	− .050
46.5	− .045	− .045	− .046	− .047	− .048	− .049	− .049	− .050	− .051
47.0	− .046	− .047	− .047	− .048	− .049	− .050	− .051	− .052	− .052
47.5	− .047	− .048	− .049	− .050	− .050	− .051	− .052	− .053	− .054
48.0	−0.048	−0.049	−0.050	−0.051	−0.052	−0.053	−0.054	−0.054	−0.055
48.5	− .050	− .050	− .051	− .052	− .053	− .054	− .055	− .056	− .057
49.0	− .051	− .052	− .053	− .054	− .054	− .055	− .056	− .057	− .058
49.5	− .052	− .053	− .054	− .055	− .056	− .057	− .058	− .059	− .060
50.0	− .053	− .054	− .055	− .056	− .057	− .058	− .059	− .060	− .061

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
50.5	—0.055	—0.055	—0.056	—0.057	—0.058	—0.059	—0.060	—0.061	—0.062
51.0	— .056	— .057	— .058	— .059	— .060	— .061	— .062	— .063	— .064
51.5	— .057	— .058	— .059	— .060	— .061	— .062	— .063	— .064	— .065
52.0	— .058	— .059	— .060	— .061	— .062	— .064	— .065	— .066	— .067
52.5	— .059	— .061	— .062	— .063	— .064	— .065	— .066	— .067	— .068
53.0	—0.061	—0.062	—0.063	—0.064	—0.065	—0.066	—0.067	—0.068	—0.070
53.5	— .062	— .063	— .064	— .065	— .066	— .068	— .069	— .070	— .071
54.0	— .063	— .064	— .066	— .067	— .068	— .069	— .070	— .071	— .072
54.5	— .064	— .066	— .067	— .068	— .069	— .070	— .071	— .073	— .074
55.0	— .066	— .067	— .068	— .069	— .070	— .072	— .073	— .074	— .075
55.5	—0.067	—0.068	—0.069	—0.071	—0.072	—0.073	—0.074	—0.075	—0.077
56.0	— .068	— .069	— .071	— .072	— .073	— .074	— .076	— .077	— .078
56.5	— .069	— .071	— .072	— .073	— .074	— .076	— .077	— .078	— .080
57.0	— .071	— .072	— .073	— .075	— .076	— .077	— .078	— .080	— .081
57.5	— .072	— .073	— .075	— .076	— .077	— .078	— .080	— .081	— .082
58.0	—0.073	—0.074	—0.076	—0.077	—0.078	—0.080	—0.081	—0.082	—0.084
58.5	— .074	— .076	— .077	— .078	— .080	— .081	— .083	— .084	— .085
59.0	— .076	— .077	— .078	— .080	— .081	— .083	— .084	— .085	— .087
59.5	— .077	— .078	— .080	— .081	— .082	— .084	— .085	— .087	— .088
60.0	— .078	— .080	— .081	— .082	— .084	— .085	— .087	— .088	— .089
60.5	—0.079	—0.081	—0.082	—0.084	—0.085	—0.087	—0.088	—0.089	—0.091
61.0	— .081	— .082	— .084	— .085	— .086	— .088	— .089	— .091	— .092
61.5	— .082	— .083	— .085	— .086	— .088	— .089	— .091	— .092	— .094
62.0	— .083	— .085	— .086	— .088	— .089	— .091	— .092	— .094	— .095
62.5	— .084	— .086	— .087	— .089	— .090	— .092	— .094	— .095	— .097
63.0	—0.086	—0.087	—0.089	—0.090	—0.092	—0.093	—0.095	—0.096	—0.098
63.5	— .087	— .088	— .090	— .092	— .093	— .095	— .096	— .098	— .099
64.0	— .088	— .090	— .091	— .093	—.094	— .096	— .098	— .099	— .101
64.5	— .089	— .091	— .093	— .094	— .096	— .097	— .099	— .101	— .102
65.0	— .091	— .092	— .094	— .095	— .097	— .099	— .100	— .102	— .104
65.5	—0.092	—0.093	—0.095	—0.097	—0.098	—0.100	—0.102	—0.103	—0.105
66.0	— .093	— .095	— .096	— .098	— .100	— .101	— .103	— .105	— .107
66.5	— .094	— .096	— .098	— .099	— .101	— .103	— .105	— .106	— .108
67.0	— .095	— .097	— .099	— .101	— .102	— .104	— .106	— .108	— .109
67.5	— .097	— .098	— .100	— .102	— .104	— .106	— .107	— .109	— .111
68.0	—0.098	—0.100	—0.102	—0.103	—0.105	—0.107	—0.109	—0.110	—0.112
68.5	— .099	— .101	— .103	— .105	— .106	— .108	— .110	— .112	— .114
69.0	— .100	— .102	— .104	— .106	— .108	— .110	— .111	— .113	— .115
69.5	— .102	— .104	— .105	— .107	— .109	— .111	— .113	— .115	— .116
70.0	— .103	— .105	— .107	— .109	— .110	— .112	— .114	— .116	— .118
70.5	—0.104	—0.106	—0.108	—0.110	—0.112	—0.114	—0.116	—0.117	—0.119
71.0	— .105	— .107	— .109	— .111	— .113	— .115	— .117	— .119	— .121
71.5	— .107	— .109	— .110	— .112	— .114	— .116	— .118	— .120	— .122
72.0	— .108	— .110	— .112	— .114	— .116	— .118	— .120	— .122	— .124
72.5	— .109	— .111	— .113	— .115	— .117	— .119	— .121	— .123	— .125
73.0	—0.110	—0.112	—0.114	—0.116	—0.118	—0.120	—0.122	—0.124	—0.126
73.5	— .112	— .114	— .116	— .118	— .120	— .122	— .124	— .126	— .128
74.0	— .113	— .115	— .117	— .119	— .121	— .123	— .125	— .127	— .129
74.5	— .114	— .116	— .118	— .120	— .122	— .124	— .126	— .129	— .131
75.0	— .115	— .117	— .119	— .122	— .124	— .126	— .128	— .130	— .132

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
75.5	−0.117	−0.119	−0.121	−0.123	−0.125	−0.127	−0.129	−0.131	−0.133
76.0	− .118	− .120	− .122	− .124	− .126	− .128	− .131	− .133	− .135
76.5	− .119	− .121	− .123	− .125	− .128	− .130	− .132	− .134	− .136
77.0	− .120	− .122	− .125	− .127	− .129	− .131	− .133	− .136	− .138
77.5	− .121	− .124	− .126	− .128	− .130	− .133	− .135	− .137	− .139
78.0	−0.123	−0.125	−0.127	−0.129	−0.132	−0.134	−0.136	−0.138	−0.141
78.5	− .124	− .126	− .128	− .131	− .133	− .135	− .137	− .140	− .142
79.0	− .125	− .127	− .130	− .132	− .134	− .137	− .139	− .141	− .143
79.5	− .126	− .129	− .131	− .133	− .136	− .138	− .140	− .143	− .145
80.0	− .128	− .130	− .132	− .135	− .137	− .139	− .142	− .144	− .146
80.5	−0.129	−0.131	−0.134	−0.136	−0.138	−0.141	−0.143	−0.145	−0.148
81.0	− .130	− .132	− .135	− .137	− .140	− .142	− .144	− .147	− .149
81.5	− .131	− .134	− .136	− .139	− .141	− .143	− .146	− .148	− .150
82.0	− .133	− .135	− .137	− .140	− .142	− .145	− .147	− .149	− .152
82.5	− .134	− .136	− .139	− .141	− .144	− .146	− .148	− .151	− .153
83.0	−0.135	−0.138	−0.140	−0.142	−0.145	−0.147	−0.150	−0.152	−0.155
83.5	− .136	− .139	− .141	− .144	− .146	− .149	− .151	− .154	− .156
84.0	− .138	− .140	− .143	− .145	− .148	− .150	− .153	− .155	− .158
84.5	− .139	− .141	− .144	− .146	− .149	− .151	− .154	− .156	− .159
85.0	− .140	− .143	− .145	− .148	− .150	− .153	− .155	− .158	− .160
85.5	−0.141	−0.144	−0.146	−0.149	−0.152	−0.154	−0.157	−0.159	−0.162
86.0	− .142	− .145	− .148	− .150	− .153	− .155	− .158	− .161	− .163
86.5	− .144	− .146	− .149	− .152	− .154	− .157	− .159	− .162	− .165
87.0	− .145	− .148	− .150	− .153	− .155	− .158	− .161	− .163	− .166
87.5	− .146	− .149	− .151	− .154	− .157	− .159	− .162	− .165	− .167
88.0	−0.147	−0.150	−0.153	−0.155	−0.158	−0.161	−0.163	−0.166	−0.169
88.5	− .149	− .151	− .154	− .157	− .159	− .162	− .165	− .168	− .170
89.0	− .150	− .153	− .155	− .158	− .161	− .164	− .166	− .169	− .172
89.5	− .151	− .154	− .157	− .159	− .162	− .165	− .168	− .170	− .173
90.0	− .152	− .155	− .158	− .161	− .163	− .166	− .169	− .172	− .175
90.5	−0.154	−0.156	−0.159	−0.162	−0.165	−0.168	−0.170	−0.173	−0.176
91.0	− .155	− .158	− .160	− .163	− .166	− .169	− .172	− .175	− .177
91.5	− .156	− .159	− .162	− .165	− .167	− .170	− .173	− .176	− .179
92.0	− .157	− .160	− .163	− .166	− .169	− .172	− .174	− .177	− .180
92.5	− .159	− .161	− .164	− .167	− .170	− .173	− .176	− .179	− .182
93.0	−0.160	−0.163	−0.166	−0.168	−0.171	−0.174	−0.177	−0.180	−0.183
93.5	− .161	− .164	− .167	− .170	− .173	− .176	− .179	− .181	− .184
94.0	− .162	− .165	− .168	− .171	− .174	− .177	− .180	− .183	− .186
94.5	− .163	− .166	− .169	− .172	− .175	− .178	− .181	− .184	− .187
95.0	− .165	− .168	− .171	− .174	− .177	− .180	− .183	− .186	− .189
95.5	−0.166	−0.169	−0.172	−0.175	−0.178	−0.181	−0.184	−0.187	−0.190
96.0	− .167	− .170	− .173	− .176	− .179	− .182	− .185	− .188	− .191
96.5	− .168	− .171	− .174	− .178	− .181	− .184	− .187	− .190	− .193
97.0	− .170	− .173	− .176	− .179	− .182	− .185	− .188	− .191	− .194
97.5	− .171	− .174	− .177	− .180	− .183	− .186	− .189	− .193	− .196
98.0	−0.172	−0.175	−0.178	−0.181	−0.185	−0.188	−0.191	−0.194	−0.197
98.5	− .173	− .176	− .180	− .183	− .186	− .189	− .192	− .195	− .199
99.0	− .175	− .178	− .181	− .184	− .187	− .190	− .194	− .197	− .200
99.5	− .176	− .179	− .182	− .185	− .189	− .192	− .195	− .198	− .201
100.0	− .177	− .180	− .183	− .187	− .190	− .193	− .196	− .200	− .203

TABLE 5.2.1 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 62° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
100.0	−0.177	−0.180	−0.183	−0.187	−0.190	−0.193	−0.196	−0.200	−0.203
100.5	−0.178	−0.181	−0.185	−0.188	−0.191	−0.194	−0.198	−0.201	−0.204
101.0	− .179	− .183	− .186	− .189	− .193	− .196	− .199	− .202	− .206
101.5	− .181	− .184	− .187	− .191	− .194	− .197	− .200	− .204	− .207
102.0	− .182	− .185	− .189	− .192	− .195	− .198	− .202	− .205	− .208
102.5	− .183	− .186	− .190	− .193	− .196	− .200	− .203	− .206	− .210
103.0	−0.184	−0.188	−0.191	−0.194	−0.198	−0.201	−0.204	−0.208	−0.211
103.5	− .186	− .189	− .192	− .196	− .199	− .202	− .206	− .209	− .213
104.0	− .187	− .190	− .194	− .197	− .200	− .204	− .207	− .211	− .214
104.5	− .188	− .191	− .195	− .198	− .202	− .205	− .209	− .212	− .215
105.0	− .189	− .193	− .196	− .200	− .203	− .207	− .210	− .213	− .217
105.5	−0.191	−0.194	−0.197	−0.201	−0.204	−0.208	−0.211	−0.215	−0.218
106.0	− .192	− .195	− .199	− .202	− .206	− .209	− .213	− .216	− .220
106.5	− .193	− .196	− .200	− .204	− .207	− .211	− .214	− .218	− .221
107.0	− .194	− .198	− .201	− .205	− .208	− .212	− .215	− .219	− .222
107.5	− .195	− .199	− .203	− .206	− .210	− .213	− .217	− .220	− .224
108.0	−0.197	−0.200	−0.204	−0.207	−0.211	−0.215	−0.218	−0.222	−0.225
108.5	− .198	− .202	− .205	− .209	− .212	− .216	− .219	− .223	− .227
109.0	− .199	− .203	− .206	− .210	− .214	− .217	− .221	− .224	− .228
109.5	− .200	− .204	− .208	− .211	− .215	− .219	− .222	− .226	− .230
110.0	− .202	− .205	− .209	− .213	− .216	− .220	− .224	− .227	− .231
110.5	−0.203	−0.207	−0.210	−0.214	−0.218	−0.221	−0.225	−0.229	−0.232
111.0	− .204	− .208	− .211	− .215	− .219	− .223	− .226	− .230	− .234
111.5	− .205	− .209	− .213	− .216	− .220	− .224	− .228	− .231	− .235
112.0	− .207	− .210	− .214	− .218	− .222	− .225	− .229	− .233	− .237
112.5	− .208	− .212	− .215	− .219	− .223	− .227	− .230	− .234	− .238
113.0	−0.209	−0.213	−0.217	−0.220	−0.224	−0.228	−0.232	−0.236	−0.239
113.5	− .210	− .214	− .218	− .222	− .225	− .229	− .233	− .237	− .241
114.0	− .211	− .215	− .219	− .223	− .227	− .231	− .234	− .238	− .242
114.5	− .213	− .217	− .220	− .224	− .228	− .232	− .236	− .240	− .244
115.0	− .214	− .218	− .222	− .226	− .229	− .233	− .237	− .241	− .245
115.5	−0.215	−0.219	−0.223	−0.227	−0.231	−0.235	−0.239	−0.242	−0.246
116.0	− .216	− .220	− .224	− .228	− .232	− .236	− .240	− .244	− .248
116.5	− .218	− .222	− .225	− .229	− .233	− .237	− .241	− .245	− .249
117.0	− .219	− .223	− .227	− .231	− .235	− .239	− .243	− .247	− .251
117.5	− .220	− .224	− .228	− .232	− .236	− .240	− .244	− .248	− .252
118.0	−0.221	−0.225	−0.229	−0.233	−0.237	−0.241	−0.245	−0.249	−0.253
118.5	− .222	− .227	− .231	− .235	− .239	− .243	− .247	− .251	− .255
119.0	− .224	− .228	− .232	− .236	− .240	− .244	− .248	− .252	− .256
119.5	− .225	− .229	− .233	− .237	− .241	− .245	− .249	− .254	− .258
120.0	− .226	− .230	− .234	− .238	− .243	− .247	− .251	− .255	− .259

TABLE 5.2.2

Correction of Mercurial Barometer for Temperature

Metric measures (barometer in mb. or mm.—scale true at 0° C.)

[For temperatures $\left\{\begin{matrix}\text{below}\\ \text{above}\end{matrix}\right\}$ 0° C., the correction is to be $\left\{\begin{matrix}\text{subtracted}\\ \text{added}\end{matrix}\right\}$ (that is, make algebraic sign of correction opposite to that of temperature, and apply accordingly).]

Attached thermometer (° C.)	Height of mercury column, mb. or mm.							
	400	500	600	700	720	740	760	780
	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.
0	0	0	0	0	0	0	0	0
.5	.03	.04	.05	.06	.06	.06	.06	.06
1.0	.07	.08	.10	.11	.12	.12	.12	.13
1.5	.10	.12	.15	.17	.18	.18	.19	.19
2.0	.13	.16	.20	.23	.24	.24	.25	.25
2.5	0.16	0.20	0.24	0.29	0.29	0.30	0.31	0.32
3.0	.20	.24	.29	.34	.35	.36	.37	.38
3.5	.23	.29	.34	.40	.41	.42	.43	.45
4.0	.26	.33	.39	.46	.47	.48	.50	.51
4.5	.29	.37	.44	.51	.53	.54	.56	.57
5.0	0.33	0.41	0.49	0.57	0.59	0.60	0.62	0.64
5.5	.36	.45	.54	.63	.65	.66	.68	.70
6.0	.39	.49	.59	.69	.71	.72	.74	.76
6.5	.42	.53	.64	.74	.76	.79	.81	.83
7.0	.46	.57	.69	.80	.82	.85	.87	.89
7.5	0.49	0.61	0.73	0.86	0.88	0.91	0.93	0.95
8.0	.52	.65	.78	.91	.94	.97	.99	1.02
8.5	.55	.69	.83	.97	1.00	1.03	1.05	1.08
9.0	.59	.73	.88	1.03	1.06	1.09	1.12	1.15
9.5	.62	.77	.93	1.08	1.12	1.15	1.18	1.21
10.0	0.65	0.82	0.98	1.14	1.17	1.21	1.24	1.27
10.5	.68	.86	1.03	1.20	1.23	1.27	1.30	1.34
11.0	.72	.90	1.08	1.26	1.29	1.33	1.36	1.40
11.5	.75	.94	1.13	1.31	1.35	1.39	1.43	1.46
12.0	.78	.98	1.17	1.37	1.41	1.45	1.49	1.53
12.5	0.82	1.02	1.22	1.43	1.47	1.51	1.55	1.59
13.0	.85	1.06	1.27	1.49	1.53	1.57	1.61	1.66
13.5	.88	1.10	1.32	1.54	1.58	1.63	1.67	1.72
14.0	.91	1.14	1.37	1.60	1.64	1.69	1.73	1.78
14.5	.95	1.18	1.42	1.65	1.70	1.75	1.80	1.84
15.0	0.98	1.22	1.47	1.71	1.76	1.81	1.86	1.91
15.5	1.01	1.26	1.52	1.77	1.82	1.87	1.92	1.97
16.0	1.04	1.30	1.56	1.82	1.88	1.93	1.98	2.03
16.5	1.08	1.34	1.61	1.88	1.94	1.99	2.04	2.10
17.0	1.11	1.38	1.66	1.94	1.99	2.05	2.10	2.16
17.5	1.14	1.43	1.71	2.00	2.05	2.11	2.17	2.22
18.0	1.17	1.47	1.76	2.05	2.11	2.17	2.23	2.29
18.5	1.21	1.51	1.81	2.11	2.17	2.23	2.29	2.35
19.0	1.24	1.55	1.86	2.17	2.23	2.29	2.35	2.41
19.5	1.27	1.59	1.91	2.22	2.29	2.35	2.41	2.48
20.0	1.30	1.63	1.95	2.28	2.34	2.41	2.47	2.54
20.5	1.33	1.67	2.00	2.34	2.40	2.47	2.54	2.60
21.0	1.37	1.71	2.05	2.39	2.46	2.53	2.60	2.67
21.5	1.40	1.75	2.10	2.45	2.52	2.59	2.66	2.73
22.0	1.43	1.79	2.15	2.51	2.58	2.65	2.72	2.79

TABLE 5.2.2 (CONTINUED)

Correction of Mercurial Barometer for Temperature

Metric measures (barometer in mb. or mm.—scale true at 0° C.)

[For temperatures {above / below} 0° C., the correction is to be {subtracted / added} (that is, make algebraic sign of correction opposite to that of temperature, and apply accordingly).]

Attached ther- mometer (° C.)	Height of mercury column, mb. or mm.							
	400	500	600	700	720	740	760	780
	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.
22.5	1.46	1.83	2.20	2.56	2.64	2.71	2.78	2.86
23.0	1.50	1.87	2.25	2.62	2.69	2.77	2.84	2.92
23.5	1.53	1.91	2.29	2.68	2.75	2.83	2.91	2.98
24.0	1.56	1.95	2.34	2.73	2.81	2.89	2.97	3.05
24.5	1.59	1.99	2.39	2.79	2.87	2.95	3.03	3.11
25.0	1.63	2.03	2.44	2.85	2.93	3.01	3.09	3.17
25.5	1.66	2.07	2.49	2.90	2.99	3.07	3.15	3.24
26.0	1.69	2.11	2.54	2.96	3.04	3.13	3.21	3.30
26.5	1.72	2.15	2.59	3.02	3.10	3.19	3.28	3.36
27.0	1.76	2.20	2.63	3.07	3.16	3.25	3.34	3.42
27.5	1.79	2.24	2.68	3.13	3.22	3.31	3.40	3.49
28.0	1.82	2.28	2.73	3.19	3.28	3.37	3.46	3.55
28.5	1.85	2.32	2.78	3.24	3.34	3.43	3.52	3.61
29.0	1.89	2.36	2.83	3.30	3.39	3.49	3.58	3.68
29.5	1.92	2.40	2.88	3.36	3.45	3.55	3.64	3.74
30.0	1.95	2.44	2.93	3.41	3.51	3.61	3.71	3.80
30.5	1.98	2.48	2.97	3.47	3.57	3.67	3.77	3.87
31.0	2.01	2.52	3.02	3.53	3.63	3.73	3.83	3.93
31.5	2.05	2.56	3.07	3.58	3.68	3.79	3.89	3.99
32.0	2.08	2.60	3.12	3.64	3.74	3.85	3.95	4.05
32.5	2.11	2.64	3.17	3.70	3.80	3.91	4.01	4.12
33.0	2.14	2.68	3.22	3.75	3.86	3.97	4.07	4.18
33.5	2.18	2.72	3.26	3.81	3.92	4.03	4.13	4.24
34.0	2.21	2.76	3.31	3.87	3.98	4.09	4.20	4.31
34.5	2.24	2.80	3.36	3.92	4.03	4.15	4.26	4.37
35.0	2.27	2.84	3.41	3.98	4.09	4.21	4.32	4.43
35.5	2.31	2.88	3.46	4.03	4.15	4.26	4.38	4.50
36.0	2.34	2.92	3.51	4.09	4.21	4.32	4.44	4.56
36.5	2.37	2.96	3.55	4.15	4.27	4.38	4.50	4.62
37.0	2.40	3.00	3.60	4.20	4.32	4.44	4.56	4.68
37.5	2.43	3.04	3.65	4.26	4.38	4.50	4.63	4.75
38.0	2.47	3.08	3.70	4.32	4.44	4.56	4.69	4.81
38.5	2.50	3.12	3.75	4.37	4.50	4.62	4.75	4.87
39.0	2.53	3.16	3.80	4.43	4.56	4.68	4.81	4.94
39.5	2.56	3.20	3.84	4.49	4.61	4.74	4.87	5.00
40.0	2.60	3.24	3.89	4.54	4.67	4.80	4.93	5.06
40.5	2.63	3.28	3.94	4.60	4.73	4.86	4.99	5.12
41.0	2.66	3.32	3.99	4.65	4.79	4.92	5.05	5.19
41.5	2.69	3.37	4.04	4.71	4.84	4.98	5.12	5.25
42.0	2.72	3.41	4.09	4.77	4.90	5.04	5.18	5.31
42.5	2.76	3.45	4.13	4.82	4.96	5.10	5.24	5.38
43.0	2.79	3.49	4.18	4.88	5.02	5.16	5.30	5.44
43.5	2.82	3.53	4.23	4.94	5.08	5.22	5.36	5.50
44.0	2.85	3.57	4.28	4.99	5.14	5.28	5.42	5.56
44.5	2.89	3.61	4.33	5.05	5.19	5.34	5.48	5.63
45.0	2.92	3.65	4.38	5.11	5.25	5.40	5.54	5.69

TABLE 5.2.2 (CONTINUED)

Correction of Mercurial Barometer for Temperature

Metric measures (barometer in mb. or mm.—scale true at 0° C.)

[For temperatures $\left\{\begin{matrix}\text{above}\\ \text{below}\end{matrix}\right\}$ 0° C., the correction is to be $\left\{\begin{matrix}\text{subtracted}\\ \text{added}\end{matrix}\right\}$ (that is, make algebraic sign of correction opposite to that of temperature, and apply accordingly).]

Attached thermometer (° C.)	Height of mercury column, mb. or mm.							
	780	800	820	840	860	880	900	920
	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.
0	0	0	0	0	0	0	0	0
.5	.06	.07	.07	.07	.07	.07	.07	.08
1.0	.13	.13	.13	.14	.14	.14	.15	.15
1.5	.19	.20	.20	.21	.21	.22	.22	.23
2.0	.25	.26	.27	.27	.28	.29	.29	.30
2.5	0.32	0.33	0.33	0.34	0.35	0.36	0.37	0.38
3.0	.38	.39	.40	.41	.42	.43	.44	.45
3.5	.45	.46	.47	.48	.49	.50	.51	.53
4.0	.51	.52	.54	.55	.56	.57	.59	.60
4.5	.57	.59	.60	.62	.63	.65	.66	.68
5.0	0.64	0.65	0.67	0.69	0.70	0.72	0.73	0.75
5.5	.70	.72	.74	.75	.77	.79	.81	.83
6.0	.76	.78	.80	.82	.84	.86	.88	.90
6.5	.83	.85	.87	.89	.91	.93	.95	.98
7.0	.89	.91	.94	.96	.98	1.01	1.03	1.05
7.5	0.95	0.98	1.00	1.03	1.05	1.08	1.10	1.13
8.0	1.02	1.04	1.07	1.10	1.12	1.15	1.17	1.20
8.5	1.08	1.11	1.14	1.16	1.19	1.22	1.25	1.28
9.0	1.15	1.17	1.20	1.23	1.26	1.29	1.32	1.35
9.5	1.21	1.24	1.27	1.30	1.33	1.36	1.39	1.43
10.0	1.27	1.30	1.34	1.37	1.40	1.44	1.47	1.50
10.5	1.34	1.37	1.40	1.44	1.47	1.51	1.54	1.58
11.0	1.40	1.44	1.47	1.51	1.54	1.58	1.61	1.65
11.5	1.46	1.50	1.54	1.58	1.61	1.65	1.69	1.73
12.0	1.53	1.57	1.60	1.64	1.68	1.72	1.76	1.80
12.5	1.59	1.63	1.67	1.71	1.75	1.79	1.83	1.87
13.0	1.66	1.70	1.74	1.78	1.83	1.87	1.91	1.95
13.5	1.72	1.76	1.80	1.85	1.89	1.94	1.98	2.02
14.0	1.78	1.83	1.87	1.92	1.96	2.01	2.05	2.10
14.5	1.84	1.89	1.94	1.98	2.03	2.08	2.13	2.17
15.0	1.91	1.96	2.00	2.05	2.10	2.15	2.20	2.25
15.5	1.97	2.02	2.07	2.12	2.17	2.22	2.27	2.32
16.0	2.03	2.09	2.14	2.19	2.24	2.29	2.35	2.40
16.5	2.10	2.15	2.20	2.26	2.31	2.37	2.42	2.47
17.0	2.16	2.22	2.27	2.33	2.38	2.44	2.49	2.55
17.5	2.22	2.28	2.34	2.39	2.45	2.51	2.57	2.62
18.0	2.29	2.35	2.40	2.46	2.52	2.58	2.64	2.70
18.5	2.35	2.41	2.47	2.53	2.59	2.65	2.71	2.77
19.0	2.41	2.48	2.54	2.60	2.66	2.72	2.78	2.85
19.5	2.48	2.54	2.60	2.67	2.73	2.79	2.86	2.92
20.0	2.54	2.60	2.67	2.74	2.80	2.87	2.93	3.00
20.5	2.60	2.67	2.74	2.80	2.87	2.94	3.00	3.07
21.0	2.67	2.73	2.80	2.87	2.94	3.01	3.08	3.14
21.5	2.73	2.80	2.87	2.94	3.01	3.08	3.15	3.22
22.0	2.79	2.86	2.94	3.01	3.08	3.15	3.22	3.29

TABLE 5.2.2 (CONTINUED)

Correction of Mercurial Barometer for Temperature

Metric measures (barometer in mb. or mm.—scale true at 0° C.)

[For temperatures {above / below} 0° C., the correction is to be {subtracted / added} (that is, make algebraic sign of correction opposite to that of temperature, and apply accordingly).]

Attached ther- mometer (° C.)	Height of mercury column, mb. or mm.							
	780	800	820	840	860	880	900	920
	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.
22.5	2.86	2.93	3.00	3.08	3.15	3.22	3.30	3.37
23.0	2.92	2.99	3.07	3.14	3.22	3.29	3.37	3.44
23.5	2.98	3.06	3.14	3.21	3.29	3.36	3.44	3.52
24.0	3.05	3.12	3.20	3.28	3.36	3.44	3.51	3.59
24.5	3.11	3.19	3.27	3.35	3.43	3.51	3.59	3.67
25.0	3.17	3.25	3.33	3.42	3.50	3.58	3.66	3.74
25.5	3.24	3.32	3.40	3.48	3.57	3.65	3.73	3.82
26.0	3.30	3.38	3.47	3.55	3.64	3.72	3.81	3.89
26.5	3.36	3.45	3.53	3.62	3.71	3.79	3.88	3.96
27.0	3.42	3.51	3.60	3.69	3.78	3.86	3.95	4.04
27.5	3.49	3.58	3.67	3.76	3.85	3.93	4.02	4.11
28.0	3.55	3.64	3.73	3.82	3.91	4.01	4.10	4.19
28.5	3.61	3.71	3.80	3.89	3.98	4.08	4.17	4.26
29.0	3.68	3.77	3.87	3.96	4.05	4.15	4.24	4.34
29.5	3.74	3.84	3.93	4.03	4.12	4.22	4.32	4.41
30.0	3.80	3.90	4.00	4.10	4.19	4.29	4.39	4.49
30.5	3.87	3.96	4.06	4.16	4.26	4.36	4.46	4.56
31.0	3.93	4.03	4.13	4.23	4.33	4.43	4.53	4.63
31.5	3.99	4.09	4.20	4.30	4.40	4.50	4.61	4.71
32.0	4.05	4.16	4.26	4.36	4.47	4.57	4.68	4.78
32.5	4.12	4.22	4.33	4.43	4.54	4.65	4.75	4.86
33.0	4.18	4.29	4.40	4.50	4.61	4.72	4.82	4.93
33.5	4.24	4.35	4.46	4.57	4.68	4.79	4.90	5.01
34.0	4.31	4.42	4.53	4.64	4.75	4.86	4.97	5.08
34.5	4.37	4.48	4.59	4.71	4.82	4.93	5.04	5.15
35.0	4.43	4.55	4.65	4.77	4.89	5.00	5.11	5.23
35.5	4.50	4.61	4.73	4.82	4.96	5.07	5.19	5.30
36.0	4.56	4.68	4.79	4.91	5.03	5.14	5.26	5.38
36.5	4.62	4.74	4.86	4.98	5.10	5.21	5.33	5.45
37.0	4.68	4.80	4.92	5.04	5.16	5.28	5.40	5.52
37.5	4.75	4.87	4.99	5.11	5.23	5.36	5.48	5.60
38.0	4.81	4.93	5.06	5.18	5.30	5.43	5.55	5.67
38.5	4.87	5.00	5.12	5.25	5.37	5.50	5.62	5.75
39.0	4.94	5.06	5.19	5.32	5.44	5.57	5.69	5.82
39.5	5.00	5.13	5.25	5.38	5.51	5.64	5.77	5.90
40.0	5.06	5.19	5.32	5.45	5.58	5.71	5.84	5.97
40.5	5.12	5.26	5.39	5.52	5.65	5.78	5.91	6.04
41.0	5.19	5.32	5.45	5.59	5.72	5.85	5.98	6.12
41.5	5.25	5.38	5.52	5.65	5.78	5.92	6.06	6.19
42.0	5.31	5.45	5.58	5.72	5.86	5.99	6.13	6.27
42.5	5.38	5.51	5.65	5.78	5.93	6.06	6.20	6.34
43.0	5.44	5.58	5.72	5.86	6.00	6.14	6.27	6.41
43.5	5.50	5.64	5.78	5.92	6.06	6.21	6.35	6.49
44.0	5.56	5.71	5.85	5.99	6.13	6.28	6.42	6.56
44.5	5.63	5.77	5.91	6.06	6.20	6.35	6.49	6.65
45.0	5.69	5.83	5.98	6.13	6.27	6.42	6.56	6.71

TABLE 5.2.2 (CONTINUED)

Correction of Mercurial Barometer for Temperature

Metric measures (barometer in mb. or mm.—scale true at 0° C.)

[For temperatures $\left\{\begin{matrix}\text{above}\\ \text{below}\end{matrix}\right\}$ 0° C., the correction is to be $\left\{\begin{matrix}\text{subtracted}\\ \text{added}\end{matrix}\right\}$ (that is, make algebraic sign of correction opposite to that of temperature, and apply accordingly).]

Attached thermometer (° C.)	Height of mercury column, mb. or mm.								
	920	940	960	980	1000	1020	1040	1060	1080
	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.
0	0	0	0	0	0	0	0	0	0
.5	.08	.08	.08	.08	.08	.08	.08	.09	.09
1.0	.15	.15	.16	.16	.16	.17	.17	.17	.18
1.5	.23	.23	.24	.24	.25	.25	.25	.26	.26
2.0	.30	.31	.31	.32	.33	.33	.34	.35	.35
2.5	0.38	0.38	0.39	0.40	0.41	0.42	0.42	0.43	0.44
3.0	.45	.46	.47	.48	.49	.50	.51	.52	.53
3.5	.53	.54	.55	.56	.57	.58	.59	.61	.62
4.0	.60	.61	.63	.64	.65	.67	.68	.69	.71
4.5	.68	.69	.71	.72	.73	.75	.76	.78	.79
5.0	0.75	0.77	0.78	0.80	0.82	0.83	0.85	0.87	0.88
5.5	.83	.84	.86	.88	.90	.92	.93	.95	.97
6.0	.90	.92	.94	.96	.98	1.00	1.02	1.04	1.06
6.5	.98	1.00	1.02	1.04	1.06	1.08	1.10	1.12	1.15
7.0	1.05	1.07	1.10	1.12	1.14	1.17	1.19	1.21	1.23
7.5	1.13	1.15	1.17	1.20	1.22	1.25	1.27	1.30	1.32
8.0	1.20	1.23	1.25	1.28	1.31	1.33	1.36	1.38	1.41
8.5	1.28	1.30	1.33	1.36	1.39	1.41	1.44	1.47	1.50
9.0	1.35	1.38	1.41	1.44	1.47	1.50	1.53	1.56	1.59
9.5	1.43	1.46	1.49	1.52	1.55	1.58	1.61	1.64	1.67
10.0	1.50	1.53	1.57	1.60	1.63	1.66	1.70	1.73	1.76
10.5	1.58	1.61	1.64	1.68	1.71	1.75	1.78	1.82	1.85
11.0	1.65	1.69	1.72	1.76	1.79	1.83	1.87	1.90	1.94
11.5	1.73	1.76	1.80	1.84	1.88	1.91	1.95	1.99	2.03
12.0	1.80	1.84	1.88	1.92	1.96	2.00	2.04	2.07	2.11
12.5	1.87	1.92	1.96	2.00	2.04	2.08	2.12	2.16	2.20
13.0	1.95	2.00	2.04	2.08	2.12	2.17	2.21	2.25	2.29
13.5	2.02	2.07	2.11	2.16	2.20	2.24	2.29	2.33	2.38
14.0	2.10	2.14	2.19	2.24	2.28	2.33	2.37	2.42	2.46
14.5	2.17	2.22	2.27	2.32	2.36	2.41	2.46	2.50	2.55
15.0	2.25	2.30	2.35	2.40	2.44	2.49	2.54	2.59	2.64
15.5	2.32	2.37	2.42	2.48	2.53	2.58	2.63	2.68	2.73
16.0	2.40	2.45	2.50	2.55	2.61	2.66	2.71	2.76	2.82
16.5	2.47	2.53	2.58	2.63	2.69	2.74	2.80	2.85	2.90
17.0	2.55	2.60	2.66	2.71	2.77	2.82	2.88	2.94	2.99
17.5	2.62	2.68	2.74	2.79	2.85	2.91	2.96	3.02	3.08
18.0	2.70	2.76	2.81	2.87	2.93	2.99	3.05	3.11	3.17
18.5	2.77	2.83	2.89	2.95	3.01	3.07	3.13	3.19	3.25
19.0	2.85	2.91	2.97	3.03	3.09	3.16	3.22	3.28	3.34
19.5	2.92	2.98	3.05	3.11	3.18	3.24	3.30	3.37	3.43
20.0	3.00	3.06	3.13	3.19	3.26	3.32	3.39	3.45	3.52
20.5	3.07	3.14	3.20	3.27	3.34	3.40	3.47	3.54	3.60
21.0	3.14	3.21	3.28	3.35	3.42	3.49	3.56	3.62	3.69
21.5	3.22	3.29	3.36	3.43	3.50	3.57	3.64	3.71	3.78
22.0	3.29	3.37	3.44	3.51	3.58	3.65	3.72	3.80	3.87

TABLE 5.2.2 (CONTINUED)

Correction of Mercurial Barometer for Temperature

Metric measures (barometer in mb. or mm.—scale true at 0° C.)

[For temperatures {above / below} 0° C., the correction is to be {subtracted / added} (that is, make algebraic sign of correction opposite to that of temperature, and apply accordingly).]

Attached thermometer (° C.)	Height of mercury column, mb. or mm.								
	920	940	960	980	1000	1020	1040	1060	1080
	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.	mb. or mm.
22.5	3.37	3.44	3.52	3.59	3.66	3.73	3.81	3.88	3.95
23.0	3.44	3.52	3.59	3.67	3.74	3.82	3.89	3.97	4.04
23.5	3.52	3.59	3.67	3.75	3.82	3.90	3.98	4.05	4.13
24.0	3.59	3.67	3.75	3.83	3.90	3.98	4.06	4.14	4.22
24.5	3.67	3.75	3.83	3.91	3.99	4.07	4.14	4.22	4.30
25.0	3.74	3.82	3.90	3.99	4.07	4.15	4.23	4.31	4.39
25.5	3.82	3.90	3.98	4.06	4.15	4.23	4.31	4.40	4.48
26.0	3.89	3.97	4.06	4.14	4.23	4.31	4.40	4.48	4.57
26.5	3.96	4.05	4.14	4.22	4.31	4.40	4.48	4.57	4.65
27.0	4.04	4.13	4.21	4.30	4.39	4.48	4.57	4.65	4.74
27.5	4.11	4.20	4.29	4.38	4.47	4.56	4.65	4.74	4.83
28.0	4.19	4.28	4.37	4.46	4.55	4.64	4.73	4.83	4.92
28.5	4.26	4.35	4.45	4.54	4.63	4.73	4.82	4.91	5.00
29.0	4.34	4.43	4.53	4.62	4.71	4.81	4.90	5.00	5.09
29.5	4.41	4.51	4.60	4.70	4.79	4.89	4.99	5.08	5.18
30.0	4.49	4.58	4.68	4.78	4.88	4.97	5.07	5.17	5.27
30.5	4.56	4.66	4.76	4.86	4.96	5.06	5.15	5.25	5.35
31.0	4.63	4.73	4.84	4.94	5.04	5.14	5.24	5.34	5.44
31.5	4.71	4.81	4.91	5.02	5.12	5.22	5.32	5.42	5.53
32.0	4.78	4.89	4.99	5.09	5.20	5.30	5.41	5.51	5.61
32.5	4.86	4.96	5.07	5.17	5.28	5.38	5.49	5.60	5.70
33.0	4.93	5.04	5.15	5.25	5.36	5.47	5.57	5.68	5.79
33.5	5.01	5.11	5.22	5.33	5.44	5.55	5.66	5.77	5.88
34.0	5.08	5.19	5.30	5.41	5.52	5.63	5.74	5.85	5.96
34.5	5.15	5.27	5.38	5.49	5.60	5.71	5.83	5.94	6.05
35.0	5.23	5.34	5.46	5.57	5.68	5.80	5.91	6.02	6.14
35.5	5.30	5.42	5.53	5.65	5.76	5.88	5.99	6.11	6.22
36.0	5.38	5.49	5.61	5.73	5.84	5.96	6.08	6.19	6.31
36.5	5.45	5.57	5.69	5.81	5.92	6.04	6.16	6.28	6.40
37.0	5.52	5.65	5.77	5.89	6.01	6.13	6.25	6.37	6.49
37.5	5.60	5.72	5.84	5.96	6.09	6.21	6.33	6.45	6.57
38.0	5.67	5.80	5.92	6.04	6.17	6.29	6.41	6.54	6.66
38.5	5.75	5.87	6.00	6.12	6.25	6.37	6.50	6.62	6.75
39.0	5.82	5.95	6.07	6.20	6.33	6.45	6.58	6.71	6.83
39.5	5.90	6.02	6.15	6.28	6.41	6.54	6.66	6.79	6.92
40.0	5.97	6.10	6.23	6.36	6.49	6.62	6.75	6.88	7.01
40.5	6.04	6.18	6.31	6.44	6.57	6.70	6.83	6.96	7.09
41.0	6.12	6.25	6.38	6.52	6.65	6.78	6.92	7.05	7.18
41.5	6.19	6.33	6.46	6.60	6.73	6.86	7.00	7.13	7.27
42.0	6.27	6.40	6.54	6.67	6.81	6.95	7.08	7.22	7.36
42.5	6.34	6.48	6.62	6.75	6.89	7.03	7.17	7.30	7.44
43.0	6.41	6.55	6.69	6.83	6.97	7.11	7.25	7.39	7.53
43.5	6.49	6.63	6.77	6.91	7.05	7.19	7.33	7.48	7.62
44.0	6.56	6.70	6.84	6.99	7.13	7.28	7.42	7.56	7.70
44.5	6.65	6.78	6.92	7.07	7.21	7.36	7.50	7.65	7.79
45.0	6.71	6.86	7.00	7.15	7.29	7.44	7.59	7.73	7.88

TABLE 5.2.3

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
−20.0	+0.074	+0.076	+0.078	+0.081	+0.083	+0.085	+0.088	+0.090	+0.093
−19.5	+0.073	+0.075	+0.078	+0.080	+0.082	+0.085	+0.087	+0.089	+0.092
−19.0	.072	.074	.077	.079	.081	.084	.086	.088	.091
−18.5	.071	.074	.076	.078	.081	.083	.085	.088	.090
−18.0	.071	.073	.075	.078	.080	.082	.084	.087	.089
−17.5	.070	.072	.075	.077	.079	.081	.084	.086	.088
−17.0	+0.069	+0.072	+0.074	+0.076	+0.078	+0.080	+0.083	+0.085	+0.087
−16.5	.069	.071	.073	.075	.077	.080	.082	.084	.086
−16.0	.068	.070	.072	.074	.077	.079	.081	.083	.085
−15.5	.067	.069	.071	.074	.076	.078	.080	.082	.084
−15.0	.066	.069	.071	.073	.075	.077	.079	.081	.084
−14.5	+0.066	+0.068	+0.070	+0.072	+0.074	+0.076	+0.078	+0.081	+0.083
−14.0	.065	.067	.069	.071	.073	.076	.078	.080	.082
−13.5	.064	.066	.068	.071	.073	.075	.077	.079	.081
−13.0	.064	.066	.068	.070	.072	.074	.076	.078	.080
−12.5	.063	.065	.067	.069	.071	.073	.075	.077	.079
−12.0	+0.062	+0.064	+0.066	+0.068	+0.070	+0.072	+0.074	+0.076	+0.078
−11.5	.061	.063	.065	.067	.069	.071	.073	.075	.077
−11.0	.061	.063	.065	.067	.069	.071	.073	.074	.076
−10.5	.060	.062	.064	.066	.068	.070	.072	.074	.076
−10.0	.059	.061	.063	.065	.067	.069	.071	.073	.075
− 9.5	+0.059	+0.061	+0.062	+0.064	+0.066	+0.068	+0.070	+0.072	+0.074
− 9.0	.058	.060	.062	.064	.065	.067	.069	.071	.073
− 8.5	.057	.059	.061	.063	.065	.066	.068	.070	.072
− 8.0	.057	.058	.060	.062	.064	.066	.067	.069	.071
− 7.5	.056	.058	.059	.061	.063	.065	.067	.068	.070
− 7.0	+0.055	+0.057	+0.059	+0.060	+0.062	+0.064	+0.066	+0.068	+0.069
− 6.5	.054	.056	.058	.060	.061	.063	.065	.067	.068
− 6.0	.054	.055	.057	.059	.061	.062	.064	.066	.068
− 5.5	.053	.055	.056	.058	.060	.062	.063	.065	.067
− 5.0	.052	.054	.056	.057	.059	.061	.062	.064	.066
− 4.5	+0.052	+0.053	+0.055	+0.057	+0.058	+0.060	+0.062	+0.063	+0.065
− 4.0	.051	.052	.054	.056	.057	.059	.061	.062	.064
− 3.5	.050	.052	.053	.055	.057	.058	.060	.061	.063
− 3.0	.049	.051	.053	.054	.056	.057	.059	.061	.062
− 2.5	.049	.050	.052	.053	.055	.057	.058	.060	.061
− 2.0	+0.048	+0.050	+0.051	+0.053	+0.054	+0.056	+0.057	+0.059	+0.060
− 1.5	.047	.049	.050	.052	.053	.055	.056	.058	.060
− 1.0	.047	.048	.050	.051	.053	.054	.056	.057	.059
− 0.5	.046	.047	.049	.050	.052	.053	.055	.056	.058
0.0	.045	.047	.048	.050	.051	.052	.054	.055	.057

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
0.0	+0.045	+0.047	+0.048	+0.050	+0.051	+0.052	+0.054	+0.055	+0.057
0.5	+0.044	+0.046	+0.047	+0.049	+0.050	+0.052	+0.053	+0.055	+0.056
1.0	.044	.045	.047	.048	.049	.051	.052	.054	.055
1.5	.043	.044	.046	.047	.049	.050	.051	.053	.054
2.0	.042	.044	.045	.046	.048	.049	.051	.052	.053
2.5	.042	.043	.044	.046	.047	.048	.050	.051	.052
3.0	+0.041	+0.042	+0.044	+0.045	+0.046	+0.048	+0.049	+0.050	+0.051
3.5	.040	.042	.043	.044	.045	.047	.048	.049	.051
4.0	.040	.041	.042	.043	.045	.046	.047	.048	.050
4.5	.039	.040	.041	.043	.044	.045	.046	.048	.049
5.0	.038	.039	.041	.042	.043	.044	.045	.047	.048
5.5	+0.037	+0.039	+0.040	+0.041	+0.042	+0.043	+0.045	+0.046	+0.047
6.0	.037	.038	.039	.040	.041	.043	.044	.045	.046
6.5	.036	.037	.038	.039	.041	.042	.043	.044	.045
7.0	.035	.036	.038	.039	.040	.041	.042	.043	.044
7.5	.035	.036	.037	.038	.039	.040	.041	.042	.043
8.0	+0.034	+0.035	+0.036	+0.037	+0.038	+0.039	+0.040	+0.041	+0.043
8.5	.033	.034	.035	.036	.037	.038	.040	.041	.042
9.0	.032	.033	.035	.036	.037	.038	.039	.040	.041
9.5	.032	.033	.034	.035	.036	.037	.038	.039	.040
10.0	.031	.032	.033	.034	.035	.036	.037	.038	.039
10.5	+0.030	+0.031	+0.032	+0.033	+0.034	+0.035	+0.036	+0.037	+0.038
11.0	.030	.031	.032	.032	.033	.034	.035	.036	.037
11.5	.029	.030	.031	.032	.033	.034	.034	.035	.036
12.0	.028	.029	.030	.031	.032	.033	.034	.035	.035
12.5	.027	.028	.029	.030	.031	.032	.033	.034	.035
13.0	+0.027	+0.028	+0.029	+0.029	+0.030	+0.031	+0.032	+0.033	+0.034
13.5	.026	.027	.028	.029	.029	.030	.031	.032	.033
14.0	.025	.026	.027	.028	.029	.029	.030	.031	.032
14.5	.025	.025	.026	.027	.028	.029	.029	.030	.031
15.0	.024	.025	.026	.026	.027	.028	.029	.029	.030
15.5	+0.023	+0.024	+0.025	+0.026	+0.026	+0.027	+0.028	+0.029	+0.029
16.0	.023	.023	.024	.025	.025	.026	.027	.028	.028
16.5	.022	.023	.023	.024	.025	.025	.026	.027	.027
17.0	.021	.022	.023	.023	.024	.025	.025	.026	.027
17.5	.020	.021	.022	.022	.023	.024	.024	.025	.026
18.0	+0.020	+0.020	+0.021	+0.022	+0.022	+0.023	+0.024	+0.024	+0.025
18.5	.019	.020	.020	.021	.021	.022	.023	.023	.024
19.0	.018	.019	.019	.020	.021	.021	.022	.022	.023
19.5	.018	.018	.019	.019	.020	.020	.021	.022	.022
20.0	.017	.017	.018	.019	.019	.020	.020	.021	.021
20.5	+0.016	+0.017	+0.017	+0.018	+0.018	+0.019	+0.019	+0.020	+0.020
21.0	.015	.016	.016	.017	.017	.018	.018	.019	.019
21.5	.015	.015	.016	.016	.017	.017	.018	.018	.019
22.0	.014	.015	.015	.015	.016	.016	.017	.017	.018
22.5	.013	.014	.014	.015	.015	.015	.016	.016	.017
23.0	+0.013	+0.013	+0.013	+0.014	+0.014	+0.015	+0.015	+0.016	+0.016
23.5	.012	.012	.013	.013	.014	.014	.014	.015	.015
24.0	.011	.012	.012	.012	.013	.013	.013	.014	.014
24.5	.011	.011	.011	.012	.012	.012	.013	.013	.013
25.0	.010	.010	.010	.011	.011	.011	.012	.012	.012

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
25.5	+0.009	+0.009	+0.010	+0.010	+0.010	+0.011	+0.011	+0.011	+0.012
26.0	.008	.009	.009	.009	.010	.010	.010	.010	.011
26.5	.008	.008	.008	.008	.009	.009	.009	.009	.010
27.0	.007	.007	.007	.008	.008	.008	.008	.009	.009
27.5	.006	.007	.007	.007	.007	.007	.008	.008	.008
28.0	+0.006	+0.006	+0.006	+0.006	+0.006	+0.007	+0.007	+0.007	+0.007
28.5	.005	.005	.005	.005	.006	.006	.006	.006	.006
29.0	.004	.004	.004	.005	.005	.005	.005	.005	.005
29.5	.004	.004	.004	.004	.004	.004	.004	.004	.004
30.0	.003	.003	.003	.003	.003	.003	.003	.003	.004
30.5	+0.002	+0.002	+0.002	+0.002	+0.002	+0.002	+0.002	+0.003	+0.003
31.0	.001	.001	.001	.002	.002	.002	.002	.002	.002
31.5	.001	.001	.001	.001	.001	.001	.001	.001	.001
32.0	.000	.000	.000	.000	.000	.000	.000	.000	.000
32.5	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
33.0	−0.001	−0.001	−0.001	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002
33.5	− .002	− .002	− .002	− .002	− .002	− .002	− .003	− .003	− .003
34.0	− .003	− .003	− .003	− .003	− .003	− .003	− .003	− .003	− .003
34.5	− .004	− .004	− .004	− .004	− .004	− .004	− .004	− .004	− .004
35.0	− .004	− .004	− .004	− .005	− .005	− .005	− .005	− .005	− .005
35.5	−0.005	−0.005	−0.005	−0.005	−0.006	−0.006	−0.006	−0.006	−0.006
36.0	− .006	− .006	− .006	− .006	− .006	− .007	− .007	− .007	− .007
36.5	− .006	− .007	− .007	− .007	− .007	− .007	− .008	− .008	− .008
37.0	− .007	− .007	− .007	− .008	− .008	− .008	− .008	− .009	− .009
37.5	− .008	− .008	− .008	− .008	− .009	− .009	− .009	− .009	− .010
38.0	−0.008	−0.009	−0.009	−0.009	−0.010	−0.010	−0.010	−0.010	−0.011
38.5	− .009	− .009	− .010	− .010	− .010	− .011	− .011	− .011	− .011
39.0	− .010	− .010	− .010	− .011	− .011	− .011	− .012	− .012	− .012
39.5	− .011	− .011	− .011	− .012	− .012	− .012	− .013	− .013	− .013
40.0	− .011	− .012	− .012	− .012	− .013	− .013	− .013	− .014	− .014
40.5	−0.012	−0.012	−0.013	−0.013	−0.013	−0.014	−0.014	−0.015	−0.015
41.0	− .013	− .013	− .013	− .014	− .014	− .015	− .015	− .016	− .016
41.5	− .013	− .014	− .014	− .015	− .015	− .016	− .016	− .016	− .017
42.0	− .014	− .015	− .015	− .015	− .016	− .016	− .017	− .017	− .018
42.5	− .015	− .015	− .016	− .016	− .017	− .017	− .018	− .018	− .019
43.0	−0.015	−0.016	−0.016	−0.017	−0.017	−0.018	−0.018	−0.019	−0.019
43.5	− .016	− .017	− .017	− .018	− .018	− .019	− .019	− .020	− .020
44.0	− .017	− .017	− .018	− .018	− .019	− .020	− .020	− .021	− .021
44.5	− .018	− .018	− .019	− .019	− .020	− .020	− .021	− .022	− .022
45.0	− .018	− .019	− .019	− .020	− .021	− .021	− .022	− .022	− .023
45.5	−0.019	−0.020	−0.020	−0.021	−0.021	−0.022	−0.023	−0.023	−0.024
46.0	− .020	− .020	− .021	− .022	− .022	− .023	− .023	− .024	− .025
46.5	− .020	− .021	− .022	− .022	− .023	− .024	− .024	− .025	− .026
47.0	− .021	− .022	− .022	− .023	− .024	− .024	− .025	− .026	− .027
47.5	− .022	− .022	− .023	− .024	− .025	− .025	− .026	− .027	− .027
48.0	−0.022	−0.023	−0.024	−0.025	−0.025	−0.026	−0.027	−0.028	−0.028
48.5	− .023	− .024	− .025	− .025	− .026	− .027	− .028	− .028	− .029
49.0	− .024	− .025	− .025	− .026	− .027	− .028	− .029	− .029	− .030
49.5	− .025	− .025	− .026	− .027	− .028	− .029	− .029	− .030	− .031
50.0	− .025	− .026	− .027	− .028	− .029	− .029	− .030	− .031	− .032

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
50.5	−0.026	−0.027	−0.028	−0.028	−0.029	−0.030	−0.031	−0.032	−0.033
51.0	− .027	− .028	− .028	− .029	− .030	− .031	− .032	− .033	− .034
51.5	− .027	− .028	− .029	− .030	− .031	− .032	− .033	− .034	− .034
52.0	− .028	− .029	− .030	− .031	− .032	− .033	− .034	− .034	− .035
52.5	− .029	− .030	− .031	− .032	− .032	− .033	− .034	− .035	− .036
53.0	−0.029	−0.030	−0.031	−0.032	−0.033	−0.034	−0.035	−0.036	−0.037
53.5	− .030	− .031	− .032	− .033	− .034	− .035	− .036	− .037	− .038
54.0	− .031	− .032	− .033	− .034	− .035	− .036	− .037	− .038	− .039
54.5	− .032	− .033	− .034	− .035	− .036	− .037	− .038	− .039	− .040
55.0	− .032	− .033	− .034	− .035	− .036	− .037	− .039	− .040	− .041
55.5	−0.033	−0.034	−0.035	−0.036	−0.037	−0.038	−0.039	−0.040	−0.042
56.0	− .034	− .035	− .036	− .037	− .038	− .039	− .040	− .041	− .042
56.5	− .034	− .035	− .037	− .038	− .039	− .040	− .041	− .042	− .043
57.0	− .035	− .036	− .037	− .038	− .040	− .041	− .042	− .043	− .044
57.5	− .036	− .037	− .038	− .039	− .040	− .042	− .043	− .044	− .045
58.0	−0.036	−0.038	−0.039	−0.040	−0.041	−0.042	−0.044	−0.045	−0.046
58.5	− .037	− .038	− .040	− .041	− .042	− .043	− .044	− .046	− .047
59.0	− .038	− .039	− .040	− .042	− .043	− .044	− .045	− .046	− .048
59.5	− .039	− .040	− .041	− .042	− .044	− .045	− .046	− .047	− .049
60.0	− .039	− .041	− .042	− .043	− .044	− .046	− .047	− .048	− .049
60.5	−0.040	−0.041	−0.043	−0.044	−0.045	−0.046	−0.048	−0.049	−0.050
61.0	− .041	− .042	− .043	− .045	− .046	− .047	− .049	− .050	− .051
61.5	− .041	− .043	− .044	− .045	− .047	− .048	− .049	− .051	− .052
62.0	− .042	− .043	− .045	− .046	− .048	− .049	− .050	− .052	− .053
62.5	− .043	− .044	− .046	− .047	− .048	− .050	− .051	− .052	− .054
63.0	−0.043	−0.045	−0.046	−0.048	−0.049	−0.050	−0.052	−0.053	−0.055
63.5	− .044	− .046	− .047	− .048	− .050	− .051	− .053	− .054	− .056
64.0	− .045	− .046	− .048	− .049	− .051	− .052	− .054	− .055	− .056
64.5	− .046	− .047	− .049	− .050	− .051	− .053	− .054	− .056	− .057
65.0	− .046	− .048	− .049	− .051	− .052	− .054	− .055	− .057	− .058
65.5	−0.047	−0.048	−0.050	−0.052	−0.053	−0.055	−0.056	−0.058	−0.059
66.0	− .048	− .049	− .051	− .052	− .054	− .055	− .057	− .058	− .060
66.5	− .048	− .050	− .051	− .053	− .055	− .056	− .058	− .059	− .061
67.0	− .049	− .051	− .052	− .054	− .055	− .057	− .059	− .060	− .062
67.5	− .050	− .051	− .053	− .055	− .056	− .058	− .059	− .061	− .063
68.0	−0.050	−0.052	−0.054	−0.055	−0.057	−0.059	−0.060	−0.062	−0.063
68.5	− .051	− .053	− .054	− .056	− .058	− .059	− .061	− .063	− .064
69.0	− .052	− .054	− .055	− .057	− .059	− .060	− .062	− .064	− .065
69.5	− .053	− .054	− .056	− .058	− .059	− .061	− .063	− .064	− .066
70.0	− .053	− .055	− .057	− .058	− .060	− .062	− .064	− .065	− .067
70.5	−0.054	−0.056	−0.057	−0.059	−0.061	−0.063	−0.064	−0.066	−0.068
71.0	− .055	− .056	− .058	− .060	− .062	− .063	− .065	− .067	− .069
71.5	− .055	− .057	− .059	− .061	− .063	− .064	− .066	− .068	− .070
72.0	− .056	− .058	− .060	− .061	− .063	− .065	− .067	− .069	− .071
72.5	− .057	− .059	− .060	− .062	− .064	− .066	− .068	− .070	− .071
73.0	−0.057	−0.059	−0.061	−0.063	−0.065	−0.067	−0.069	−0.070	−0.072
73.5	− .058	− .060	− .062	− .064	− .066	− .068	− .069	− .071	− .073
74.0	− .059	− .061	− .063	− .065	− .066	− .068	− .070	− .072	− .074
74.5	− .060	− .061	− .063	− .065	− .067	− .069	− .071	− .073	− .075
75.0	− .060	− .062	− .064	− .066	− .068	− .070	− .072	− .074	− .076

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
75.5	−0.061	−0.063	−0.065	−0.067	−0.069	−0.071	−0.073	−0.075	−0.077
76.0	− .062	− .064	− .066	− .068	− .070	− .072	− .074	− .076	− .078
76.5	− .062	− .064	− .066	− .068	− .070	− .072	− .074	− .076	− .078
77.0	− .063	− .065	− .067	− .069	− .071	− .073	− .075	− .077	− .079
77.5	− .064	− .066	− .068	− .070	− .072	− .074	− .076	− .078	− .080
78.0	−0.064	−0.067	−0.069	−0.071	−0.073	−0.075	−0.077	−0.079	−0.081
78.5	− .065	− .067	− .069	− .071	− .074	− .076	− .078	− .080	− .082
79.0	− .066	− .068	− .070	− .072	− .074	− .076	− .079	− .081	− .083
79.5	− .067	− .069	− .071	− .073	− .075	− .077	− .079	− .082	− .084
80.0	− .067	− .069	− .072	− .074	− .076	− .078	− .080	− .082	− .085
80.5	−0.068	−0.070	−0.072	−0.074	−0.077	−0.079	−0.081	−0.083	−0.085
81.0	− .069	− .071	− .073	− .075	− .077	− .080	− .082	− .084	− .086
81.5	− .069	− .072	− .074	− .076	− .078	− .080	− .083	− .085	− .087
82.0	− .070	− .072	− .075	− .077	− .079	− .081	− .084	− .086	− .088
82.5	− .071	− .073	− .075	− .078	− .080	− .082	− .084	− .087	− .089
83.0	−0.071	−0.074	−0.076	−0.078	−0.081	−0.083	−0.085	−0.088	−0.090
83.5	− .072	− .074	− .077	− .079	− .081	− .084	− .086	− .088	− .091
84.0	− .073	− .075	− .077	− .080	− .082	− .085	− .087	− .089	− .092
84.5	− .073	− .076	− .078	− .081	− .083	− .085	− .088	− .090	− .092
85.0	− .074	− .077	− .079	− .081	− .084	− .086	− .089	− .091	− .093
85.5	−0.075	−0.077	−0.080	−0.082	−0.085	−0.087	−0.089	−0.092	−0.094
86.0	− .076	− .078	− .080	− .083	− .085	− .088	− .090	− .093	− .095
86.5	− .076	− .079	− .081	− .084	− .086	− .089	− .091	− .093	− .096
87.0	− .077	− .079	− .082	− .084	− .087	− .089	− .092	− .094	− .097
87.5	− .078	− .080	− .083	− .085	− .088	− .090	− .093	− .095	− .098
88.0	−0.078	−0.081	−0.083	−0.086	−0.088	−0.091	−0.094	−0.096	−0.099
88.5	− .079	− .082	− .084	− .087	− .089	− .092	− .094	− .097	− .099
89.0	− .080	− .082	− .085	− .087	− .090	− .093	− .095	− .098	− .100
89.5	− .080	− .083	− .086	− .088	− .091	− .093	− .096	− .099	− .101
90.0	− .081	− .084	− .086	− .089	− .092	− .094	− .097	− .099	− .102
90.5	−0.082	−0.084	−0.087	−0.090	−0.092	−0.095	−0.098	−0.100	−0.103
91.0	− .083	− .085	− .088	− .091	− .093	− .096	− .098	− .101	− .104
91.5	− .083	− .086	− .089	− .091	− .094	− .097	− .099	− .102	− .105
92.0	− .084	− .087	− .089	− .092	− .095	− .097	− .100	− .103	− .106
92.5	− .085	− .087	− .090	− .093	− .096	− .098	− .101	− .104	− .106
93.0	−0.085	−0.088	−0.091	−0.094	−0.096	−0.099	−0.102	−0.105	−0.107
93.5	− .086	− .089	− .092	− .094	− .097	− .100	− .103	− .105	− .108
94.0	− .087	− .089	− .092	− .095	− .098	− .101	− .103	− .106	− .109
94.5	− .087	− .090	− .093	− .096	− .099	− .101	− .104	− .107	− .110
95.0	− .088	− .091	− .094	− .097	− .099	− .102	− .105	− .108	− .111
95.5	−0.089	−0.092	−0.095	−0.097	−0.100	−0.103	−0.106	−0.109	−0.112
96.0	− .089	− .092	− .095	− .098	− .101	− .104	− .107	− .110	− .113
96.5	− .090	− .093	− .096	− .099	− .102	− .105	− .108	− .111	− .113
97.0	− .091	− .094	− .097	− .100	− .103	− .106	− .108	− .111	− .114
97.5	− .092	− .095	− .097	− .100	− .103	− .106	− .109	− .112	− .115
98.0	−0.092	−0.095	−0.098	−0.101	−0.104	−0.107	−0.110	−0.113	−0.116
98.5	− .093	− .096	− .099	− .102	− .105	− .108	− .111	− .114	− .117
99.0	− .094	− .097	− .100	− .103	− .106	− .109	− .112	− .115	− .118
99.5	− .094	− .097	− .100	− .103	− .107	− .110	− .113	− .116	− .119
100.0	− .095	− .098	− .101	− .104	− .107	− .110	− .113	− .116	− .120

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
−20.0	+0.093	+0.095	+0.097	+0.100	+0.102	+0.104	+0.107	+0.109	+0.112
−19.5	+0.092	+0.094	+0.096	+0.099	+0.101	+0.103	+0.106	+0.108	+0.110
−19.0	.091	.093	.095	.098	.100	.102	.105	.107	.109
−18.5	.090	.092	.094	.097	.099	.101	.104	.106	.108
−18.0	.089	.091	.094	.096	.098	.100	.103	.105	.107
−17.5	.088	.090	.093	.095	.097	.099	.102	.104	.106
−17.0	+0.087	+0.089	+0.092	+0.094	+0.096	+0.098	+0.101	+0.103	+0.105
−16.5	.086	.088	.091	.093	.095	.097	.100	.102	.104
−16.0	.085	.088	.090	.092	.094	.096	.099	.101	.103
−15.5	.084	.087	.089	.091	.093	.095	.097	.100	.102
−15.0	.084	.086	.088	.090	.092	.094	.096	.099	.101
−14.5	+0.083	+0.085	+0.087	+0.089	+0.091	+0.093	+0.095	+0.098	+0.100
−14.0	.082	.084	.086	.088	.090	.092	.094	.096	.099
−13.5	.081	.083	.085	.087	.089	.091	.093	.095	.098
−13.0	.080	.082	.084	.086	.088	.090	.092	.094	.096
−12.5	.079	.081	.083	.085	.087	.089	.091	.093	.095
−12.0	+0.078	+0.080	+0.082	+0.084	+0.086	+0.088	+0.090	+0.092	+0.094
−11.5	.077	.079	.081	.083	.085	.087	.089	.091	.093
−11.0	.076	.078	.080	.082	.084	.086	.088	.090	.092
−10.5	.076	.077	.079	.081	.083	.085	.087	.089	.091
−10.0	.075	.077	.078	.080	.082	.084	.086	.088	.090
− 9.5	+0.074	+0.076	+0.078	+0.079	+0.081	+0.083	+0.085	+0.087	+0.089
− 9.0	.073	.075	.077	.078	.080	.082	.084	.086	.088
− 8.5	.072	.074	.076	.078	.079	.081	.083	.085	.087
− 8.0	.071	.073	.075	.077	.078	.080	.082	.084	.086
− 7.5	.070	.072	.074	.076	.077	.079	.081	.083	.085
− 7.0	+0.069	+0.071	+0.073	+0.075	+0.076	+0.078	+0.080	+0.082	+0.084
− 6.5	.068	.070	.072	.074	.075	.077	.079	.081	.082
− 6.0	.068	.069	.071	.073	.074	.076	.078	.080	.081
− 5.5	.067	.068	.070	.072	.073	.075	.077	.079	.080
− 5.0	.066	.067	.069	.071	.072	.074	.076	.078	.079
− 4.5	+0.065	+0.067	+0.068	+0.070	+0.072	+0.073	+0.075	+0.076	+0.078
− 4.0	.064	.066	.067	.069	.071	.072	.074	.075	.077
− 3.5	.063	.065	.066	.068	.070	.071	.073	.074	.076
− 3.0	.062	.064	.065	.067	.069	.070	.072	.073	.075
− 2.5	.061	.063	.064	.066	.068	.069	.071	.072	.074
− 2.0	+0.060	+0.062	+0.063	+0.065	+0.067	+0.068	+0.070	+0.071	+0.073
− 1.5	.060	.061	.063	.064	.066	.067	.069	.070	.072
− 1.0	.059	.060	.062	.063	.065	.066	.068	.069	.071
− 0.5	.058	.059	.061	.062	.064	.065	.067	.068	.070
0.0	.057	.058	.060	.061	.063	.064	.066	.067	.068

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
0.0	+0.057	+0.058	+0.060	+0.061	+0.063	+0.064	+0.066	+0.067	+0.068
0.5	+0.056	+0.057	+0.059	+0.060	+0.062	+0.063	+0.065	+0.066	+0.067
1.0	.055	.056	.058	.059	.061	.062	.064	.065	.066
1.5	.054	.056	.057	.058	.060	.061	.062	.064	.065
2.0	.053	.055	.056	.057	.059	.060	.061	.063	.064
2.5	.052	.054	.055	.056	.058	.059	.060	.062	.063
3.0	+0.051	+0.053	+0.054	+0.055	+0.057	+0.058	+0.059	+0.061	+0.062
3.5	.051	.052	.053	.054	.056	.057	.058	.060	.061
4.0	.050	.051	.052	.054	.055	.056	.057	.059	.060
4.5	.049	.050	.051	.053	.054	.055	.056	.058	.059
5.0	.048	.049	.050	.052	.053	.054	.055	.057	.058
5.5	+0.047	+0.048	+0.049	+0.051	+0.052	+0.053	+0.054	+0.055	+0.057
6.0	.046	.047	.049	.050	.051	.052	.053	.054	.056
6.5	.045	.046	.048	.049	.050	.051	.052	.053	.055
7.0	.044	.046	.047	.048	.049	.050	.051	.052	.053
7.5	.043	.045	.046	.047	.048	.049	.050	.051	.052
8.0	+0.043	+0.044	+0.045	+0.046	+0.047	+0.048	+0.049	+0.050	+0.051
8.5	.042	.043	.044	.045	.046	.047	.048	.049	.050
9.0	.041	.042	.043	.044	.045	.046	.047	.048	.049
9.5	.040	.041	.042	.043	.044	.045	.046	.047	.048
10.0	.039	.040	.041	.042	.043	.044	.045	.046	.047
10.5	+0.038	+0.039	+0.040	+0.041	+0.042	+0.043	+0.044	+0.045	+0.046
11.0	.037	.038	.039	.040	.041	.042	.043	.044	.045
11.5	.036	.037	.038	.039	.040	.041	.042	.043	.044
12.0	.035	.036	.037	.038	.039	.040	.041	.042	.043
12.5	.035	.035	.036	.037	.038	.039	.040	.041	.042
13.0	+0.034	+0.035	+0.035	+0.036	+0.037	+0.038	+0.039	+0.040	+0.041
13.5	.033	.034	.034	.035	.036	.037	.038	.039	.040
14.0	.032	.033	.034	.034	.035	.036	.037	.038	.038
14.5	.031	.032	.033	.033	.034	.035	.036	.037	.037
15.0	.030	.031	.032	.032	.033	.034	.035	.036	.036
15.5	+0.029	+0.030	+0.031	+0.032	+0.032	+0.033	+0.034	+0.035	+0.035
16.0	.028	.029	.030	.031	.031	.032	.033	.033	.034
16.5	.027	.028	.029	.030	.030	.031	.032	.032	.033
17.0	.027	.027	.028	.029	.029	.030	.031	.031	.032
17.5	.026	.026	.027	.028	.028	.029	.030	.030	.031
18.0	+0.025	+0.025	+0.026	+0.027	+0.027	+0.028	+0.029	+0.029	+0.030
18.5	.024	.025	.025	.026	.026	.027	.028	.028	.029
19.0	.023	.024	.024	.025	.025	.026	.027	.027	.028
19.5	.022	.023	.023	.024	.024	.025	.026	.026	.027
20.0	.021	.022	.022	.023	.023	.024	.025	.025	.026
20.5	+0.020	+0.021	+0.021	+0.022	+0.022	+0.023	+0.024	+0.024	+0.025
21.0	.019	.020	.020	.021	.021	.022	.022	.023	.023
21.5	.019	.019	.020	.020	.021	.021	.021	.022	.022
22.0	.018	.018	.019	.019	.020	.020	.020	.021	.021
22.5	.017	.017	.018	.018	.019	.019	.019	.020	.020
23.0	+0.016	+0.016	+0.017	+0.017	+0.018	+0.018	+0.018	+0.019	+0.019
23.5	.015	.015	.016	.016	.017	.017	.017	.018	.018
24.0	.014	.015	.015	.015	.016	.016	.016	.017	.017
24.5	.013	.014	.014	.014	.015	.015	.015	.016	.016
25.0	.012	.013	.013	.013	.014	.014	.014	.015	.015

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
25.5	+0.012	+0.012	+0.012	+0.012	+0.013	+0.013	+0.013	+0.014	+0.014
26.0	.011	.011	.011	.011	.012	.012	.012	.013	.013
26.5	.010	.010	.010	.010	.011	.011	.011	.011	.012
27.0	.009	.009	.009	.010	.010	.010	.010	.010	.011
27.5	.008	.008	.008	.009	.009	.009	.009	.009	.010
28.0	+0.007	+0.007	+0.007	+0.008	+0.008	+0.008	+0.008	+0.008	+0.009
28.5	.006	.006	.007	.007	.007	.007	.007	.007	.007
29.0	.005	.005	.006	.006	.006	.006	.006	.006	.006
29.5	.004	.005	.005	.005	.005	.005	.005	.005	.005
30.0	.004	.004	.004	.004	.004	.004	.004	.004	.004
30.5	+0.003	+0.003	+0.003	+0.003	+0.003	+0.003	+0.003	+0.003	+0.003
31.0	.002	.002	.002	.002	.002	.002	.002	.002	.002
31.5	.001	.001	.001	.001	.001	.001	.001	.001	.001
32.0	.000	.000	.000	.000	.000	.000	.000	.000	.000
32.5	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
33.0	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002
33.5	− .003	− .003	− .003	− .003	− .003	− .003	− .003	− .003	− .003
34.0	− .003	− .004	− .004	− .004	− .004	− .004	− .004	− .004	− .004
34.5	− .004	− .005	− .005	− .005	− .005	− .005	− .005	− .005	− .005
35.0	− .005	− .005	− .006	− .006	− .006	− .006	− .006	− .006	− .006
35.5	−0.006	−0.006	−0.007	−0.007	−0.007	−0.007	−0.007	−0.007	−0.007
36.0	− .007	− .007	− .007	− .008	− .008	− .008	− .008	− .008	− .009
36.5	− .008	− .008	− .008	− .009	− .009	− .009	− .009	− .009	− .010
37.0	− .009	− .009	− .009	− .010	− .010	− .010	− .010	− .010	− .011
37.5	− .010	− .010	− .010	− .010	− .011	− .011	− .011	− .011	− .012
38.0	−0.011	−0.011	−0.011	−0.011	−0.012	−0.012	−0.012	−0.013	−0.013
38.5	− .011	− .012	− .012	− .012	− .013	− .013	− .013	− .014	− .014
39.0	− .012	− .013	− .013	− .013	− .014	− .014	− .014	− .015	− .015
39.5	− .013	− .014	− .014	− .014	− .015	− .015	− .015	− .016	− .016
40.0	− .014	− .015	− .015	− .015	− .016	− .016	− .016	− .017	− .017
40.5	−0.015	−0.015	−0.016	−0.016	−0.017	−0.017	−0.017	−0.018	−0.018
41.0	− .016	− .016	− .017	− .017	− .018	− .018	− .018	− .019	− .019
41.5	− .017	− .017	− .018	− .018	− .019	− .019	− .019	− .020	− .020
42.0	− .018	− .018	− .019	− .019	− .019	− .020	− .020	− .021	− .021
42.5	− .019	− .019	− .020	− .020	− .020	− .021	− .021	− .022	− .022
43.0	−0.019	−0.020	−0.020	−0.021	−0.021	−0.022	−0.022	−0.023	−0.023
43.5	− .020	− .021	− .021	− .022	− .022	− .023	− .023	− .024	− .025
44.0	− .021	− .022	− .022	− .023	− .023	− .024	− .024	− .025	− .026
44.5	− .022	− .023	− .023	− .024	− .024	− .025	− .025	− .026	− .027
45.0	− .023	− .024	− .024	− .025	− .025	− .026	− .027	− .027	− .028
45.5	−0.024	−0.024	−0.025	−0.026	−0.026	−0.027	−0.028	−0.028	−0.029
46.0	− .025	− .025	− .026	− .027	− .027	− .028	− .029	− .029	− .030
46.5	− .026	− .026	− .027	− .028	− .028	− .029	− .030	− .030	− .031
47.0	− .027	− .027	− .028	− .029	− .029	− .030	− .031	− .031	− .032
47.5	− .027	− .028	− .029	− .030	−.030	− .031	− .032	− .032	− .033
48.0	−0.028	−0.029	−0.030	−0.030	−0.031	−0.032	−0.033	−0.033	−0.034
48.5	− .029	− .030	− .031	− .031	− .032	− .033	− .034	− .034	− .035
49.0	− .030	− .031	− .032	− .032	− .033	− .034	− .035	− .035	− .036
49.5	− .031	− .032	− .033	− .033	− .034	− .035	− .036	− .036	− .037
50.0	− .032	− .033	− .033	− .034	− .035	− .036	− .037	− .038	− .038

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
50.5	−0.033	−0.034	−0.034	−0.035	−0.036	−0.037	−0.038	−0.039	−0.039
51.0	− .034	− .034	− .035	− .036	− .037	− .038	− .039	− .040	− .040
51.5	− .034	− .035	− .036	− .037	− .038	− .039	− .040	− .041	− .042
52.0	− .035	− .036	− .037	− .038	− .039	− .040	− .041	− .042	− .043
52.5	− .036	− .037	− .038	− .039	− .040	− .041	− .042	− .043	− .044
53.0	−0.037	−0.038	−0.039	−0.040	−0.041	−0.042	−0.043	−0.044	−0.045
53.5	− .038	− .039	− .040	− .041	− .042	− .043	− .044	− .045	− .046
54.0	− .039	− .040	− .041	− .042	− .043	− .044	− .045	− .046	− .047
54.5	− .040	− .041	− .042	− .043	− .044	− .045	− .046	− .047	− .048
55.0	− .041	− .042	− .043	− .044	− .045	− .046	− .047	− .048	− .049
55.5	−0.042	−0.043	−0.044	−0.045	−0.046	−0.047	−0.048	−0.049	−0.050
56.0	− .042	− .043	− .045	− .046	− .047	− .048	− .049	− .050	− .051
56.5	− .043	− .044	− .045	− .047	− .048	− .049	− .050	− .051	− .052
57.0	− .044	− .045	− .046	− .048	− .049	− .050	− .051	− .052	− .053
57.5	− .045	− .046	− .047	− .048	− .050	− .051	− .052	− .053	− .054
58.0	−0.046	−0.047	−0.048	−0.049	−0.051	−0.052	−0.053	−0.054	−0.055
58.5	− .047	− .048	− .049	− .050	− .052	− .053	− .054	− .055	− .056
59.0	− .048	− .049	− .050	− .051	− .053	− .054	− .055	− .056	− .057
59.5	− .049	− .050	− .051	− .052	− .054	− .055	− .056	− .057	− .059
60.0	− .049	− .051	− .052	− .053	− .054	− .056	− .057	− .058	− .060
60.5	−0.050	−0.052	−0.053	−0.054	−0.055	−0.057	−0.058	−0.059	−0.061
61.0	− .051	− .052	− .054	− .055	− .056	− .058	− .059	− .060	− .062
61.5	− .052	− .053	− .055	− .056	− .057	− .059	− .060	− .061	− .063
62.0	− .053	− .054	− .056	− .057	− .058	− .060	− .061	− .062	− .064
62.5	− .054	− .055	− .057	− .058	− .059	− .061	− .062	− .063	− .065
63.0	−0.055	−0.056	−0.058	−0.059	−0.060	−0.062	−0.063	−0.065	−0.066
63.5	− .056	− .057	− .058	− .060	− .061	− .063	− .064	− .066	− .067
64.0	− .056	− .058	− .059	− .061	− .062	− .064	− .065	− .067	− .068
64.5	− .057	− .059	− .060	− .062	− .063	− .065	− .066	− .068	− .069
65.0	− .058	− .060	− .061	− .063	− .064	− .066	− .067	− .069	− .070
65.5	−0.059	−0.061	−0.062	−0.064	−0.065	−0.067	−0.068	−0.070	−0.071
66.0	− .060	− .062	− .063	− .065	− .066	− .068	− .069	− .071	− .072
66.5	− .061	− .062	− .064	− .066	− .067	− .069	− .070	− .072	− .073
67.0	− .062	− .063	− .065	− .066	− .068	− .070	− .071	− .073	− .074
67.5	− .063	− .064	− .066	− .067	− .069	− .071	− .072	− .074	− .075
68.0	−0.063	−0.065	−0.067	−0.068	−0.070	−0.072	−0.073	−0.075	−0.077
68.5	− .064	− .066	− .068	− .069	− .071	− .073	− .074	− .076	− .078
69.0	− .065	− .067	− .069	− .070	− .072	− .074	− .075	− .077	− .079
69.5	− .066	− .068	− .070	− .071	− .073	− .075	− .076	− .078	− .080
70.0	− .067	− .069	− .070	− .072	− .074	− .076	− .077	− .079	− .081
70.5	−0.068	−0.070	−0.071	−0.073	−0.075	−0.077	−0.078	−0.080	−0.082
71.0	− .069	− .071	− .072	− .074	− .076	− .078	− .079	− .081	− .083
71.5	− .070	− .071	− .073	− .075	− .077	− .079	− .080	− .082	− .084
72.0	− .071	− .072	− .074	− .076	− .078	− .080	− .081	− .083	− .085
72.5	− .071	− .073	− .075	− .077	− .079	− .081	− .082	− .084	− .086
73.0	−0.072	−0.074	−0.076	−0.078	−0.080	−0.082	−0.083	−0.085	−0.087
73.5	− .073	− .075	− .077	− .079	− .081	− .083	− .084	− .086	− .088
74.0	− .074	− .076	− .078	− .080	− .082	− .084	− .085	− .087	− .089
74.5	− .075	− .077	− .079	− .081	− .083	− .085	− .086	− .088	− .090
75.0	− .076	− .078	− .080	− .082	− .084	− .086	− .087	− .089	− .091

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
75.5	-0.077	-0.079	-0.081	-0.083	-0.085	-0.086	-0.088	-0.090	-0.092
76.0	- .078	- .080	- .082	- .084	- .085	- .087	- .089	- .091	- .093
76.5	- .078	- .080	- .082	- .084	- .086	- .088	- .090	- .092	- .095
77.0	- .079	- .081	- .083	- .085	- .087	- .089	- .091	- .094	- .096
77.5	- .080	- .082	- .084	- .086	- .088	- .090	- .093	- .095	- .097
78.0	-0.081	-0.083	-0.085	-0.087	-0.089	-0.091	-0.094	-0.096	-0.098
78.5	- .082	- .084	- .086	- .088	- .090	- .092	- .095	- .097	- .099
79.0	- .083	- .085	- .087	- .089	- .091	- .093	- .096	- .098	- .100
79.5	- .084	- .086	- .088	- .090	- .092	- .094	- .097	- .099	- .101
80.0	- .085	- .087	- .089	- .091	- .093	- .095	- .098	- .100	- .102
80.5	-0.085	-0.088	-0.090	-0.092	-0.094	-0.096	-0.099	-0.101	-0.103
81.0	- .086	- .089	- .091	- .093	- .095	- .097	- .100	- .102	- .104
81.5	- .087	- .089	- .092	- .094	- .096	- .098	- .101	- .103	- .105
82.0	- .088	- .090	- .093	- .095	- .097	- .099	- .102	- .104	- .106
82.5	- .089	- .091	- .094	- .096	- .098	- .100	- .103	- .105	- .107
83.0	-0.090	-0.092	-0.094	-0.097	-0.099	-0.101	-0.104	-0.106	-0.108
83.5	- .091	- .093	- .095	- .098	- .100	- .102	- .105	- .107	- .109
84.0	- .092	- .094	- .096	- .099	- .101	- .103	- .106	- .108	- .110
84.5	- .092	- .095	- .097	- .100	- .102	- .104	- .107	- .109	- .111
85.0	- .093	- .096	- .098	- .100	- .103	- .105	- .108	- .110	- .112
85.5	-0.094	-0.097	-0.099	-0.101	-0.104	-0.106	-0.109	-0.111	-0.114
86.0	- .095	- .098	- .100	- .102	- .105	- .107	- .110	- .112	- .115
86.5	- .096	- .098	- .101	- .103	- .106	- .108	- .111	- .113	- .116
87.0	- .097	- .099	- .102	- .104	- .107	- .109	- .112	- .114	- .117
87.5	- .098	- .100	- .103	- .105	- .108	- .110	- .113	- .115	- .118
88.0	-0.099	-0.101	-0.104	-0.106	-0.109	-0.111	-0.114	-0.116	-0.119
88.5	- .099	- .102	- .105	- .107	- .110	- .112	- .115	- .117	- .120
89.0	- .100	- .103	- .105	- .108	- .111	- .113	- .116	- .118	- .121
89.5	- .101	- .104	- .106	- .109	- .112	- .114	- .117	- .119	- .122
90.0	- .102	- .105	- .107	- .110	- .113	- .115	- .118	- .120	- .123
90.5	-0.103	-0.106	-0.108	-0.111	-0.114	-0.116	-0.119	-0.121	-0.124
91.0	- .104	- .106	- .109	- .112	- .114	- .117	- .120	- .122	- .125
91.5	- .105	- .107	- .110	- .113	- .115	- .118	- .121	- .123	- .126
92.0	- .106	- .108	- .111	- .114	- .116	- .119	- .122	- .125	- .127
92.5	- .106	- .109	- .112	- .115	- .117	- .120	- .123	- .126	- .128
93.0	-0.107	-0.110	-0.113	-0.116	-0.118	-0.121	-0.124	-0.127	-0.129
93.5	- .108	- .111	- .114	- .117	- .119	- .122	- .125	- .128	- .130
94.0	- .109	- .112	- .115	- .117	- .120	- .123	- .126	- .129	- .131
94.5	- .110	- .113	- .116	- .118	- .121	- .124	- .127	- .130	- .132
95.0	- .111	- .114	- .116	- .119	- .122	- .125	- .128	- .131	- .134
95.5	-0.112	-0.115	-0.117	-0.120	-0.123	-0.126	-0.129	-0.132	-0.135
96.0	- .113	- .115	- .118	- .121	- .124	- .127	- .130	- .133	- .136
96.5	- .113	- .116	- .119	- .122	- .125	- .128	- .131	- .134	- .137
97.0	- .114	- .117	- .120	- .123	- .126	- .129	- .132	- .135	- .138
97.5	- .115	- .118	- .121	- .124	- .127	- .130	- .133	- .136	- .139
98.0	-0.116	-0.119	-0.122	-0.125	-0.128	-0.131	-0.134	-0.137	-0.140
98.5	- .117	- .120	- .123	- .126	- .129	- .132	- .135	- .138	- .141
99.0	- .118	- .121	- .124	- .127	- .130	- .133	- .136	- .139	- .142
99.5	- .119	- .122	- .125	- .128	- .131	- .134	- .137	- .140	- .143
100.0	- .120	- .123	- .126	- .129	- .132	- .135	- .138	- .141	- .144

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached ther- mometer (° F.)	Height of mercury column, inches								
	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
−20.0	+0.112	+0.114	+0.116	+0.119	+0.121	+0.123	+0.126	+0.128	+0.130
−19.5	+0.110	+0.113	+0.115	+0.117	+0.120	+0.122	+0.125	+0.127	+0.129
−19.0	.109	.112	.114	.116	.119	.121	.123	.126	.128
−18.5	.108	.111	.113	.115	.117	.120	.122	.124	.127
−18.0	.107	.109	.112	.114	.116	.119	.121	.123	.125
−17.5	.106	.108	.111	.113	.115	.117	.120	.122	.124
−17.0	+0.105	+0.107	+0.110	+0.112	+0.114	+0.116	+0.118	+0.121	+0.123
−16.5	.104	.106	.108	.111	.113	.115	.117	.119	.122
−16.0	.103	.105	.107	.109	.112	.114	.116	.118	.120
−15.5	.102	.104	.106	.108	.110	.113	.115	.117	.119
−15.0	.101	.103	.105	.107	.109	.111	.114	.116	.118
−14.5	+0.100	+0.102	+0.104	+0.106	+0.108	+0.110	+0.112	+0.115	+0.117
−14.0	.099	.101	.103	.105	.107	.109	.111	.113	.115
−13.5	.098	.100	.102	.104	.106	.108	.110	.112	.114
−13.0	.096	.098	.101	.103	.105	.107	.109	.111	.113
−12.5	.095	.097	.099	.101	.103	.106	.108	.110	.112
−12.0	+0.094	+0.096	+0.098	+0.100	+0.102	+0.104	+0.106	+0.108	+0.110
−11.5	.093	.095	.097	.099	.101	.103	.105	.107	.109
−11.0	.092	.094	.096	.098	.100	.102	.104	.106	.108
−10.5	.091	.093	.095	.097	.099	.101	.103	.105	.107
−10.0	.090	.092	.094	.096	.098	.100	.101	.103	.105
− 9.5	+0.089	+0.091	+0.093	+0.095	+0.096	+0.098	+0.100	+0.102	+0.104
− 9.0	.088	.090	.092	.093	.095	.097	.099	.101	.103
− 8.5	.087	.089	.090	.092	.094	.096	.098	.100	.102
− 8.0	.086	.088	.089	.091	.093	.095	.097	.098	.100
− 7.5	.085	.086	.088	.090	.092	.094	.095	.097	.099
− 7.0	+0.084	+0.085	+0.087	+0.089	+0.091	+0,092	+0.094	+0.096	+0.098
− 6.5	.082	.084	.086	.088	.089	.091	.093	.095	.096
− 6.0	.081	.083	.085	.087	.088	.090	.092	.093	.095
− 5.5	.080	.082	.084	.085	.087	.089	.091	.092	.094
− 5.0	.079	.081	.083	.084	.086	.088	.089	.091	.093
− 4.5	+0.078	+0.080	+0.081	+0.083	+0.085	+0.086	+0.088	+0.090	+0.091
− 4.0	.077	.079	.080	.082	.084	.085	.087	.089	.090
− 3.5	.076	.078	.079	.081	.082	.084	.086	.087	.089
− 3.0	.075	.077	.078	.080	.081	.083	.084	.086	.088
− 2.5	.074	.075	.077	.079	.080	.082	.083	.085	.086
− 2.0	+0.073	+0.074	+0.076	+0.077	+0.079	+0.081	+0.082	+0.084	+0.085
− 1.5	.072	.073	.075	.076	.078	.079	.081	.082	.084
− 1.0	.071	.072	.074	.075	.077	.078	.080	.081	.083
− 0.5	.070	.071	.073	.074	.075	.077	.078	.080	.081
0.0	.068	.070	.071	.073	.074	.076	.077	.079	.080

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
0.0	+0.068	+0.070	+0.071	+0.073	+0.074	+0.076	+0.077	+0.079	+0.080
0.5	+0.067	+0.069	+0.070	+0.072	+0.073	+0.075	+0.076	+0.077	+0.079
1.0	.066	.068	.069	.071	.072	.073	.075	.076	.078
1.5	.065	.067	.068	.069	.071	.072	.074	.075	.076
2.0	.064	.066	.067	.068	.070	.071	.072	.074	.075
2.5	.063	.064	.066	.067	.068	.070	.071	.073	.074
3.0	+0.062	+0.063	+0.065	+0.066	+0.067	+0.069	+0.070	+0.071	+0.073
3.5	.061	.062	.064	.065	.066	.067	.069	.070	.071
4.0	.060	.061	.062	.064	.065	.066	.068	.069	.070
4.5	.059	.060	.061	.062	.064	.065	.066	.068	.069
5.0	.058	.059	.060	.061	.063	.064	.065	.066	.068
5.5	+0.057	+0.058	+0.059	+0.060	+0.062	+0.063	+0.064	+0.065	+0.066
6.0	.056	.057	.058	.059	.060	.062	.063	.064	.065
6.5	.055	.056	.057	.058	.059	.060	.062	.063	.064
7.0	.053	.055	.056	.057	.058	.059	.060	.061	.063
7.5	.052	.054	.055	.056	.057	.058	.059	.060	.061
8.0	+0.051	+0.052	+0.054	+0.055	+0.056	+0.057	+0.058	+0.059	+0.060
8.5	.050	.051	.052	.053	.055	.056	.057	.058	.059
9.0	.049	.050	.051	.052	.053	.054	.055	.057	.058
9.5	.048	.049	.050	.051	.052	.053	.054	.055	.056
10.0	.047	.048	.049	.050	.051	.052	.053	.054	.055
10.5	+0.046	+0.047	+0.048	+0.049	+0.050	+0.051	+0.052	+0.053	+0.054
11.0	.045	.046	.047	.048	.049	.050	.051	.052	.053
11.5	.044	.045	.046	.047	.048	.048	.049	.050	.051
12.0	.043	.044	.045	.045	.046	.047	.048	.049	.050
12.5	.042	.043	.043	.044	.045	.046	.047	.048	.049
13.0	+0.041	+0.041	+0.042	+0.043	+0.044	+0.045	+0.046	+0.047	+0.048
13.5	.040	.040	.041	.042	.043	.044	.045	.045	.046
14.0	.038	.039	.040	.041	.042	.043	.043	.044	.045
14.5	.037	.038	.039	.040	.041	.041	.042	.043	.044
15.0	.036	.037	.038	.039	.039	.040	.041	.042	.043
15.5	+0.035	+0.036	+0.037	+0.038	+0.038	+0.039	+0.040	+0.041	+0.041
16.0	.034	.035	.036	.036	.037	.038	.039	.039	.040
16.5	.033	.034	.035	.035	.036	.037	.037	.038	.039
17.0	.032	.033	.033	.034	.035	.035	.036	.037	.038
17.5	.031	.032	.032	.033	.034	.034	.035	.036	.036
18.0	+0.030	+0.031	+0.031	+0.032	+0.032	+0.033	+0.034	+0.034	+0.035
18.5	.029	.029	.030	.031	.031	.032	.033	.033	.034
19.0	.028	.028	.029	.030	.030	.031	.031	.032	.032
19.5	.027	.027	.028	.028	.029	.030	.030	.031	.031
20.0	.026	.026	.027	.027	.028	.028	.029	.029	.030
20.5	+0.025	+0.025	+0.026	+0.026	+0.027	+0.027	+0.028	+0.028	+0.029
21.0	.023	.024	.024	.025	.025	.026	.026	.027	.027
21.5	.022	.023	.023	.024	.024	.025	.025	.026	.026
22.0	.021	.022	.022	.023	.023	.024	.024	.024	.025
22.5	.020	.021	.021	.022	.022	.022	.023	.023	.024
23.0	+0.019	+0.020	+0.020	+0.020	+0.021	+0.021	+0.022	+0.022	+0.022
23.5	.018	.019	.019	.019	.020	.020	.020	.021	.021
24.0	.017	.017	.018	.018	.019	.019	.019	.020	.020
24.5	.016	.016	.017	.017	.017	.018	.018	.018	.019
25.0	.015	.015	.016	.016	.016	.017	.017	.017	.017

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
25.5	+0.014	+0.014	+0.014	+0.015	+0.015	+0.015	+0.016	+0.016	+0.016
26.0	.013	.013	.013	.014	.014	.014	.014	.015	.015
26.5	.012	.012	.012	.012	.013	.013	.013	.013	.014
27.0	.011	.011	.011	.011	.012	.012	.012	.012	.012
27.5	.010	.010	.010	.010	.010	.011	.011	.011	.011
28.0	+0.009	+0.009	+0.009	+0.009	+0.009	+0.009	+0.010	+0.010	+0.010
28.5	.007	.008	.008	.008	.008	.008	.008	.009	.009
29.0	.006	.007	.007	.007	.007	.007	.007	.007	.007
29.5	.005	.005	.006	.006	.006	.006	.006	.006	.006
30.0	.004	.004	.004	.005	.005	.005	.005	.005	.005
30.5	+0.003	+0.003	+0.003	+0.003	+0.003	+0.004	+0.004	+0.004	+0.004
31.0	.002	.002	.002	.002	.002	.002	.002	.002	.002
31.5	.001	.001	.001	.001	.001	.001	.001	.001	.001
32.0	.000	.000	.000	.000	.000	.000	.000	.000	.000
32.5	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
33.0	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002
33.5	− .003	− .003	− .003	− .003	− .003	− .004	− .004	− .004	− .004
34.0	− .004	− .004	− .004	− .005	− .005	− .005	− .005	− .005	− .005
34.5	− .005	− .005	− .006	− .006	− .006	− .006	− .006	− .006	− .006
35.0	− .006	− .007	− .007	− .007	− .007	− .007	− .007	− .007	− .007
35.5	−0.007	−0.008	−0.008	−0.008	−0.008	−0.008	−0.008	−0.009	−0.009
36.0	− .009	− .009	− .009	− .009	− .009	− .009	− .010	− .010	− .010
36.5	− .010	− .010	− .010	− .010	− .010	− .011	− .011	− .011	− .011
37.0	− .011	− .011	− .011	− .011	− .012	− .012	− .012	− .012	− .012
37.5	− .012	− .012	− .012	− .012	− .013	− .013	− .013	− .013	− .014
38.0	−0.013	−0.013	−0.013	−0.014	−0.014	−0.014	−0.014	−0.015	−0.015
38.5	− .014	− .014	− .014	− .015	− .015	− .015	− .016	− .016	− .016
39.0	− .015	− .015	− .016	− .016	− .016	− .017	− .017	− .017	− .017
39.5	− .016	− .016	− .017	− .017	− .017	− .018	− .018	− .018	− .019
40.0	− .017	− .017	− .018	− .018	− .019	− .019	− .019	− .020	− .020
40.5	−0.018	−0.019	−0.019	−0.019	−0.020	−0.020	−0.020	−0.021	−0.021
41.0	− .019	− .020	− .020	− .020	− .021	− .021	− .022	− .022	− .022
41.5	− .020	− .021	− .021	− .022	− .022	− .022	− .023	− .023	− .024
42.0	− .021	− .022	− .022	− .023	− .023	− .024	− .024	− .024	− .025
42.5	− .022	− .023	− .023	− .024	− .024	− .025	− .025	− .026	− .026
43.0	−0.023	−0.024	−0.024	−0.025	−0.025	−0.026	−0.026	−0.027	−0.027
43.5	− .025	− .025	− .026	− .026	− .027	− .027	− .028	− .028	− .029
44.0	− .026	− .026	− .027	− .027	− .028	− .028	− .029	− .029	− .030
44.5	− .027	− .027	− .028	− .028	− .029	− .029	− .030	− .031	− .031
45.0	− .028	− .028	− .029	− .029	− .030	− .031	− .031	−.032	− .032
45.5	−0.029	−0.029	−0.030	−0.031	−0.031	−0.032	−0.032	−0.033	−0.034
46.0	− .030	− .030	− .031	− .032	− .032	− .033	− .034	− .034	− .035
46.5	− .031	− .032	− .032	− .033	− .034	− .034	− .035	− .035	− .036
47.0	− .032	− .033	− .033	− .034	− .035	− .035	− .036	− .037	− .037
47.5	− .033	− .034	− .034	− .035	− .036	− .037	− .037	− .038	− .039
48.0	−0.034	−0.035	−0.036	−0.036	−0.037	−0.038	−0.038	−0.039	−0.040
48.5	− .035	− .036	− .037	− .037	− .038	− .039	− .040	− .040	− .041
49.0	− .036	− .037	− .038	− .039	− .039	− .040	− .041	− .042	− .042
49.5	− .037	− .038	− .039	− .040	− .040	− .041	− .042	− .043	− .044
50.0	− .038	− .039	− .040	− .041	− .042	− .042	− .043	− .044	− .045

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
50.5	−0.039	−0.040	−0.041	−0.042	−0.043	−0.044	−0.044	−0.045	−0.046
51.0	− .040	− .041	− .042	− .043	− .044	− .045	− .046	− .046	− .047
51.5	− .042	− .042	− .043	− .044	− .045	− .046	− .047	− .048	− .049
52.0	− .043	− .043	− .044	− .045	− .046	− .047	− .048	− .049	− .050
52.5	− .044	− .045	− .045	− .046	− .047	− .048	− .049	− .050	− .051
53.0	−0.045	−0.046	−0.047	−0.048	−0.049	−0.049	−0.050	−0.051	−0.052
53.5	− .046	− .047	− .048	− .049	− .050	− .051	− .052	− .053	− .054
54.0	− .047	− .048	− .049	− .050	− .051	− .052	− .053	− .054	− .055
54.5	− .048	− .049	− .050	− .051	− .052	− .053	− .054	− .055	− .056
55.0	− .049	− .050	− .051	− .052	− .053	− .054	− .055	− .056	− .057
55.5	−0.050	−0.051	−0.052	−0.053	−0.054	−0.055	−0.056	−0.057	−0.059
56.0	− .051	− .052	− .053	− .054	− .055	− .057	− .058	− .059	− .060
56.5	− .052	− .053	− .054	− .055	− .057	− .058	− .059	− .060	− .061
57.0	− .053	− .054	− .055	− .057	− .058	− .059	− .060	− .061	− .062
57.5	− .054	− .055	− .057	− .058	− .059	− .060	− .061	− .062	− .063
58.0	−0.055	−0.056	−0.058	−0.059	−0.060	−0.061	−0.062	−0.064	−0.065
58.5	− .056	− .058	− .059	− .060	− .061	− .062	− .064	− .065	− .066
59.0	− .057	− .059	− .060	− .061	− .062	− .064	− .065	− .066	− .067
59.5	− .059	− .060	− .061	− .062	− .063	− .065	− .066	− .067	− .068
60.0	− .060	− .061	− .062	− .063	− .065	− .066	− .067	− .068	− .070
60.5	−0.061	−0.062	−0.063	−0.064	−0.066	−0.067	−0.068	−0.070	−0.071
61.0	− .062	− .063	− .064	− .066	− .067	− .068	− .070	− .071	− .072
61.5	− .063	− .064	− .065	− .067	− .068	− .069	− .071	− .072	− .073
62.0	− .064	− .065	− .067	− .068	− .069	− .071	− .072	− .073	− .075
62.5	− .065	− .066	− .068	− .069	− .070	− .072	− .073	− .075	− .076
63.0	−0.066	−0.067	−0.069	−0.070	−0.072	−0.073	−0.074	−0.076	−0.077
63.5	− .067	− .068	− .070	− .071	− .073	− .074	− .076	− .077	− .078
64.0	− .068	− .069	− .071	− .072	− .074	− .075	− .077	− .078	− .080
64.5	− .069	− .071	− .072	− .074	− .075	− .076	− .078	− .079	− .081
65.0	− .070	− .072	− .073	− .075	− .076	− .078	− .079	− .081	− .082
65.5	−0.071	−0.073	−0.074	−0.076	−0.077	−0.079	−0.080	−0.082	−0.083
66.0	− .072	− .074	− .075	− .077	− .078	− .080	− .082	− .083	− .085
66.5	− .073	− .075	− .076	− .078	− .080	− .081	− .083	− .084	− .086
67.0	− .074	− .076	− .078	− .079	− .081	− .082	− .084	− .085	− .087
67.5	− .075	− .077	− .079	− .080	− .082	− .083	− .085	− .087	− .088
68.0	−0.077	−0.078	−0.080	−0.081	−0.083	−0.085	−0.086	−0.088	−0.090
68.5	− .078	− .079	− .081	− .083	− .084	− .086	− .087	− .089	− .091
69.0	− .079	− .080	− .082	− .084	− .085	− .087	− .089	− .090	− .092
69.5	− .080	− .081	− .083	− .085	− .086	− .088	− .090	− .092	− .093
70.0	− .081	− .082	− .084	− .086	− .088	− .089	− .091	− .093	− .095
70.5	−0.082	−0.084	−0.085	−0.087	−0.089	−0.091	−0.092	−0.094	−0.096
71.0	− .083	− .085	− .086	− .088	− .090	− .092	− .093	− .095	− .097
71.5	− .084	− .086	− .088	− .089	− .091	− .093	− .095	− .096	− .098
72.0	− .085	− .087	− .089	− .090	− .092	− .094	− .096	− .098	− .099
72.5	− .086	− .088	− .090	− .092	− .093	− .095	− .097	− .099	− .101
73.0	−0.087	−0.089	−0.091	−0.093	−0.095	−0.096	−0.098	−0.100	−0.102
73.5	− .088	− .090	− .092	− .094	− .096	− .098	− .099	− .101	− .103
74.0	− .089	− .091	− .093	− .095	− .097	− .099	− .101	− .103	− .104
74.5	− .090	− .092	− .094	− .096	− .098	− .100	− .102	− .104	− .106
75.0	− .091	− .093	− .095	− .097	− .099	− .101	− .103	− .105	− .107

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
75.5	−0.092	−0.094	−0.096	−0.098	−0.100	−0.102	−0.104	−0.106	−0.108
76.0	− .093	− .095	− .097	− .099	− .101	− .103	− .105	− .107	− .109
76.5	− .095	− .097	− .099	− .101	− .103	− .105	− .107	− .109	− .111
77.0	− .096	− .098	− .100	− .102	− .104	− .106	− .108	− .110	− .112
77.5	− .097	− .099	− .101	− .103	− .105	− .107	− .109	− .111	− .113
78.0	−0.098	−0.100	−0.102	−0.104	−0.106	−0.108	−0.110	−0.112	−0.114
78.5	− .099	− .101	− .103	− .105	− .107	− .109	− .111	− .113	− .116
79.0	− .100	− .102	− .104	− .106	− .108	− .110	− .113	− .115	− .117
79.5	− .101	− .103	− .105	− .107	− .109	− .112	− .114	− .116	− .118
80.0	− .102	− .104	− .106	− .108	− .111	− .113	− .115	− .117	− .119
80.5	−0.103	−0.105	−0.107	−0.110	−0.112	−0.114	−0.116	−0.118	−0.120
81.0	− .104	− .106	− .108	− .111	− .113	− .115	− .117	− .120	− .122
81.5	− .105	− .107	− .110	− .112	− .114	− .116	− .118	− .121	− .123
82.0	− .106	− .108	− .111	− .113	− .115	− .117	− .120	− .122	− .124
82.5	− .107	− .109	− .112	− .114	− .116	− .119	− .121	− .123	− .125
83.0	−0.108	−0.111	−0.113	−0.115	−0.117	−0.120	−0.122	−0.124	−0.127
83.5	− .109	− .112	− .114	− .116	− .119	− .121	− .123	− .126	− .128
84.0	− .110	− .113	− .115	− .117	− .120	− .122	− .124	− .127	− .129
84.5	− .111	− .114	− .116	− .119	− .121	− .123	− .126	− .128	− .130
85.0	− .112	− .115	− .117	− .120	− .122	− .124	− .127	− .129	− .132
85.5	−0.114	−0.116	−0.118	−0.121	−0.123	−0.126	−0.128	−0.130	−0.133
86.0	− .115	− .117	− .119	− .122	− .124	− .127	− .129	− .132	− .134
86.5	− .116	− .118	− .121	− .123	− .125	− .128	− .130	− .133	− .135
87.0	− .117	− .119	− .122	− .124	− .127	− .129	− .132	− .134	− .137
87.5	− .118	− .120	− .123	− .125	− .128	− .130	− .133	− .135	− .138
88.0	−0.119	−0.121	−0.124	−0.126	−0.129	−0.131	−0.134	−0.136	−0.139
88.5	− .120	− .122	− .125	− .127	− .130	− .133	− .135	− .138	− .140
89.0	− .121	− .123	− .126	− .129	− .131	− .134	− .136	− .139	− .141
89.5	− .122	− .125	− .127	− .130	− .132	− .135	− .138	− .140	− .143
90.0	− .123	− .126	− .128	− .131	− .133	− .136	− .139	− .141	− .144
90.5	−0.124	−0.127	−0.129	−0.132	−0.135	−0.137	−0.140	−0.143	−0.145
91.0	− .125	− .128	− .130	− .133	− .136	− .138	− .141	− .144	− .146
91.5	− .126	− .129	− .132	− .134	− .137	− .140	− .142	− .145	− .148
92.0	− .127	− .130	− .133	− .135	− .138	− .141	− .143	− .146	− .149
92.5	− .128	− .131	− .134	− .136	− .139	− .142	− .145	− .147	− .150
93.0	−0.129	−0.132	−0.135	−0.138	−0.140	−0.143	−0.146	−0.149	−0.151
93.5	− .130	− .133	− .136	− .139	− .141	− .144	− .147	− .150	− .153
94.0	− .131	− .134	− .137	− .140	− .143	− .145	− .148	− .151	− .154
94.5	− .132	− .135	− .138	− .141	− .144	− .147	− .149	− .152	− .155
95.0	− .134	− .136	− .139	− .142	− .145	− .148	− .151	− .153	− .156
95.5	−0.135	−0.137	−0.140	−0.143	−0.146	−0.149	−0.152	−0.155	−0.158
96.0	− .136	− .139	− .141	− .144	− .147	− .150	− .153	− .156	− .159
96.5	− .137	− .140	− .143	− .145	− .148	− .151	− .154	− .157	− .160
97.0	− .138	− .141	− .144	− .147	− .149	− .152	− .155	− .158	− .161
97.5	− .139	− .142	− .145	− .148	− .151	− .154	− .157	− .159	− .162
98.0	−0.140	−0.143	−0.146	−0.149	−0.152	−0.155	−0.158	−0.161	−0.164
98.5	− .141	− .144	− .147	− .150	− .153	− .156	− .159	− .162	− .165
99.0	− .142	− .145	− .148	− .151	− .154	− .157	− .160	− .163	− .166
99.5	− .143	− .146	− .149	− .152	− .155	− .158	− .161	− .164	− .167
100.0	− .144	− .147	− .150	− .153	− .156	− .159	− .162	− .166	− .169

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
100.0	−0.144	−0.147	−0.150	−0.153	−0.156	−0.159	−0.162	−0.166	−0.169
100.5	−0.145	−0.148	−0.151	−0.154	−0.157	−0.161	−0.164	−0.167	−0.170
101.0	− .146	− .149	− .152	− .156	− .159	− .162	− .165	− .168	− .171
101.5	− .147	− .150	− .153	− .157	− .160	− .163	− .166	− .169	− .172
102.0	− .148	− .151	− .155	− .158	− .161	− .164	− .167	− .170	− .174
102.5	− .149	− .153	− .156	− .159	− .162	− .165	− .168	− .172	− .175
103.0	−0.150	−0.154	−0.157	−0.160	−0.163	−0.166	−0.170	−0.173	−0.176
103.5	− .151	− .155	− .158	− .161	− .164	− .168	− .171	− .174	− .177
104.0	− .152	− .156	− .159	− .162	− .165	− .169	− .172	− .175	− .178
104.5	− .154	− .157	− .160	− .163	− .167	− .170	− .173	− .176	− .180
105.0	− .155	− .158	− .161	− .164	− .168	− .171	− .174	− .178	− .181
105.5	−0.156	−0.159	−0.162	−0.166	−0.169	−0.172	−0.176	−0.179	−0.182
106.0	− .157	− .160	− .163	− .167	− .170	− .173	− .177	− .180	− .183
106.5	− .158	− .161	− .164	− .168	− .171	− .175	− .178	− .181	− .185
107.0	− .159	− .162	− .166	− .169	− .172	− .176	− .179	− .182	− .186
107.5	− .160	− .163	− .167	− .170	− .173	− .177	− .180	− .184	− .187
108.0	−0.161	−0.164	−0.168	−0.171	−0.175	−0.178	−0.181	−0.185	−0.188
108.5	− .162	− .165	− .169	− .172	− .176	− .179	− .183	− .186	− .190
109.0	− .163	− .166	− .170	− .173	− .177	− .180	− .184	− .187	− .191
109.5	− .164	− .168	− .171	− .175	− .178	− .181	− .185	− .188	− .192
110.0	− .165	− .169	− .172	− .176	− .179	− .183	− .186	− .190	− .193
110.5	−0.166	−0.170	−0.173	−0.177	−0.180	−0.184	−0.187	−0.191	−0.194
111.0	− .167	− .171	− .174	− .178	− .181	− .185	− .189	− .192	− .196
111.5	− .168	− .172	− .175	− .179	− .183	− .186	− .190	− .193	− .197
112.0	− .169	− .173	− .176	− .180	− .184	− .187	− .191	− .195	− .198
112.5	− .170	− .174	− .178	− .181	− .185	− .188	− .192	− .196	− .199
113.0	−0.171	−0.175	−0.179	−0.182	−0.186	−0.190	−0.193	−0.197	−0.201
113.5	− .172	− .176	− .180	− .183	− .187	− .191	− .194	− .198	− .202
114.0	− .173	− .177	− .181	− .185	− .188	− .192	− .196	− .199	− .203
114.5	− .175	− .178	− .182	− .186	− .189	− .193	− .197	− .201	− .204
115.0	− .176	− .179	− .183	− .187	− .191	− .194	− .198	− .202	− .205
115.5	−0.177	−0.180	−0.184	−0.188	−0.192	−0.195	−0.199	−0.203	−0.207
116.0	− .178	− .181	− .185	− .189	− .193	− .197	− .200	− .204	− .208
116.5	− .179	− .183	− .186	− .190	− .194	− .198	− .202	− .205	− .209
117.0	− .180	− .184	− .187	− .191	− .195	− .199	− .203	− .206	− .210
117.5	− .181	− .185	− .189	− .192	− .196	− .200	− .204	− .208	− .212
118.0	−0.182	−0.186	−0.190	−0.193	−0.197	−0.201	−0.205	−0.209	−0.213
118.5	− .183	− .187	− .191	− .195	− .198	− .202	− .206	− .210	− .214
119.0	− .184	− .188	− .192	− .196	− .200	− .204	− .207	− .211	− .215
119.5	− .185	− .189	− .193	− .197	− .201	− .205	− .209	− .213	− .217
120.0	− .186	− .190	− .194	− .198	− .202	− .206	− .210	− .214	− .218

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
−20.0	+0.130	+0.133	+0.135	+0.138	+0.140	+0.142	+0.145	+0.147	+0.149
−19.5	+0.129	+0.132	+0.134	+0.136	+0.139	+0.141	+0.143	+0.146	+0.148
−19.0	.128	.130	.133	.135	.137	.140	.142	.144	.147
−18.5	.127	.129	.131	.134	.136	.138	.141	.143	.145
−18.0	.125	.128	.130	.132	.135	.137	.139	.141	.144
−17.5	.124	.126	.129	.131	.133	.135	.138	.140	.142
−17.0	+0.123	+0.125	+0.127	+0.130	+0.132	+0.134	+0.136	+0.139	+0.141
−16.5	.122	.124	.126	.128	.131	.133	.135	.137	.139
−16.0	.120	.123	.125	.127	.129	.131	.134	.136	.138
−15.5	.119	.121	.123	.126	.128	.130	.132	.134	.136
−15.0	.118	.120	.122	.124	.126	.129	.131	.133	.135
−14.5	+0.117	+0.119	+0.121	+0.123	+0.125	+0.127	+0.129	+0.131	+0.134
−14.0	.115	.117	.120	.122	.124	.126	.128	.130	.132
−13.5	.114	.116	.118	.120	.122	.124	.127	.129	.131
−13.0	.113	.115	.117	.119	.121	.123	.125	.127	.129
−12.5	.112	.114	.116	.118	.120	.122	.124	.126	.128
−12.0	+0.110	+0.112	+0.114	+0.116	+0.118	+0.120	+0.122	+0.124	+0.126
−11.5	.109	.111	.113	.115	.117	.119	.121	.123	.125
−11.0	.108	.110	.112	.114	.116	.118	.120	.122	.123
−10.5	.107	.108	.110	.112	.114	.116	.118	.120	.122
−10.0	.105	.107	.109	.111	.113	.115	.117	.119	.121
− 9.5	+0.104	+0.106	+0.108	+0.110	+0.112	+0.113	+0.115	+0.117	+0.119
− 9.0	.103	.105	.107	.108	.110	.112	.114	.116	.118
− 8.5	.102	.103	.105	.107	.109	.111	.113	.114	.116
− 8.0	.100	.102	.104	.106	.108	.109	.111	.113	.115
− 7.5	.099	.101	.103	.104	.106	.108	.110	.112	.113
− 7.0	+0.098	+0.100	+0.101	+0.103	+0.105	+0.107	+0.108	+0.110	+0.112
− 6.5	.096	.098	.100	.102	.104	.105	.107	.109	.111
− 6.0	.095	.097	.099	.100	.102	.104	.106	.107	.109
− 5.5	.094	.096	.097	.099	.101	.103	.104	.106	.108
− 5.0	.093	.094	.096	.098	.099	.101	.103	.105	.106
− 4.5	+0.091	+0.093	+0.095	+0.096	+0.098	+0.100	+0.101	+0.103	+0.105
− 4.0	.090	.092	.093	.095	.097	.098	.100	.102	.103
− 3.5	.089	.091	.092	.094	.095	.097	.099	.100	.102
− 3.0	.088	.089	.091	.092	.094	.096	.097	.099	.100
− 2.5	.086	.088	.090	.091	.093	.094	.096	.097	.099
− 2.0	+0.085	+0.087	+0.088	+0.090	+0.091	+0.093	+0.094	+0.096	+0.098
− 1.5	.084	.085	.087	.088	.090	.092	.093	.095	.096
− 1.0	.083	.084	.086	.087	.089	.090	.092	.093	.095
− 0.5	.081	.083	.084	.086	.087	.089	.090	.092	.093
0.0	.080	.082	.083	.085	.086	.087	.089	.090	.092

TABLE 5.2.3. (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
0.0	+0.080	+0.082	+0.083	+0.085	+0.086	+0.087	+0.089	+0.090	+0.092
0.5	+0.079	+0.080	+0.082	+0.083	+0.085	+0.086	+0.087	+0.089	+0.090
1.0	.078	.079	.080	.082	.083	.085	.086	.088	.089
1.5	.076	.078	.079	.081	.082	.083	.085	.086	.087
2.0	.075	.076	.078	.079	.081	.082	.083	.085	.086
2.5	.074	.075	.077	.078	.079	.081	.082	.083	.085
3.0	+0.073	+0.074	+0.075	+0.077	+0.078	+0.079	+0.081	+0.082	+0.083
3.5	.071	.073	.074	.075	.077	.078	.079	.080	.082
4.0	.070	.071	.073	.074	.075	.076	.078	.079	.080
4.5	.069	.070	.071	.073	.074	.075	.076	.078	.079
5.0	.068	.069	.070	.071	.073	.074	.075	.076	.077
5.5	+0.066	+0.068	+0.069	+0.070	+0.071	+0.072	+0.074	+0.075	+0.076
6.0	.065	.066	.067	.069	.070	.071	.072	.073	.075
6.5	.064	.065	.066	.067	.068	.070	.071	.072	.073
7.0	.063	.064	.065	.066	.067	.068	.069	.071	.072
7.5	.061	.062	.064	.065	.066	.067	.068	.069	.070
8.0	+0.060	+0.061	+0.062	+0.063	+0.064	+0.066	+0.067	+0.068	+0.069
8.5	.059	.060	.061	.062	.063	.064	.065	.066	.067
9.0	.058	.059	.060	.061	.062	.063	.064	.065	.066
9.5	.056	.057	.058	.059	.060	.061	.062	.063	.064
10.0	.055	.056	.057	.058	.059	.060	.061	.062	.063
10.5	+0.054	+0.055	+0.056	+0.057	+0.058	+0.059	+0.060	+0.061	+0.062
11.0	.053	.053	.054	.055	.056	.057	.058	.059	.060
11.5	.051	.052	.053	.054	.055	.056	.057	.058	.059
12.0	.050	.051	.052	.053	.054	.055	.055	.056	.057
12.5	.049	.050	.051	.051	.052	.053	.054	.055	.056
13.0	+0.048	+0.048	+0.049	+0.050	+0.051	+0.052	+0.053	+0.054	+0.054
13.5	.046	.047	.048	.049	.050	.050	.051	.052	.053
14.0	.045	.046	.047	.047	.048	.049	.050	.051	.052
14.5	.044	.045	.045	.046	.047	.048	.049	.049	.050
15.0	.043	.043	.044	.045	.046	.046	.047	.048	.049
15.5	+0.041	+0.042	+0.043	+0.044	+0.044	+0.045	+0.046	+0.047	+0.047
16.0	.040	.041	.041	.042	.043	.044	.044	.045	.046
16.5	.039	.039	.040	.041	.042	.042	.043	.044	.044
17.0	.038	.038	.039	.040	.040	.041	.042	.042	.043
17.5	.036	.037	.038	.038	.039	.040	.040	.041	.042
18.0	+0.035	+0.036	+0.036	+0.037	+0.038	+0.038	+0.039	+0.039	+0.040
18.5	.034	.034	.035	.036	.036	.037	.037	.038	.039
19.0	.032	.033	.034	.034	.035	.035	.036	.037	.037
19.5	.031	.032	.032	.033	.034	.034	.035	.035	.036
20.0	.030	.031	.031	.032	.032	.033	.033	.034	.034
20.5	+0.029	+0.029	+0.030	+0.030	+0.031	+0.031	+0.032	+0.032	+0.033
21.0	.027	.028	.028	.029	.029	.030	.030	.031	.031
21.5	.026	.027	.027	.028	.028	.029	.029	.030	.030
22.0	.025	.025	.026	.026	.027	.027	.028	.028	.029
22.5	.024	.024	.025	.025	.025	.026	.026	.027	.027
23.0	+0.022	+0.023	+0.023	+0.024	+0.024	+0.025	+0.025	+0.025	+0.026
23.5	.021	.022	.022	.022	.023	.023	.024	.024	.024
24.0	.020	.020	.021	.021	.021	.022	.022	.023	.023
24.5	.019	.019	.019	.020	.020	.020	.021	.021	.021
25.0	.017	.018	.018	.018	.019	.019	.019	.020	.020

TABLE 5.2.3. (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
25.5	+0.016	+0.017	+0.017	+0.017	+0.017	+0.018	+0.018	+0.018	+0.019
26.0	.015	.015	.016	.016	.016	.016	.017	.017	.017
26.5	.014	.014	.014	.014	.015	.015	.015	.015	.016
27.0	.012	.013	.013	.013	.013	.014	.014	.014	.014
27.5	.011	.011	.012	.012	.012	.012	.012	.013	.013
28.0	+0.010	+0.010	+0.010	+0.011	+0.011	+0.011	+0.011	+0.011	+0.011
28.5	.009	.009	.009	.009	.009	.010	.010	.010	.010
29.0	.007	.008	.008	.008	.008	.008	.008	.008	.009
29.5	.006	.006	.006	.007	.007	.007	.007	.007	.007
30.0	.005	.005	.005	.005	.005	.005	.006	.006	.006
30.5	+0.004	+0.004	+0.004	+0.004	+0.004	+0.004	+0.004	+0.004	+0.004
31.0	.002	.003	.003	.003	.003	.003	.003	.003	.003
31.5	.001	.001	.001	.001	.001	.001	.001	.001	.001
32.0	.000	.000	.000	.000	.000	.000	.000	.000	.000
32.5	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
33.0	−0.002	−0.003	−0.003	−0.003	−0.003	−0.003	−0.003	−0.003	−0.003
33.5	− .004	− .004	− .004	− .004	− .004	− .004	− .004	− .004	− .004
34.0	− .005	− .005	− .005	− .005	− .005	− .005	− .006	− .006	− .006
34.5	− .006	− .006	− .006	− .007	− .007	− .007	− .007	− .007	− .007
35.0	− .007	− .008	− .008	− .008	− .008	− .008	− .008	− .008	− .008
35.5	−0.009	−0.009	−0.009	−0.009	−0.009	−0.010	−0.010	−0.010	−0.010
36.0	− .010	− .010	− .010	− .011	− .011	− .011	− .011	− .011	− .011
36.5	− .011	− .011	− .012	− .012	− .012	− .012	− .012	− .013	− .013
37.0	− .012	− .013	− .013	− .013	− .013	− .014	− .014	− .014	− .014
37.5	− .014	− .014	− .014	− .014	− .015	− .015	− .015	− .015	− .016
38.0	−0.015	−0.015	−0.016	−0.016	−0.016	−0.016	−0.017	−0.017	−0.017
38.5	− .016	− .017	− .017	− .017	− .017	− .018	− .018	− .018	− .019
39.0	− .017	− .018	− .018	− .018	− .019	− .019	− .019	− .020	− .020
39.5	− .019	− .019	− .019	− .020	− .020	− .020	− .021	− .021	− .021
40.0	− .020	− .020	− .021	− .021	− .021	− .022	− .022	− .022	− .023
40.5	−0.021	−0.022	−0.022	−0.022	−0.023	−0.023	−0.024	−0.024	−0.024
41.0	− .022	− .023	− .023	− .024	− .024	− .024	− .025	− .025	− .026
41.5	− .024	− .024	− .025	− .025	− .025	− .026	− .026	− .027	− .027
42.0	− .025	− .025	− .026	− .026	− .027	− .027	− .028	− .028	− .029
42.5	− .026	− .027	− .027	− .028	− .028	− .029	− .029	− .030	− .030
43.0	−0.027	−0.028	−0.028	−0.029	−0.029	−0.030	−0.030	−0.031	−0.031
43.5	− .029	− .029	− .030	− .030	− .031	− .031	− .032	− .032	− .033
44.0	− .030	− .030	− .031	− .032	− .032	− .033	− .033	− .034	− .034
44.5	− .031	− .032	− .032	− .033	− .033	− .034	− .035	− .035	− .036
45.0	− .032	− .033	− .034	− .034	− .035	− .035	− .036	− .037	− .037
45.5	−0.034	−0.034	−0.035	−0.035	−0.036	−0.037	−0.037	−0.038	−0.039
46.0	− .035	− .036	− .036	− .037	− .037	− .038	− .039	− .039	− .040
46.5	− .036	− .037	− .037	− .038	− .039	− .039	− .040	− .041	− .041
47.0	− .037	− .038	− .039	− .039	− .040	− .041	− .041	− .042	− .043
47.5	− .039	− .039	− .040	− .041	− .041	− .042	− .043	− .044	− .044
48.0	−0.040	−0.041	−0.041	−0.042	−0.043	−0.044	−0.044	−0.045	−0.046
48.5	− .041	− .042	− .043	− .043	− .044	− .045	− .046	− .046	− .047
49.0	− .042	− .043	− .044	− .045	− .045	− .046	− .047	− .048	− .049
49.5	− .044	− .044	− .045	− .046	− .047	− .048	− .048	− .049	− .050
50.0	− .045	− .046	− .046	− .047	− .048	− .049	− .050	− .051	− .051

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached ther-mometer (° F.)	Height of mercury column, inches								
	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
50.5	—0.046	—0.047	—0.048	—0.049	—0.049	—0.050	—0.051	—0.052	—0.053
51.0	— .047	— .048	— .049	— .050	— .051	— .052	— .053	— .053	— .054
51.5	— .049	— .049	— .050	— .051	— .052	— .053	— .054	— .055	— .056
52.0	— .050	— .051	— .052	— .053	— .053	— .054	— .055	— .056	— .057
52.5	— .051	— .052	— .053	— .054	— .055	— .056	— .057	— .058	— .058
53.0	—0.052	—0.053	—0.054	—0.055	—0.056	—0.057	—0.058	—0.059	—0.060
53.5	— .054	— .055	— .056	— .056	— .057	— .058	— .059	— .060	— .061
54.0	— .055	— .056	— .057	— .058	— .059	— .060	— .061	— .062	— .063
54.5	— .056	— .057	— .058	— .059	— .060	— .061	— .062	— .063	— .064
55.0	— .057	— .058	— .059	— .060	— .061	— .062	— .064	— .065	— .066
55.5	—0.059	—0.060	—0.061	—0.062	—0.063	—0.064	—0.065	—0.066	—0.067
56.0	— .060	— .061	— .062	— .063	— .064	— .065	— .066	— .067	— .068
56.5	— .061	— .062	— .063	— .064	— .065	— .067	— .068	— .069	— .070
57.0	— .062	— .063	— .065	— .066	— .067	— .068	— .069	— .070	— .071
57.5	— .063	— .065	— .066	— .067	— .068	— .069	— .070	— .072	— .073
58.0	—0.065	—0.066	—0.067	—0.068	—0.069	—0.071	—0.072	—0.073	—0.074
58.5	— .066	— .067	— .068	— .070	— .071	— .072	— .073	— .074	— .076
59.0	— .067	— .068	— .070	— .071	— .072	— .073	— .075	— .076	— .077
59.5	— .068	— .070	— .071	— .072	— .073	— .075	— .076	— .077	— .078
60.0	— .070	— .071	— .072	— .074	— .075	— .076	— .077	— .079	— .080
60.5	—0.071	—0.072	—0.074	—0.075	—0.076	—0.077	—0.079	—0.080	—0.081
61.0	— .072	— .073	— .075	— .076	— .077	— .079	— .080	— .081	— .083
61.5	— .073	— .075	— .076	— .077	— .079	— .080	— .081	— .083	— .084
62.0	— .075	— .076	— .077	— .079	— .080	— .081	— .083	— .084	— .086
62.5	— .076	— .077	— .079	— .080	— .081	— .083	— .084	— .086	— .087
63.0	—0.077	—0.079	—0.080	—0.081	—0.083	—0.084	—0.086	—0.087	—0.088
63.5	— .078	— .080	— .081	— .083	— .084	— .086	— .087	— .088	— .090
64.0	— .080	— .081	— .083	— .084	— .085	— .087	— .088	— .090	— .091
64.5	— .081	— .082	— .084	— .085	— .087	— .088	— .090	— .091	— .093
65.0	— .082	— .084	— .085	— .087	—.088	— .090	— .091	— .093	— .094
65.5	—0.083	—0.085	—0.086	—0.088	—0.089	—0.091	—0.092	—0.094	—0.095
66.0	— .085	— .086	— .088	— .089	— .091	— .092	— .094	— .095	— .097
66.5	— .086	— .087	— .089	— .091	— .092	— .094	— .095	— .097	— .098
67.0	— .087	— .089	— .090	— .092	— .093	— .095	— .097	— .098	— .100
67.5	— .088	— .090	— .092	— .093	— .095	— .096	— .098	— .100	— .101
68.0	—0.090	—0.091	—0.093	—0.094	—0.096	—0.098	—0.099	—0.101	—0.103
68.5	— .091	— .092	— .094	— .096	— .097	— .099	— .101	— .102	— .104
69.0	— .092	— .094	— .095	— .097	— .099	— .100	— .102	— .104	— .105
69.5	— .093	— .095	— .097	— .098	— .100	— .102	— .103	— .105	— .107
70.0	— .095	— .096	— .098	— .100	— .101	— .103	— .105	— .107	— .108
70.5	—0.096	—0.097	—0.099	—0.101	—0.103	—0.104	—0.106	—0.108	—0.110
71.0	— .097	— .099	— .101	— .102	— .104	— .106	— .108	— .109	— .111
71.5	— .098	— .100	— .102	— .104	— .105	— .107	— .109	— .111	— .113
72.0	— .099	— .101	— .103	— .105	— .107	— .108	— .110	— .112	— .114
72.5	— .101	— .103	— .104	— .106	— .108	— .110	— .112	— .114	— .115
73.0	—0.102	—0.104	—0.106	—0.107	—0.109	—0.111	—0.113	—0.115	—0.117
73.5	— .103	— .105	— .107	— .109	— .111	— .113	— .114	— .116	— .118
74.0	— .104	— .106	— .108	— .110	— .112	— .114	— .116	— .118	— .120
74.5	— .106	— .108	— .109	— .111	— .113	— .115	— .117	— .119	— .121
75.0	— .107	— .109	— .111	— .113	— .115	— .117	— .119	— .120	— .122

TABLE 5.2.3. (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
75.5	—0.108	—0.110	—0.112	—0.114	—0.116	—0.118	—0.120	—0.122	—0.124
76.0	— .109	— .111	— .113	— .115	— .117	— .119	— .121	— .123	— .125
76.5	— .111	— .113	— .115	— .117	— .119	— .121	— .123	— .125	— .127
77.0	— .112	— .114	— .116	— .118	— .120	— .122	— .124	— .126	— .128
77.5	— .113	— .115	— .117	— .119	— .121	— .123	— .125	— .127	— .130
78.0	—0.114	—0.116	—0.118	—0.121	—0.123	—0.125	—0.127	—0.129	—0.131
78.5	— .116	— .118	— .120	— .122	— .124	— .126	— .128	— .130	— .132
79.0	— .117	— .119	— .121	— .123	— .125	— .127	— .130	— .132	— .134
79.5	— .118	— .120	— .122	— .124	— .127	— .129	— .131	— .133	— .135
80.0	— .119	— .121	— .124	— .126	— .128	— .130	— .132	— .134	— .137
80.5	—0.120	—0.123	—0.125	—0.127	—0.129	—0.131	—0.134	—0.136	—0.138
81.0	— .122	— .124	— .126	— .128	— .131	— .133	— .135	— .137	— .139
81.5	— .123	— .125	— .127	— .130	— .132	— .134	— .136	— .139	— .141
82.0	— .124	— .126	— .129	— .131	— .133	— .135	— .138	— .140	— .142
82.5	— .125	— .128	— .130	— .132	— .135	— .137	— .139	— .141	— .144
83.0	—0.127	—0.129	—0.131	—0.134	—0.136	—0.138	—0.140	—0.143	—0.145
83.5	— .128	— .130	— .133	— .135	— .137	— .140	— .142	— .144	— .146
84.0	— .129	— .131	— .134	— .136	— .139	— .141	— .143	— .146	— .148
84.5	— .130	— .133	— .135	— .137	— .140	— .142	— .145	— .147	— .149
85.0	— .132	— .134	— .136	— .139	— .141	— .144	— .146	— .148	— .151
85.5	—0.133	—0.135	—0.138	—0.140	—0.143	—0.145	—0.147	—0.150	—0.152
86.0	— .134	— .137	— .139	— .141	— .144	— .146	— .149	— .151	— .154
86.5	— .135	— .138	— .140	— .143	— .145	— .148	— .150	— .153	— .155
87.0	— .137	— .139	— .142	— .144	— .146	— .149	— .151	— .154	— .156
87.5	— .138	— .140	— .143	— .145	— .148	— .150	— .153	— .155	— .158
88.0	—0.139	—0.142	—0.144	—0.147	—0.149	—0.152	—0.154	—0.157	—0.159
88.5	— .140	— .143	— .145	— .148	— .150	— .153	— .156	— .158	— .161
89.0	— .141	— .144	— .147	— .149	— .152	— .154	— .157	— .159	— .162
89.5	— .143	— .145	— .148	— .150	— .153	— .156	— .158	— .161	— .163
90.0	— .144	— .147	— .149	— .152	— .154	— .157	— .160	— .162	— .165
90.5	—0.145	—0.148	—0.150	—0.153	—0.156	—0.158	—0.161	—0.164	—0.166
91.0	— .146	— .149	— .152	— .154	— .157	— .160	— .162	— .165	— .168
91.5	— .148	— .150	— .153	— .156	— .158	— .161	— .164	— .166	— .169
92.0	— .149	— .152	— .154	— .157	— .160	— .162	— .165	— .168	— .171
92.5	— .150	— .153	— .156	— .158	— .161	— .164	— .166	— .169	— .172
93.0	—0.151	—0.154	—0.157	—0.160	—0.162	—0.165	—0.168	—0.171	—0.173
93.5	— .153	— .155	— .158	— .161	— .164	— .166	— .169	— .172	— .175
94.0	— .154	— .157	— .159	— .162	— .165	— .168	— .171	— .173	— .176
94.5	— .155	— .158	— .161	— .164	— .166	— .169	— .172	— .175	— .178
95.0	— .156	— .159	— .162	— .165	— .168	— .170	— .173	— .176	— .179
95.5	—0.158	—0.160	—0.163	—0.166	—0.169	—0.172	—0.175	—0.178	—0.180
96.0	— .159	— .162	— .165	— .167	— .170	— .173	— .176	— .179	— .182
96.5	— .160	— .163	— .166	— .169	— .172	— .175	— .177	— .180	— .183
97.0	— .161	— .164	— .167	— .170	— .173	— .176	— .179	— .182	— .185
97.5	— .162	— .165	— .168	— .171	— .174	— .177	— .180	— .183	— .186
98.0	—0.164	—0.167	—0.170	—0.173	—0.176	—0.179	—0.182	—0.185	—0.187
98.5	— .165	— .168	— .171	— .174	— .177	— .180	— .183	— .186	— .189
99.0	— .166	— .169	— .172	— .175	— .178	— .181	— .184	— .187	— .190
99.5	— .167	— .170	— .173	— .176	— .180	— .183	— .186	— .189	— .192
100.0	— .169	— .172	— .175	— .178	— .181	— .184	— .187	— .190	— .193

TABLE 5.2.3 (CONTINUED)

Correction of Mercurial Barometer for Temperature

English measures (scale true at 32° F.)

[Apply according to indicated algebraic sign.]

Attached thermometer (° F.)	Height of mercury column, inches								
	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5
	inch	inch	inch	inch	inch	inch	inch	inch	inch
100.0	−0.169	−0.172	−0.175	−0.178	−0.181	−0.184	−0.187	−0.190	−0.193
100.5	−0.170	−0.173	−0.176	−0.179	−0.182	−0.185	−0.188	−0.191	−0.195
101.0	− .171	− .174	− .177	− .180	− .183	− .187	− .190	− .193	− .196
101.5	− .172	− .175	− .179	− .182	− .185	− .188	− .191	− .194	− .197
102.0	− .174	− .177	− .180	− .183	− .186	− .189	− .192	− .196	− .199
102.5	− .175	− .178	− .181	− .184	− .187	− .191	− .194	− .197	− .200
103.0	−0.176	−0.179	−0.182	−0.186	−0.189	−0.192	−0.195	−0.198	−0.202
103.5	− .177	− .180	− .184	− .187	− .190	− .193	− .197	− .200	− .203
104.0	− .178	− .182	− .185	− .188	− .191	− .195	− .198	− .201	− .204
104.5	− .180	− .183	− .186	− .189	− .193	− .196	− .199	− .203	− .206
105.0	− .181	− .184	− .187	− .191	− .194	− .197	− .201	− .204	− .207
105.5	−0.182	−0.185	−0.189	−0.192	−0.195	−0.199	−0.202	−0.205	−0.209
106.0	− .183	− .187	− .190	− .193	− .197	− .200	− .203	− .207	− .210
106.5	− .185	− .188	− .191	− .195	− .198	− .201	− .205	− .208	− .211
107.0	− .186	− .189	− .193	− .196	− .199	− .203	− .206	− .209	− .213
107.5	− .187	− .190	− .194	− .197	− .201	− .204	− .207	− .211	− .214
108.0	−0.188	−0.192	−0.195	−0.199	−0.202	−0.205	−0.209	−0.212	−0.216
108.5	− .190	− .193	− .196	− .200	− .203	− .207	− .210	− .214	− .217
109.0	− .191	− .194	− .198	− .201	− .205	− .208	− .212	− .215	− .218
109.5	− .192	− .195	− .199	− .202	− .206	− .209	− .213	− .216	− .220
110.0	− .193	− .197	− .200	− .204	− .207	− .211	− .214	− .218	− .221
110.5	−0.194	−0.198	−0.201	−0.205	−0.209	−0.212	−0.216	−0.219	−0.223
111.0	− .196	− .199	− .203	− .206	− .210	− .213	− .217	− .221	− .224
111.5	− .197	− .200	− .204	− .208	− .211	− .215	− .218	− .222	− .226
112.0	− .198	− .202	− .205	− .209	− .213	− .216	− .220	− .223	− .227
112.5	− .199	− .203	− .207	− .210	− .214	− .217	− .221	− .225	− .228
113.0	−0.201	−0.204	−0.208	−0.212	−0.215	−0.219	−0.222	−0.226	−0.230
113.5	− .202	− .205	− .209	− .213	− .216	− .220	− .224	− .227	− .231
114.0	− .203	− .207	− .210	− .214	− .218	− .221	− .225	− .229	− .233
114.5	− .204	− .208	− .212	− .215	− .219	− .223	− .227	− .230	− .234
115.0	− .205	− .209	− .213	− .217	− .220	− .224	− .228	− .232	− .235
115.5	−0.207	−0.210	−0.214	−0.218	−0.222	−0.225	−0.229	−0.233	−0.237
116.0	− .208	− .212	− .215	− .219	− .223	− .227	− .231	− .234	− .238
116.5	− .209	− .213	− .217	− .221	− .224	− .228	− .232	− .236	− .240
117.0	− .210	− .214	− .218	− .222	− .226	− .230	− .233	− .237	− .241
117.5	− .212	− .215	− .219	− .223	− .227	− .231	− .235	− .239	− .242
118.0	−0.213	−0.217	−0.221	−0.224	−0.228	−0.232	−0.236	−0.240	−0.244
118.5	− .214	− .218	− .222	− .226	− .230	− .234	− .237	− .241	− .245
119.0	− .215	− .219	− .223	− .227	− .231	− .235	− .239	− .243	− .247
119.5	− .217	− .220	− .224	− .228	− .232	− .236	− .240	− .244	− .248
120.0	− .218	− .222	− .226	− .230	− .234	− .238	− .242	− .245	− .249

INFORMATION SHEET—TABLE 5.4.1

Barometer "Total Correction" Table (Inches of Mercury)

Preparation of Table:

Prepare a separate copy of this table for each barometer, by adding algebraically the "Sum of Corrections" as given on the barometer correction card to each value of the temperature correction given in the first column of the table. The algebraic sum is the total barometer correction. This is to be entered in the blank columns headed "Total Corr." on the same line as the temperature correction. Enter the station name (or geographical coordinates), station elevation (H_p), actual barometer elevation (H_z), barometer number, and "Sum of Corrections" in the appropriate spaces at the head of the table.

Example:

Consider a station for which the station elevation, $H_p = 253$ ft., the barometer elevation, $H_z = 249$ ft., and the "Sum of Corrections" for the barometer = —.023 inch. Values to be entered in the "Total Corr." columns are obtained as follows:

Line	Temp. corr.	Sum of corr.	Total corr.	Thermometer reading 70.0° F.
	in.	in.	in.	in.*
1	—.118	—.023	—.141	31.668
2	—.117	—.023	—.140	31.401
3	—.116	—.023	—.139	31.133
4	—.115	—.023	—.138	30.866
5	—.114	—.023	—.137	30.599
6	—.113	—.023	—.136	30.332
7	—.112	—.023	—.135	30.064
8	—.111	—.023	—.134	29.797
9	—.110	—.023	—.133	29.530
		etc.		

* Pick the *smallest* tabular value, in column below, which equals or exceeds the observed barometer reading. (See Instructions for Use.)

The table is to be used only for the particular "Sum of Corrections" appropriate to the given barometer installation. Any change of barometer, barometer calibration, station location, or elevation which alters the "Sum of Corrections" will necessitate revision of the values in the "Total Corr." columns of the table. A mobile station, for which the latitude, station elevation, and barometer elevation undergo frequent changes, may find it convenient to enter the total corrections in pencil so that they may be erased and revised as necessary, or to paste new strips of total corrections over the previous values in the "Total Corr." columns.

Instructions for Use:

Find the column of the table corresponding to the reading of the attached thermometer to the nearest 0.5° F. The columns are identified as to temperature at both top and bottom. Proceed up or down in the column, as convenient, to the *smallest* pressure value which equals or exceeds the observed barometer reading. Then proceed horizontally along this line to the right or left to the nearest of the two identical columns marked "Total Corr." and read this value. Add this value of total correction algebraically to the observed barometer reading to obtain the station pressure.

Example:

Suppose that a given station barometer has sum of corrections = —.023 in. Hg. as indicated in the previous example and in Figure 5.4.1. Then assume that the observed barometer reading = 29.845 inches, and the attached thermometer reading = 70.0° F. To find the total correction and station pressure: proceed down the 70.0° column to pressure 30.064 in., which is the smallest value that is equal to or greater than the observed barometer reading; then proceed horizontally to the "Total Corr." column and read —0.135 in. Therefore station pressure = 29.845 in. —0.135 in. = 29.710 in. Hg.

TABLE 5.4.1—Page 1A *Barometer Total Correction Table* **TEMP. 120.0–115.5°F**

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*120.0°F*	*119.5°F*	*119.0°F*	*118.5°F*	*118.0°F*	*117.5°F*	*117.0°F*	*116.5°F*	*116.0°F*	*115.5°F*	Total Corr. in.
—.259		31.557										
—.258		31.436	31.607									
—.257		31.314	31.485									
—.256		31.192	31.362	31.534								
—.255		31.071	31.240	31.411	31.585							
—.254		30.949	31.118	31.288	31.461							
—.253		30.828	30.995	31.166	31.337	31.511						
—.252		30.706	30.873	31.043	31.214	31.387	31.562					
—.251		30.584	30.751	30.920	31.090	31.263	31.437	31.613				
—.250		30.463	30.629	30.797	30.967	31.138	31.312	31.487				
—.249		30.341	30.506	30.674	30.843	31.014	31.187	31.362	31.539			
—.248		30.220	30.384	30.551	30.719	30.890	31.062	31.236	31.412	31.590		
—.247		30.098	30.262	30.428	30.596	30.765	30.937	31.110	31.286	31.463		
—.246		29.976	30.140	30.305	30.472	30.641	30.812	30.985	31.159	31.336	31.515	
—.245		29.855	30.017	30.182	30.348	30.517	30.687	30.859	31.033	31.209	31.387	
—.244		29.733	29.895	30.059	30.225	30.393	30.562	30.733	30.907	31.082	31.259	
—.243		29.612	29.773	29.936	30.101	30.268	30.437	30.607	30.780	30.955	31.131	
—.242		29.490	29.650	29.813	29.978	30.144	30.312	30.482	30.654	30.828	31.004	
—.241		29.368	29.528	29.690	29.854	30.020	30.187	30.356	30.527	30.700	30.876	
—.240		29.247	29.406	29.567	29.730	29.895	30.062	30.230	30.401	30.573	30.748	
—.239		29.125	29.284	29.444	29.607	29.771	29.937	30.105	30.274	30.446	30.620	
—.238		29.003	29.161	29.321	29.483	29.647	29.812	29.979	30.148	30.319	30.492	
—.237		28.882	29.039	29.198	29.359	29.522	29.687	29.853	30.022	30.192	30.364	
—.236		28.760	28.917	29.076	29.236	29.398	29.562	29.728	29.895	30.065	30.236	
—.235		28.639	28.795	28.953	29.112	29.274	29.437	29.602	29.769	29.938	30.109	
—.234		28.517	28.672	28.830	28.989	29.149	29.312	29.476	29.642	29.811	29.981	
—.233		28.395	28.550	28.707	28.865	29.025	29.187	29.350	29.516	29.683	29.853	
—.232		28.274	28.428	28.584	28.741	28.901	29.062	29.225	29.390	29.556	29.725	
—.231		28.152	28.305	28.461	28.618	28.777	28.937	29.099	29.263	29.429	29.597	
—.230		28.031	28.183	28.338	28.494	28.652	28.812	28.973	29.137	29.302	29.469	
—.229		27.909	28.061	28.215	28.371	28.528	28.687	28.848	29.010	29.175	29.342	
—.228		27.787	27.939	28.092	28.247	28.404	28.562	28.722	28.884	29.048	29.214	
—.227		27.666	27.816	27.969	28.123	28.279	28.437	28.596	28.758	28.921	29.086	
—.226		27.544	27.694	27.846	28.000	28.155	28.312	28.471	28.631	28.794	28.958	
—.225		27.423	27.572	27.723	27.876	28.031	28.187	28.345	28.505	28.666	28.830	
—.224		27.301	27.450	27.600	27.752	27.906	28.062	28.219	28.378	28.539	28.702	
—.223		27.179	27.327	27.477	27.629	27.782	27.937	28.093	28.252	28.412	28.574	
—.222		27.058	27.205	27.354	27.505	27.658	27.812	27.968	28.126	28.285	28.447	
—.221		26.936	27.083	27.231	27.382	27.534	27.687	27.842	27.999	28.158	28.319	
—.220		26.815	26.960	27.108	27.258	27.409	27.562	27.716	27.873	28.031	28.191	
—.219		26.693	26.838	26.985	27.134	27.285	27.437	27.591	27.746	27.904	28.063	
—.218		26.571	26.716	26.863	27.011	27.161	27.312	27.465	27.620	27.777	27.935	
—.217		26.450	26.594	26.740	26.887	27.036	27.187	27.339	27.493	27.649	27.807	
—.216		26.328	26.471	26.617	26.763	26.912	27.062	27.214	27.367	27.522	27.679	
—.215		26.206	26.349	26.494	26.640	26.788	26.937	27.088	27.241	27.395	27.552	
—.214		26.085	26.227	26.371	26.516	26.663	26.812	26.962	27.114	27.268	27.424	
—.213		25.963	26.105	26.248	26.393	26.539	26.687	26.836	26.988	27.141	27.296	
—.212		25.842	25.982	26.125	26.269	26.415	26.562	26.711	26.861	27.014	27.168	
—.211		25.720	25.860	26.002	26.145	26.290	26.437	26.585	26.735	26.887	27.040	
		120.0°F	*119.5°F*	*119.0°F*	*118.5°F*	*118.0°F*	*117.5°F*	*117.0°F*	*116.5°F*	*116.0°F*	*115.5°F*	

TABLE 5.4.1—Page 1B

Barometer Total Correction Table

TEMP. 120.0-115.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Temp. Corr. in.	Total Corr. in.	*120.0°F*	*119.5°F*	*119.0°F*	*118.5°F*	*118.0°F*	*117.5°F*	*117.0°F*	*116.5°F*	*116.0°F*	*115.5°F*	Total Corr. in.
—.210		25.598	25.738	25.879	26.022	26.166	26.312	26.459	26.609	26.760	26.912	
—.209		25.477	25.615	25.756	25.898	26.042	26.187	26.334	26.482	26.632	26.784	
—.208		25.355	25.493	25.633	25.774	25.918	26.062	26.208	26.356	26.505	26.657	
—.207		25.234	25.371	25.510	25.651	25.793	25.937	26.082	26.229	26.378	26.529	
—.206		25.112	25.249	25.387	25.527	25.669	25.812	25.957	26.103	26.251	26.401	
—.205		24.990	25.126	25.264	25.404	25.545	25.687	25.831	25.977	26.124	26.273	
—.204		24.869	25.004	25.141	25.280	25.420	25.562	25.705	25.850	25.997	26.145	
—.203		24.747	24.882	25.018	25.156	25.296	25.437	25.579	25.724	25.870	26.017	
—.202		24.626	24.760	24.895	25.033	25.172	25.312	25.454	25.597	25.743	25.890	
—.201		24.504	24.637	24.773	24.909	25.047	25.187	25.328	25.471	25.615	25.762	
—.200		24.382	24.515	24.650	24.786	24.923	25.062	25.202	25.345	25.488	25.634	
—.199		24.261	24.393	24.527	24.662	24.799	24.937	25.077	25.218	25.361	25.506	
—.198		24.139	24.270	24.404	24.538	24.674	24.812	24.951	25.092	25.234	25.378	
—.197		24.017	24.148	24.281	24.415	24.550	24.687	24.825	24.965	25.107	25.250	
—.196		23.896	24.026	24.158	24.291	24.426	24.562	24.700	24.839	24.980	25.122	
—.195		23.774	23.904	24.035	24.167	24.302	24.437	24.574	24.712	24.853	24.995	
—.194		23.653	23.781	23.912	24.044	24.177	24.312	24.448	24.586	24.726	24.867	
—.193		23.531	23.659	23.789	23.920	24.053	24.187	24.322	24.460	24.598	24.739	
—.192		23.409	23.537	23.666	23.797	23.929	24.062	24.197	24.333	24.471	24.611	
—.191		23.288	23.415	23.543	23.673	23.804	23.937	24.071	24.207	24.344	24.483	
—.190		23.166	23.292	23.420	23.549	23.680	23.812	23.945	24.080	24.217	24.355	
—.189		23.045	23.170	23.297	23.426	23.556	23.687	23.820	23.954	24.090	24.227	
—.188		22.923	23.048	23.174	23.302	23.431	23.562	23.694	23.828	23.963	24.100	
—.187		22.801	22.926	23.051	23.178	23.307	23.437	23.568	23.701	23.836	23.972	
—.186		22.680	22.803	22.928	23.055	23.183	23.312	23.443	23.575	23.708	23.844	
—.185		22.558	22.681	22.805	22.931	23.058	23.187	23.317	23.448	23.581	23.716	
—.184		22.437	22.559	22.682	22.808	22.934	23.062	23.191	23.322	23.454	23.588	
—.183		22.315	22.436	22.560	22.684	22.810	22.937	23.065	23.196	23.327	23.460	
—.182		22.193	22.314	22.437	22.560	22.686	22.812	22.940	23.069	23.200	23.332	
—.181		22.072	22.192	22.314	22.437	22.561	22.687	22.814	22.943	23.073	23.205	
—.180		21.950	22.070	22.191	22.313	22.437	22.562	22.688	22.816	22.946	23.077	
—.179		21.828	21.947	22.068	22.189	22.313	22.437	22.563	22.690	22.819	22.949	
—.178		21.707	21.825	21.945	22.066	22.188	22.312	22.437	22.564	22.691	22.821	
—.177		21.585	21.703	21.822	21.942	22.064	22.187	22.311	22.437	22.564	22.693	
—.176		21.464	21.581	21.699	21.819	21.940	22.062	22.186	22.311	22.437	22.565	
—.175		21.342	21.458	21.576	21.695	21.815	21.937	22.060	22.184	22.310	22.438	
—.174		21.220	21.336	21.453	21.571	21.691	21.812	21.934	22.058	22.183	22.310	
—.173		21.099	21.214	21.330	21.448	21.567	21.687	21.808	21.931	22.056	22.182	
—.172		20.977	21.091	21.207	21.324	21.442	21.562	21.683	21.805	21.929	22.054	
—.171		20.856	20.969	21.084	21.201	21.318	21.437	21.557	21.679	21.802	21.926	
—.170		....	20.847	20.961	21.077	21.194	21.312	21.431	21.552	21.674	21.798	
—.169		....	....	20.838	20.953	21.070	21.187	21.306	21.426	21.547	21.670	
—.168		....	....	....	20.830	20.945	21.062	21.180	21.299	21.420	21.543	
—.167		....	....	....	....	20.821	20.937	21.054	21.173	21.293	21.415	
—.166		....	....	....	....	....	20.812	20.929	21.047	21.166	21.287	
—.165		....	....	....	....	....	....	20.803	20.920	21.039	21.159	
—.164		....	....	....	....	....	....	....	20.794	20.912	21.031	
—.163		....	....	....	....	....	....	....	....	20.785	20.903	
		120.0°F	*119.5°F*	*119.0°F*	*118.5°F*	*118.0°F*	*117.5°F*	*117.0°F*	*116.5°F*	*116.0°F*	*115.5°F*	

TABLE 5.4.1—Page 2A

Barometer Total Correction Table

TEMP. 115.0–110.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*115.0°F*										Total Corr. in.
—.245		31.567	*114.5°F*									
—.244		31.439	31.620	*114.0°F*	....	....	....	....	....	....	....	
—.243		31.310	31.491	....	*113.5°F*	....	....	....	....	....	....	
—.242		31.181	31.362	31.543	....	*113.0°F*	....	....	....	....	....	
—.241		31.053	31.232	31.413	31.597	....	*112.5°F*	....	....	....	....	
—.240		30.924	31.103	31.283	31.466	....	....	*112.0°F*	....	....	....	
—.239		30.796	30.974	31.153	31.335	31.519	....	....	....	....	....	
—.238		30.667	30.844	31.023	31.204	31.388	31.573	....	*111.5°F*	....	....	
—.237		30.538	30.715	30.893	31.074	31.256	31.441	31.628	....	....	....	
—.236		30.410	30.586	30.763	30.943	31.125	31.309	31.495	....	*111.0°F*	....	
—.235		30.281	30.456	30.633	30.812	30.993	31.176	31.362	31.549	....	....	
—.234		30.153	30.327	30.503	30.681	30.861	31.044	31.229	31.415	31.604	*110.5°F*	
—.233		30.024	30.198	30.373	30.550	30.730	30.911	31.095	31.281	31.470	....	
—.232		29.896	30.068	30.243	30.419	30.598	30.779	30.962	31.147	31.335	31.525	
—.231		29.767	29.939	30.113	30.288	30.467	30.647	30.829	31.013	31.200	31.389	
—.230		29.638	29.810	29.982	30.158	30.335	30.514	30.696	30.879	31.065	31.253	
—.229		29.510	29.680	29.852	30.027	30.203	30.382	30.563	30.745	30.931	31.118	
—.228		29.381	29.551	29.722	29.896	30.072	30.249	30.430	30.611	30.796	30.982	
—.227		29.253	29.422	29.592	29.765	29.940	30.117	30.296	30.477	30.661	30.847	
—.226		29.124	29.292	29.462	29.634	29.808	29.985	30.163	30.343	30.526	30.711	
—.225		28.995	29.163	29.332	29.503	29.677	29.852	30.030	30.210	30.391	30.575	
—.224		28.867	29.034	29.202	29.373	29.545	29.720	29.897	30.076	30.257	30.440	
—.223		28.738	28.904	29.072	29.242	29.414	29.588	29.764	29.942	30.122	30.304	
—.222		28.610	28.775	28.942	29.111	29.282	29.455	29.630	29.808	29.987	30.169	
—.221		28.481	28.646	28.812	28.980	29.150	29.323	29.497	29.674	29.852	30.033	
—.220		28.352	28.516	28.682	28.849	29.019	29.190	29.364	29.540	29.718	29.898	
—.219		28.224	28.387	28.552	28.718	28.887	29.058	29.231	29.406	29.583	29.762	
—.218		28.095	28.258	28.422	28.588	28.756	28.926	29.098	29.272	29.448	29.626	
—.217		27.967	28.128	28.291	28.457	28.624	28.793	28.965	29.138	29.313	29.491	
—.216		27.838	27.999	28.161	28.326	28.492	28.661	28.831	29.004	29.179	29.355	
—.215		27.710	27.870	28.031	28.195	28.361	28.528	28.698	28.870	29.044	29.220	
—.214		27.581	27.740	27.901	28.064	28.229	28.396	28.565	28.736	28.909	29.084	
—.213		27.452	27.611	27.771	27.933	28.098	28.264	28.432	28.602	28.774	28.948	
—.212		27.324	27.482	27.641	27.803	27.966	28.131	28.299	28.468	28.639	28.813	
—.211		27.195	27.352	27.511	27.672	27.834	27.999	28.166	28.334	28.505	28.677	
—.210		27.067	27.223	27.381	27.541	27.703	27.867	28.032	28.200	28.370	28.542	
—.209		26.938	27.094	27.251	27.410	27.571	27.734	27.899	28.066	28.235	28.406	
—.208		26.809	26.964	27.121	27.279	27.440	27.602	27.766	27.932	28.100	28.270	
—.207		26.681	26.835	26.991	27.148	27.308	27.469	27.633	27.798	27.966	28.135	
—.206		26.552	26.706	26.861	27.018	27.176	27.337	27.500	27.664	27.831	27.999	
—.205		26.424	26.576	26.731	26.887	27.045	27.205	27.367	27.530	27.696	27.864	
—.204		26.295	26.447	26.600	26.756	26.913	27.072	27.233	27.396	27.561	27.728	
—.203		26.167	26.318	26.470	26.625	26.782	26.940	27.100	27.262	27.426	27.592	
—.202		26.038	26.188	26.340	26.494	26.650	26.807	26.967	27.128	27.292	27.457	
—.201		25.909	26.059	26.210	26.363	26.518	26.675	26.834	26.994	27.157	27.321	
—.200		25.781	25.930	26.080	26.233	26.387	26.543	26.701	26.860	27.022	27.186	
—.199		25.652	25.800	25.950	26.102	26.255	26.410	26.568	26.726	26.887	27.050	
—.198		25.524	25.671	25.820	25.971	26.123	26.278	26.434	26.592	26.753	26.915	
—.197		25.395	25.542	25.690	25.840	25.992	26.146	26.301	26.458	26.618	26.779	
		115.0°F	*114.5°F*	*114.0°F*	*113.5°F*	*113.0°F*	*112.5°F*	*112.0°F*	*111.5°F*	*111.0°F*	*110.5°F*	

TABLE 5.4.1—Page 2B

Barometer Total Correction Table

TEMP. 115.0-110.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*115.0°F*	*114.5°F*	*114.0°F*	*113.5°F*	*113.0°F*	*112.5°F*	*112.0°F*	*111.5°F*	*111.0°F*	*110.5°F*	Total Corr. in.
—.196		25.266	25.412	25.560	25.709	25.860	26.013	26.168	26.324	26.483	26.643	
—.195		25.138	25.283	25.430	25.578	25.729	25.881	26.035	26.190	26.348	26.508	
—.194		25.009	25.154	25.300	25.447	25.597	25.748	25.902	26.056	26.213	26.372	
—.193		24.881	25.024	25.170	25.317	25.465	25.616	25.768	25.923	26.079	26.237	
—.192		24.752	24.895	25.040	25.186	25.334	25.484	25.635	25.789	25.944	26.101	
—.191		24.624	24.766	24.909	25.055	25.202	25.351	25.502	25.655	25.809	25.965	
—.190		24.495	24.636	24.779	24.924	25.071	25.219	25.369	25.521	25.674	25.830	
—.189		24.366	24.507	24.649	24.793	24.939	25.086	25.236	25.387	25.540	25.694	
—.188		24.238	24.378	24.519	24.662	24.807	24.954	25.103	25.253	25.405	25.559	
—.187		24.109	24.249	24.389	24.532	24.676	24.822	24.969	25.119	25.270	25.423	
—.186		23.981	24.119	24.259	24.401	24.544	24.689	24.836	24.985	25.135	25.287	
—.185		23.852	23.990	24.129	24.270	24.413	24.557	24.703	24.851	25.000	25.152	
—.184		23.723	23.861	23.999	24.139	24.281	24.425	24.570	24.717	24.866	25.016	
—.183		23.595	23.731	23.869	24.008	24.149	24.292	24.437	24.583	24.731	24.881	
—.182		23.466	23.602	23.739	23.877	24.018	24.160	24.304	24.449	24.596	24.745	
—.181		23.338	23.473	23.609	23.747	23.886	24.027	24.170	24.315	24.461	24.609	
—.180		23.209	23.343	23.479	23.616	23.755	23.895	24.037	24.181	24.327	24.474	
—.179		23.081	23.214	23.349	23.485	23.623	23.763	23.904	24.047	24.192	24.338	
—.178		22.952	23.085	23.218	23.354	23.491	23.630	23.771	23.913	24.057	24.203	
—.177		22.823	22.955	23.088	23.223	23.360	23.498	23.638	23.779	23.922	24.067	
—.176		22.695	22.826	22.958	23.092	23.228	23.365	23.505	23.645	23.787	23.931	
—.175		22.566	22.697	22.828	22.962	23.097	23.233	23.371	23.511	23.653	23.796	
—.174		22.438	22.567	22.698	22.831	22.965	23.101	23.238	23.377	23.518	23.660	
—.173		22.309	22.438	22.568	22.700	22.833	22.968	23.105	23.243	23.383	23.525	
—.172		22.180	22.309	22.438	22.569	22.702	22.836	22.972	23.109	23.248	23.389	
—.171		22.052	22.179	22.308	22.438	22.570	22.704	22.839	22.975	23.114	23.254	
—.170		21.923	22.050	22.178	22.307	22.438	22.571	22.705	22.841	22.979	23.118	
—.169		21.795	21.921	22.048	22.177	22.307	22.439	22.572	22.707	22.844	22.982	
—.168		21.666	21.791	21.918	22.046	22.175	22.306	22.439	22.573	22.709	22.847	
—.167		21.537	21.662	21.788	21.915	22.044	22.174	22.306	22.439	22.574	22.711	
—.166		21.409	21.533	21.657	21.784	21.912	22.042	22.173	22.305	22.440	22.576	
—.165		21.280	21.403	21.527	21.653	21.780	21.909	22.040	22.171	22.305	22.440	
—.164		21.152	21.274	21.397	21.522	21.649	21.777	21.906	22.037	22.170	22.304	
—.163		21.023	21.145	21.267	21.392	21.517	21.644	21.773	21.903	22.035	22.169	
—.162		20.895	21.015	21.137	21.261	21.386	21.512	21.640	21.769	21.901	22.033	
—.161		....	20.886	21.007	21.130	21.254	21.380	21.507	21.635	21.766	21.898	
—.160		....	....	20.877	20.999	21.122	21.247	21.374	21.502	21.631	21.762	
—.159		....	....	....	20.868	20.991	21.115	21.241	21.368	21.496	21.626	
—.158		....	....	....	....	20.859	20.983	21.107	21.234	21.361	21.491	
—.157		....	....	....	....	....	20.850	20.974	21.100	21.227	21.355	
—.156		....	....	....	....	....	....	20.841	20.966	21.092	21.220	
—.155		....	....	....	....	....	....	....	20.832	20.957	21.084	
—.154		....	....	....	....	....	....	....	....	20.822	20.948	
—.153		....	....	....	....	....	....	....	....	....	20.813	
		115.0°F	*114.5°F*	*114.0°F*	*113.5°F*	*113.0°F*	*112.5°F*	*112.0°F*	*111.5°F*	*111.0°F*	*110.5°F*	

TABLE 5.4.1—Page 3A

Barometer Total Correction Table

TEMP. 110.0-105.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. ________ Sum of Corrections ________ Date ________

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*110.0°F*	*109.5°F*	*109.0°F*	*108.5°F*	*108.0°F*	*107.5°F*	*107.0°F*	*106.5°F*	*106.0°F*	*105.5°F*	Total Corr. in.
—.231		31.580										
—.230		31.444										
—.229		31.308	31.500									
—.228		31.171	31.362	31.556								
—.227		31.035	31.225	31.417	31.613							
—.226		30.898	31.088	31.279	31.474							
—.225		30.762	30.951	31.141	31.335	31.530						
—.224		30.626	30.813	31.003	31.196	31.391	31.588					
—.223		30.489	30.676	30.865	31.057	31.251	31.448					
—.222		30.353	30.539	30.727	30.918	31.111	31.307	31.505				
—.221		30.216	30.401	30.589	30.779	30.971	31.166	31.363	31.563			
—.220		30.080	30.264	30.451	30.640	30.831	31.025	31.222	31.421	31.622		
—.219		29.943	30.127	30.313	30.501	30.692	30.885	31.080	31.278	31.479		
—.218		29.807	29.990	30.175	30.362	30.552	30.744	30.939	31.136	31.335	31.537	
—.217		29.671	29.852	30.036	30.223	30.412	30.603	30.797	30.993	31.192	31.393	
—.216		29.534	29.715	29.898	30.084	30.272	30.463	30.655	30.851	31.048	31.249	
—.215		29.398	29.578	29.760	29.945	30.132	30.322	30.514	30.708	30.905	31.104	
—.214		29.261	29.441	29.622	29.806	29.992	30.181	30.372	30.566	30.762	30.960	
—.213		29.125	29.303	29.484	29.667	29.853	30.040	30.231	30.423	30.618	30.816	
—.212		28.989	29.166	29.346	29.529	29.713	29.900	30.089	30.281	30.475	30.671	
—.211		28.852	29.029	29.208	29.390	29.573	29.759	29.947	30.138	30.331	30.527	
—.210		28.716	28.892	29.070	29.251	29.433	29.618	29.806	29.996	30.188	30.383	
—.209		28.579	28.754	28.932	29.112	29.293	29.478	29.664	29.853	30.045	30.238	
—.208		28.443	28.617	28.794	28.973	29.153	29.337	29.523	29.711	29.901	30.094	
—.207		28.306	28.480	28.655	28.834	29.014	29.196	29.381	29.568	29.758	29.950	
—.206		28.170	28.343	28.517	28.695	28.874	29.055	29.239	29.426	29.614	29.805	
—.205		28.034	28.205	28.379	28.556	28.734	28.915	29.098	29.283	29.471	29.661	
—.204		27.897	28.068	28.241	28.417	28.594	28.774	28.956	29.141	29.327	29.517	
—.203		27.761	27.931	28.103	28.278	28.454	28.633	28.815	28.998	29.184	29.372	
—.202		27.624	27.794	27.965	28.139	28.314	28.493	28.673	28.856	29.041	29.228	
—.201		27.488	27.656	27.827	28.000	28.175	28.352	28.531	28.713	28.897	29.084	
—.200		27.352	27.519	27.689	27.861	28.035	28.211	28.390	28.571	28.754	28.939	
—.199		27.215	27.382	27.551	27.722	27.895	28.071	28.248	28.428	28.610	28.795	
—.198		27.079	27.245	27.413	27.583	27.755	27.930	28.107	28.286	28.467	28.651	
—.197		26.942	27.107	27.274	27.444	27.615	27.789	27.965	28.143	28.324	28.506	
—.196		26.806	26.970	27.136	27.305	27.476	27.648	27.824	28.001	28.180	28.362	
—.195		26.669	26.833	26.998	27.166	27.336	27.508	27.682	27.858	28.037	28.218	
—.194		26.533	26.696	26.860	27.027	27.196	27.367	27.540	27.716	27.893	28.073	
—.193		26.397	26.558	26.722	26.888	27.056	27.226	27.399	27.573	27.750	27.929	
—.192		26.260	26.421	26.584	26.749	26.916	27.086	27.257	27.431	27.607	27.785	
—.191		26.124	26.284	26.446	26.610	26.776	26.945	27.116	27.288	27.463	27.640	
—.190		25.987	26.147	26.308	26.471	26.637	26.804	26.974	27.146	27.320	27.496	
—.189		25.851	26.009	26.170	26.332	26.497	26.663	26.832	27.003	27.176	27.352	
—.188		25.714	25.872	26.032	26.193	26.357	26.523	26.691	26.861	27.033	27.207	
—.187		25.578	25.735	25.893	26.055	26.217	26.382	26.549	26.718	26.889	27.063	
—.186		25.442	25.598	25.755	25.916	26.077	26.241	26.408	26.576	26.746	26.919	
—.185		25.305	25.460	25.617	25.777	25.937	26.101	26.266	26.433	26.603	26.774	
—.184		25.169	25.323	25.479	25.638	25.798	25.960	26.124	26.291	26.459	26.630	
—.183		25.032	25.186	25.341	25.499	25.658	25.819	25.983	26.148	26.316	26.486	
		110.0°F	*109.5°F*	*109.0°F*	*108.5°F*	*108.0°F*	*107.5°F*	*107.0°F*	*106.5°F*	*106.0°F*	*105.5°F*	

TABLE 5.4.1—Page 3B

Barometer Total Correction Table

TEMP. 110.0–105.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*110.0°F*	*109.5°F*	*109.0°F*	*108.5°F*	*108.0°F*	*107.5°F*	*107.0°F*	*106.5°F*	*106.0°F*	*105.5°F*	Total Corr. in.
—.187		25.578	25.735	25.893	26.055	26.217	26.382	26.549	26.718	26.889	27.063	
—.186		25.442	25.598	25.755	25.916	26.077	26.241	26.408	26.576	26.746	26.919	
—.185		25.305	25.460	25.617	25.777	25.937	26.101	26.266	26.433	26.603	26.774	
—.184		25.169	25.323	25.479	25.638	25.798	25.960	26.124	26.291	26.459	26.630	
—.183		25.032	25.186	25.341	25.499	25.658	25.819	25.983	26.148	26.316	26.486	
—.182		24.896	25.049	25.203	25.360	25.518	25.679	25.841	26.006	26.172	26.341	
—.181		24.760	24.911	25.065	25.221	25.378	25.538	25.700	25.863	26.029	26.197	
—.180		24.623	24.774	24.927	25.082	25.238	25.397	25.558	25.721	25.886	26.053	
—.179		24.487	24.637	24.789	24.943	25.098	25.256	25.416	25.578	25.742	25.908	
—.178		24.350	24.500	24.651	24.804	24.959	25.116	25.275	25.436	25.599	25.764	
—.177		24.214	24.362	24.512	24.665	24.819	24.975	25.133	25.293	25.455	25.619	
—.176		24.077	24.225	24.374	24.526	24.679	24.834	24.992	25.151	25.312	25.475	
—.175		23.941	24.088	24.236	24.387	24.539	24.694	24.850	25.008	25.168	25.331	
—.174		23.805	23.950	24.098	24.248	24.399	24.553	24.708	24.866	25.025	25.186	
—.173		23.668	23.813	23.960	24.109	24.259	24.412	24.567	24.723	24.882	25.042	
—.172		23.532	23.676	23.822	23.970	24.120	24.271	24.425	24.581	24.738	24.898	
—.171		23.395	23.539	23.684	23.831	23.980	24.131	24.284	24.438	24.595	24.753	
—.170		23.259	23.401	23.546	23.692	23.840	23.990	24.142	24.296	24.451	24.609	
—.169		23.123	23.264	23.408	23.553	23.700	23.849	24.000	24.153	24.308	24.465	
—.168		22.986	23.127	23.270	23.414	23.560	23.709	23.859	24.011	24.165	24.320	
—.167		22.850	22.990	23.131	23.275	23.421	23.568	23.717	23.868	24.021	24.176	
—.166		22.713	22.852	22.993	23.136	23.281	23.427	23.576	23.726	23.878	24.032	
—.165		22.577	22.715	22.855	22.997	23.141	23.287	23.434	23.583	23.734	23.887	
—.164		22.440	22.578	22.717	22.858	23.001	23.146	23.292	23.441	23.591	23.743	
—.163		22.304	22.441	22.579	22.719	22.861	23.005	23.151	23.298	23.448	23.599	
—.162		22.168	22.303	22.441	22.581	22.721	22.864	23.009	23.156	23.304	23.454	
—.161		22.031	22.166	22.303	22.442	22.582	22.724	22.868	23.013	23.161	23.310	
—.160		21.895	22.029	22.165	22.303	22.442	22.583	22.726	22.871	23.017	23.166	
—.159		21.758	21.892	22.027	22.164	22.302	22.442	22.584	22.728	22.874	23.021	
—.158		21.622	21.754	21.889	22.025	22.162	22.302	22.443	22.586	22.730	22.877	
—.157		21.485	21.617	21.750	21.886	22.022	22.161	22.301	22.443	22.587	22.733	
—.156		21.349	21.480	21.612	21.747	21.882	22.020	22.160	22.301	22.444	22.588	
—.155		21.213	21.343	21.474	21.608	21.743	21.879	22.018	22.158	22.300	22.444	
—.154		21.076	21.205	21.336	21.469	21.603	21.739	21.876	22.016	22.157	22.300	
—.153		20.940	21.068	21.198	21.330	21.463	21.598	21.735	21.873	22.013	22.155	
—.152		20.803	20.931	21.060	21.191	21.323	21.457	21.593	21.731	21.870	22.011	
—.151		....	20.794	20.922	21.052	21.183	21.317	21.452	21.588	21.727	21.867	
—.150		....	....	20.784	20.913	21.043	21.176	21.310	21.446	21.583	21.722	
—.149		....	....	....	20.774	20.904	21.035	21.168	21.303	21.440	21.578	
—.148		....	....	....	....	20.764	20.894	21.027	21.161	21.296	21.434	
—.147		....	....	....	....	....	....	20.885	21.018	21.153	21.289	
—.146		....	....	....	....	....	....	....	20.876	21.010	21.145	
—.145		....	....	....	....	....	....	....	....	20.866	21.001	
—.144		....	....	....	....	....	....	....	....	....	20.856	
		110.0°F	*109.5°F*	*109.0°F*	*108.5°F*	*108.0°F*	*107.5°F*	*107.0°F*	*106.5°F*	*106.0°F*	*105.5°F*	

TABLE 5.4.1—Page 4A

Barometer Total Correction Table

TEMP. 105 0–100.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.											Total Corr. in.
		105.0°F										
—.217		31.597	*104.5°F*									
—.216		31.452	....	*104.0°F*	....	....	....	....	....	....	....	
—.215		31.307	31.511	....	*103.5°F*	....	....	....	....	....	....	
—.214		31.161	31.365	31.572	....	....	....	....	....	....	....	
—.213		31.016	31.219	31.425	31.633	*103.0°F*	....	....	....	....	....	
—.212		30.871	31.073	31.277	31.485	....	*102.5°F*	....	....	....	....	
—.211		30.726	30.926	31.130	31.336	31.546	....	....	....	....	....	
—.210		30.580	30.780	30.983	31.188	31.396	31.607	*102.0°F*	....	....	....	
—.209		30.435	30.634	30.836	31.040	31.247	31.457	....	*101.5°F*	....	....	
—.208		30.290	30.488	30.689	30.892	31.098	31.307	31.519	....	*101.0°F*	....	
—.207		30.144	30.341	30.541	30.744	30.949	31.157	31.368	31.581	....	....	
—.206		29.999	30.195	30.394	30.596	30.800	31.007	31.217	31.429	31.644	*100.5°F*	
—.205		29.854	30.049	30.247	30.447	30.651	30.857	31.065	31.277	31.491	....	
—.204		29.709	29.903	30.100	30.299	30.501	30.706	30.914	31.125	31.338	31.555	
—.203		29.563	29.756	29.953	30.151	30.352	30.556	30.763	30.972	31.185	31.400	
—.202		29.418	29.610	29.805	30.003	30.203	30.406	30.612	30.820	31.031	31.246	
—.201		29.273	29.464	29.658	29.855	30.054	30.256	30.461	30.668	30.878	31.092	
—.200		29.128	29.318	29.511	29.707	29.905	30.106	30.309	30.516	30.725	30.937	
—.199		28.982	29.172	29.364	29.558	29.756	29.956	30.158	30.364	30.572	30.783	
—.198		28.837	29.025	29.217	29.410	29.607	29.805	30.007	30.211	30.418	30.629	
—.197		28.692	28.879	29.070	29.262	29.457	29.655	29.856	30.059	30.265	30.475	
—.196		28.546	28.733	28.922	29.114	29.308	29.505	29.705	29.907	30.112	30.320	
—.195		28.401	28.587	28.775	28.966	29.159	29.355	29.554	29.755	29.959	30.166	
—.194		28.256	28.440	28.628	28.818	29.010	29.205	29.402	29.603	29.805	30.012	
—.193		28.111	28.294	28.481	28.669	28.861	29.055	29.251	29.450	29.652	29.857	
—.192		27.965	28.148	28.334	28.521	28.712	28.905	29.100	29.298	29.499	29.703	
—.191		27.820	28.002	28.186	28.373	28.562	28.754	28.949	29.146	29.346	29.549	
—.190		27.675	27.856	28.039	28.225	28.413	28.604	28.798	28.994	29.192	29.394	
—.189		27.529	27.709	27.892	28.077	28.264	28.454	28.647	28.842	29.039	29.240	
—.188		27.384	27.563	27.745	27.929	28.115	28.304	28.495	28.689	28.886	29.086	
—.187		27.239	27.417	27.598	27.780	27.966	28.154	28.344	28.537	28.733	28.932	
—.186		27.094	27.271	27.450	27.632	27.817	28.004	28.193	28.385	28.580	28.777	
—.185		26.948	27.124	27.303	27.484	27.668	27.853	28.042	28.233	28.426	28.623	
—.184		26.803	26.978	27.156	27.336	27.518	27.703	27.891	28.081	28.273	28.469	
—.183		26.658	26.832	27.009	27.188	27.369	27.553	27.740	27.928	28.120	28.314	
—.182		26.513	26.686	26.862	27.040	27.220	27.403	27.588	27.776	27.967	28.160	
—.181		26.367	26.540	26.714	26.891	27.071	27.253	27.437	27.624	27.813	28.006	
—.180		26.222	26.393	26.567	26.743	26.922	27.103	27.286	27.472	27.660	27.851	
—.179		26.077	26.247	26.420	26.595	26.773	26.953	27.135	27.320	27.507	27.697	
—.178		25.931	26.101	26.273	26.447	26.623	26.802	26.984	27.167	27.354	27.543	
—.177		25.786	25.955	26.126	26.299	26.474	26.652	26.833	27.015	27.200	27.388	
—.176		25.641	25.808	25.979	26.151	26.325	26.502	26.681	26.863	27.047	27.234	
—.175		25.496	25.662	25.831	26.002	26.176	26.352	26.530	26.711	26.894	27.080	
—.174		25.350	25.516	25.684	25.854	26.027	26.202	26.379	26.559	26.741	26.926	
—.173		25.205	25.370	25.537	25.706	25.878	26.052	26.228	26.406	26.587	26.771	
—.172		25.060	25.223	25.390	25.558	25.729	25.901	26.077	26.254	26.434	26.617	
—.171		24.915	25.077	25.243	25.410	25.579	25.751	25.925	26.102	26.281	26.463	
—.170		24.769	24.931	25.095	25.262	25.430	25.601	25.774	25.950	26.128	26.308	
—.169		24.624	24.785	24.948	25.113	25.281	25.451	25.623	25.798	25.974	26.154	
		105.0°F	*104.5°F*	*104.0°F*	*103.5°F*	*103.0°F*	*102.5°F*	*102.0°F*	*101.5°F*	*101.0°F*	*100.5°F*	

TABLE 5.4.1—Page 4B *Barometer Total Correction Table* **TEMP. 105.0–100.5°F**

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*105.0°F*	*104.5°F*	*104.0°F*	*103.5°F*	*103.0°F*	*102.5°F*	*102.0°F*	*101.5°F*	*101.0°F*	*100.5°F*	Total Corr. in.
—.173		25.205	25.370	25.537	25.706	25.878	26.052	26.228	26.406	26.587	26.771	
—.172		25.060	25.223	25.390	25.558	25.729	25.901	26.077	26.254	26.434	26.617	
—.171		24.915	25.077	25.243	25.410	25.579	25.751	25.925	26.102	26.281	26.463	
—.170		24.769	24.931	25.095	25.262	25.430	25.601	25.774	25.950	26.128	26.308	
—.169		24.624	24.785	24.948	25.113	25.281	25.451	25.623	25.798	25.974	26.154	
—.168		24.479	24.639	24.801	24.965	25.132	25.301	25.472	25.645	25.821	26.000	
—.167		24.333	24.492	24.654	24.817	24.983	25.151	25.321	25.493	25.668	25.845	
—.166		24.188	24.346	24.507	24.669	24.834	25.000	25.170	25.341	25.515	25.691	
—.165		24.043	24.200	24.359	24.521	24.684	24.850	25.018	25.189	25.361	25.537	
—.164		23.898	24.054	24.212	24.373	24.535	24.700	24.867	25.037	25.208	25.383	
—.163		23.752	23.907	24.065	24.224	24.386	24.550	24.716	24.884	25.055	25.228	
—.162		23.607	23.761	23.918	24.076	24.237	24.400	24.565	24.732	24.902	25.074	
—.161		23.462	23.615	23.771	23.928	24.088	24.250	24.414	24.580	24.748	24.920	
—.160		23.316	23.469	23.623	23.780	23.939	24.100	24.263	24.428	24.595	24.765	
—.159		23.171	23.323	23.476	23.632	23.790	23.949	24.111	24.276	24.442	24.611	
—.158		23.026	23.176	23.329	23.484	23.640	23.799	23.960	24.123	24.289	24.457	
—.157		22.881	23.030	23.182	23.335	23.491	23.649	23.809	23.971	24.135	24.302	
—.156		22.735	22.884	23.035	23.187	23.342	23.499	23.658	23.819	23.982	24.148	
—.155		22.590	22.738	22.888	23.039	23.193	23.349	23.507	23.667	23.829	23.994	
—.154		22.445	22.591	22.740	22.891	23.044	23.199	23.356	23.515	23.676	23.839	
—.153		22.300	22.445	22.593	22.743	22.895	23.048	23.204	23.362	23.522	23.685	
—.152		22.154	22.299	22.446	22.595	22.745	22.898	23.053	23.210	23.369	23.531	
—.151		22.009	22.153	22.299	22.446	22.596	22.748	22.902	23.058	23.216	23.377	
—.150		21.864	22.007	22.152	22.298	22.447	22.598	22.751	22.906	23.063	23.222	
—.149		21.718	21.860	22.004	22.150	22.298	22.448	22.600	22.754	22.909	23.068	
—.148		21.573	21.714	21.857	22.002	22.149	22.298	22.449	22.601	22.756	22.914	
—.147		21.428	21.568	21.710	21.854	22.000	22.148	22.297	22.449	22.603	22.759	
—.146		21.283	21.422	21.563	21.706	21.851	21.997	22.146	22.297	22.450	22.605	
—.145		21.137	21.275	21.416	21.558	21.701	21.847	21.995	22.145	22.297	22.451	
—.144		20.992	21.129	21.268	21.409	21.552	21.697	21.844	21.993	22.143	22.296	
—.143		20.847	20.983	21.121	21.261	21.403	21.547	21.693	21.840	21.990	22.142	
—.142		....	20.837	20.974	21.113	21.254	21.397	21.542	21.688	21.837	21.988	
—.141		....	....	20.827	20.965	21.105	21.247	21.390	21.536	21.684	21.834	
—.140		....	....	....	20.817	20.956	21.096	21.239	21.384	21.530	21.679	
—.139		....	....	....	....	20.806	20.946	21.088	21.232	21.377	21.525	
—.138		....	....	....	....	....	20.796	20.937	21.079	21.224	21.371	
—.137		....	....	....	....	....	....	20.786	20.927	21.071	21.216	
—.136		....	....	....	....	....	....	....	20.775	20.917	21.062	
—.135		....	....	....	....	....	....	....	....	20.764	20.908	
—.134		....	....	....	....	....	....	....	....	....	20.753	
		105.0°F	*104.5°F*	*104.0°F*	*103.5°F*	*103.0°F*	*102.5°F*	*102.0°F*	*101.5°F*	*101.0°F*	*100.5°F*	

TABLE 5.4.1—Page 5A

Barometer Total Correction Table

TEMP. 100.0–95.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. ____________ Sum of Corrections ____________ Date ____________

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.											Total Corr. in.
		100.0°F										
—.203		31.619	*99.5°F*									
—.202		31.463	-----	*99.0°F*	-----	-----	-----	-----	-----	-----	-----	
—.201		31.308	31.527	-----	*98.5°F*	-----	-----	-----	-----	-----	-----	
—.200		31.152	31.371	31.592	-----	-----	-----	-----	-----	-----	-----	
—.199		30.997	31.214	31.435	31.658	*98.0°F*	-----	-----	-----	-----	-----	
—.198		30.842	31.058	31.277	31.499	-----	*97.5°F*	-----	-----	-----	-----	
—.197		30.686	30.901	31.119	31.341	31.565	-----	-----	-----	-----	-----	
—.196		30.531	30.745	30.962	31.182	31.405	31.631	*97.0°F*	-----	-----	-----	
—.195		30.376	30.588	30.804	31.023	31.245	31.470	-----	*96.5°F*	-----	-----	
—.194		30.220	30.432	30.647	30.865	31.085	31.309	31.537	-----	-----	-----	
—.193		30.065	30.275	30.489	30.706	30.925	31.148	31.375	31.604	*96.0°F*	-----	
—.192		29.909	30.119	30.332	30.547	30.766	30.987	31.213	31.441	-----	*95.5°F*	
—.191		29.754	29.963	30.174	30.388	30.606	30.826	31.050	31.277	31.508	-----	
—.190		29.599	29.806	30.016	30.230	30.446	30.665	30.888	31.114	31.344	31.576	
—.189		29.443	29.650	29.859	30.071	30.286	30.504	30.726	30.951	31.179	31.410	
—.188		29.288	29.493	29.701	29.912	30.126	30.343	30.564	30.787	31.015	31.245	
—.187		29.133	29.337	29.544	29.754	29.967	30.183	30.402	30.624	30.850	31.079	
—.186		28.977	29.180	29.386	29.595	29.807	30.022	30.240	30.461	30.685	30.913	
—.185		28.822	29.024	29.229	29.436	29.647	29.861	30.078	30.297	30.521	30.747	
—.184		28.666	28.867	29.071	29.278	29.487	29.700	29.915	30.134	30.356	30.582	
—.183		28.511	28.711	28.913	29.119	29.327	29.539	29.753	29.971	30.192	30.416	
—.182		28.356	28.554	28.756	28.960	29.167	29.378	29.591	29.807	30.027	30.250	
—.181		28.200	28.398	28.598	28.802	29.008	29.217	29.429	29.644	29.863	30.084	
—.180		28.045	28.241	28.441	28.643	28.848	29.056	29.267	29.481	29.698	29.919	
—.179		27.889	28.085	28.283	28.484	28.688	28.895	29.105	29.317	29.534	29.753	
—.178		27.734	27.929	28.126	28.325	28.528	28.734	28.943	29.154	29.369	29.587	
—.177		27.579	27.772	27.968	28.167	28.368	28.573	28.780	28.991	29.205	29.421	
—.176		27.423	27.616	27.810	28.008	28.208	28.412	28.618	28.827	29.040	29.256	
—.175		27.268	27.459	27.653	27.849	28.049	28.251	28.456	28.664	28.876	29.090	
—.174		27.113	27.303	27.495	27.691	27.889	28.090	28.294	28.501	28.711	28.924	
—.173		26.957	27.146	27.338	27.532	27.729	27.929	28.132	28.337	28.546	28.758	
—.172		26.802	26.990	27.180	27.373	27.569	27.768	27.970	28.174	28.382	28.593	
—.171		26.646	26.833	27.023	27.215	27.409	27.607	27.808	28.011	28.217	28.427	
—.170		26.491	26.677	26.865	27.056	27.249	27.446	27.645	27.847	28.053	28.261	
—.169		26.336	26.520	26.707	26.897	27.090	27.285	27.483	27.684	27.888	28.095	
—.168		26.180	26.364	26.550	26.739	26.930	27.124	27.321	27.521	27.724	27.930	
—.167		26.025	26.207	26.392	26.580	26.770	26.963	27.159	27.357	27.559	27.764	
—.166		25.870	26.051	26.235	26.421	26.610	26.802	26.997	27.194	27.395	27.598	
—.165		25.714	25.894	26.077	26.263	26.450	26.641	26.835	27.031	27.230	27.432	
—.164		25.559	25.738	25.920	26.104	26.291	26.480	26.673	26.867	27.066	27.267	
—.163		25.403	25.582	25.762	25.945	26.131	26.319	26.510	26.704	26.901	27.101	
—.162		25.248	25.425	25.604	25.786	25.971	26.158	26.348	26.541	26.737	26.935	
—.161		25.093	25.269	25.447	25.628	25.811	25.997	26.186	26.377	26.572	26.769	
—.160		24.937	25.112	25.289	25.469	25.651	25.836	26.024	26.214	26.408	26.603	
—.159		24.782	24.956	25.132	25.310	25.491	25.675	25.862	26.051	26.243	26.438	
—.158		24.627	24.799	24.974	25.152	25.332	25.514	25.700	25.887	26.078	26.272	
—.157		24.471	24.643	24.817	24.993	25.172	25.353	25.537	25.724	25.914	26.106	
—.156		24.316	24.486	24.659	24.834	25.012	25.192	25.375	25.561	25.749	25.940	
—.155		24.160	24.330	24.501	24.676	24.852	25.031	25.213	25.397	25.585	25.755	
		100.0°F	*99.5°F*	*99.0°F*	*98.5°F*	*98.0°F*	*97.5°F*	*97.0°F*	*96.5°F*	*96.0°F*	*95.5°F*	

TABLE 5.4.1—Page 5B

Barometer Total Correction Table

TEMP. 100.0–95.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*100.0°F*	*99.5°F*	*99.0°F*	*98.5°F*	*98.0°F*	*97.5°F*	*97.0°F*	*96.5°F*	*96.0°F*	*95.5°F*	Total Corr. in.
—.159		24.782	24.956	25.132	25.310	25.491	25.675	25.862	26.051	26.243	26.438	
—.158		24.627	24.799	24.974	25.152	25.332	25.514	25.700	25.887	26.078	26.272	
—.157		24.471	24.643	24.817	24.993	25.172	25.353	25.537	25.724	25.914	26.106	
—.156		24.316	24.486	24.659	24.834	25.012	25.192	25.375	25.561	25.749	25.940	
—.155		24.160	24.330	24.501	24.676	24.852	25.031	25.213	25.397	25.585	25.775	
—.154		24.005	24.173	24.344	24.517	24.692	24.870	25.051	25.234	25.420	25.609	
—.153		23.850	24.017	24.186	24.358	24.532	24.709	24.889	25.071	25.256	25.443	
—.152		23.694	23.860	24.029	24.200	24.373	24.548	24.727	24.907	25.091	25.277	
—.151		23.539	23.704	23.871	24.041	24.213	24.387	24.565	24.744	24.927	25.112	
—.150		23.384	23.547	23.714	23.882	24.053	24.226	24.402	24.581	24.762	24.946	
—.149		23.228	23.391	23.556	23.724	23.893	24.065	24.240	24.417	24.598	24.780	
—.148		23.073	23.235	23.398	23.565	23.733	23.904	24.078	24.254	24.433	24.614	
—.147		22.917	23.078	23.241	23.406	23.574	23.743	23.916	24.091	24.269	24.449	
—.146		22.762	22.922	23.083	23.247	23.414	23.582	23.754	23.927	24.104	24.283	
—.145		22.607	22.765	22.926	23.089	23.254	23.422	23.592	23.764	23.939	24.117	
—.144		22.451	22.609	22.768	22.930	23.094	23.261	23.430	23.601	23.775	23.951	
—.143		22.296	22.452	22.611	22.771	22.934	23.100	23.267	23.437	23.610	23.786	
—.142		22.141	22.296	22.453	22.613	22.774	22.939	23.105	23.274	23.446	23.620	
—.141		21.985	22.139	22.296	22.454	22.615	22.778	22.943	23.111	23.281	23.454	
—.140		21.830	21.983	22.138	22.295	22.455	22.617	22.781	22.948	23.117	23.288	
—.139		21.674	21.826	21.980	22.137	22.295	22.456	22.619	22.784	22.952	23.123	
—.138		21.519	21.670	21.823	21.978	22.135	22.295	22.457	22.621	22.788	22.957	
—.137		21.364	21.513	21.665	21.819	21.975	22.134	22.295	22.458	22.623	22.791	
—.136		21.208	21.357	21.508	21.661	21.815	21.973	22.132	22.294	22.459	22.625	
—.135		21.053	21.201	21.350	21.502	21.656	21.812	21.970	22.131	22.294	22.460	
—.134		20.898	21.044	21.193	21.343	21.496	21.651	21.808	21.968	22.130	22.294	
—.133		....	20.888	21.035	21.184	21.336	21.490	21.646	21.804	21.965	22.128	
—.132		....	....	20.877	21.026	21.176	21.329	21.484	21.641	21.801	21.962	
—.131		....	....	....	20.867	21.016	21.168	21.322	21.478	21.636	21.797	
—.130		....	....	....	....	20.857	21.007	21.160	21.314	21.471	21.631	
—.129		....	....	....	....	....	20.846	20.997	21.151	21.307	21.465	
—.128		....	....	....	....	....	....	20.835	20.988	21.142	21.299	
—.127		....	....	....	....	....	....	....	20.824	20.978	21.134	
—.126		....	....	....	....	....	....	....	....	20.813	20.968	
—.125		....	....	....	....	....	....	....	....	....	20.802	
		100.0°F	*99.5°F*	*99.0°F*	*98.5°F*	*98.0°F*	*97.5°F*	*97.0°F*	*96.5°F*	*96.0°F*	*95.5°F*	

TABLE 5.4.1—Page 6A

Barometer Total Correction Table

TEMP. 95.0–90.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*95.0°F*										Total Corr. in.
—.189		31.646	*94.5°F*									
—.188		31.479	....	*94.0°F*	....	....	....	....	....	....	....	
—.187		31.312	31.548	....	....	....	....	....	....	....	....	
—.186		31.145	31.379	31.618	*93.5°F*	....	....	....	....	....	....	
—.185		30.978	31.211	31.448	....	*93.0°F*	....	....	....	....	....	
—.184		30.811	31.043	31.279	31.518	....	*92.5°F*	....	....	....	....	
—.183		30.644	30.875	31.109	31.348	31.589	....	....	....	....	....	
—.182		30.477	30.706	30.940	31.177	31.417	31.662	*92.0°F*	....	....	....	
—.181		30.310	30.538	30.770	31.006	31.245	31.488	....	*91.5°F*	....	....	
—.180		30.143	30.370	30.601	30.835	31.073	31.315	31.560	....	....	....	
—.179		29.976	30.202	30.431	30.664	30.901	31.141	31.385	31.633	*91.0°F*	....	
—.178		29.809	30.033	30.262	30.493	30.729	30.968	31.210	31.457	....	*90.5°F*	
—.177		29.642	29.865	30.092	30.323	30.556	30.794	31.036	31.281	31.530	....	
—.176		29.475	29.697	29.923	30.152	30.384	30.621	30.861	31.105	31.352	31.604	
—.175		29.308	29.529	29.753	29.981	30.212	30.447	30.686	30.928	31.175	31.425	
—.174		29.141	29.360	29.584	29.810	30.040	30.274	30.511	30.752	30.997	31.246	
—.173		28.974	29.192	29.414	29.639	29.868	30.100	30.336	30.576	30.820	31.067	
—.172		28.807	29.024	29.244	29.468	29.696	29.927	30.161	30.400	30.642	30.888	
—.171		28.640	28.856	29.075	29.298	29.524	29.753	29.986	30.223	30.464	30.709	
—.170		28.473	28.687	28.905	29.127	29.351	29.580	29.812	30.047	30.287	30.530	
—.169		28.306	28.519	28.736	28.956	29.179	29.406	29.637	29.871	30.109	30.351	
—.168		28.139	28.351	28.566	28.785	29.007	29.233	29.462	29.695	29.931	30.172	
—.167		27.972	28.183	28.397	28.614	28.835	29.059	29.287	29.519	29.754	29.993	
—.166		27.805	28.014	28.227	28.443	28.663	28.886	29.112	29.342	29.576	29.814	
—.165		27.638	27.846	28.058	28.273	28.491	28.712	28.937	29.166	29.398	29.635	
—.164		27.471	27.678	27.888	28.102	28.319	28.539	28.762	28.990	29.221	29.456	
—.163		27.304	27.510	27.719	27.931	28.146	28.365	28.588	28.814	29.043	29.276	
—.162		27.137	27.341	27.549	27.760	27.974	28.192	28.413	28.637	28.866	29.097	
—.161		26.970	27.173	27.380	27.589	27.802	28.018	28.238	28.461	28.688	28.918	
—.160		26.803	27.005	27.210	27.418	27.630	27.845	28.063	28.285	28.510	28.739	
—.159		26.636	26.836	27.040	27.248	27.458	27.671	27.888	28.109	28.333	28.560	
—.158		26.469	26.668	26.871	27.077	27.286	27.498	27.713	27.932	28.155	28.381	
—.157		26.302	26.500	26.701	26.906	27.113	27.324	27.539	27.756	27.977	28.202	
—.156		26.135	26.332	26.532	26.735	26.941	27.151	27.364	27.580	27.800	28.023	
—.155		25.968	26.163	26.362	26.564	26.769	26.977	27.189	27.404	27.622	27.844	
—.154		25.801	25.995	26.193	26.393	26.597	26.804	27.014	27.227	27.444	27.665	
—.153		25.634	25.827	26.023	26.223	26.425	26.630	26.839	27.051	27.267	27.486	
—.152		25.467	25.659	25.854	26.052	26.253	26.457	26.664	26.875	27.089	27.307	
—.151		25.300	25.490	25.684	25.881	26.081	26.283	26.489	26.699	26.912	27.128	
—.150		25.133	25.322	25.515	25.710	25.908	26.110	26.315	26.523	26.734	26.949	
—.149		24.966	25.154	25.345	25.539	25.736	25.936	26.140	26.346	26.556	26.770	
—.148		24.799	24.986	25.176	25.368	25.564	25.763	25.965	26.170	26.379	26.591	
—.147		24.632	24.817	25.006	25.198	25.392	25.589	25.790	25.994	26.201	26.411	
—.146		24.465	24.649	24.837	25.027	25.220	25.416	25.615	25.818	26.023	26.232	
—.145		24.298	24.481	24.667	24.856	25.048	25.242	25.440	25.641	25.846	26.053	
—.144		24.131	24.313	24.497	24.685	24.875	25.069	25.265	25.465	25.668	25.874	
—.143		23.964	24.144	24.328	24.514	24.703	24.895	25.091	25.289	25.490	25.695	
—.142		23.797	23.976	24.158	24.343	24.531	24.722	24.916	25.113	25.313	25.516	
—.141		23.630	23.808	23.989	24.173	24.359	24.548	24.741	24.936	25.135	25.337	
		95.0°F	*94.5°F*	*94.0°F*	*93.5°F*	*93.0°F*	*92.5°F*	*92.0°F*	*91.5°F*	*91.0°F*	*90.5°F*	

TABLE 5.4.1—Page 6B *Barometer Total Correction Table* **TEMP. 95.0–90.5°F**

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*95.0°F*	*94.5°F*	*94.0°F*	*93.5°F*	*93.0°F*	*92.5°F*	*92.0°F*	*91.5°F*	*91.0°F*	*90.5°F*	Total Corr. in.
—.145		24.298	24.481	24.667	24.856	25.048	25.242	25.440	25.641	25.846	26.053	
—.144		24.131	24.313	24.497	24.685	24.875	25.069	25.265	25.465	25.668	25.874	
—.143		23.964	24.144	24.328	24.514	24.703	24.895	25.091	25.289	25.490	25.695	
—.142		23.797	23.976	24.158	24.343	24.531	24.722	24.916	25.113	25.313	25.516	
—.141		23.630	23.808	23.989	24.173	24.359	24.548	24.741	24.936	25.135	25.337	
—.140		23.463	23.640	23.819	24.002	24.187	24.375	24.566	24.760	24.957	25.158	
—.139		23.296	23.471	23.650	23.831	24.015	24.201	24.391	24.584	24.780	24.979	
—.138		23.129	23.303	23.480	23.660	23.843	24.028	24.216	24.408	24.602	24.800	
—.137		22.962	23.135	23.311	23.489	23.670	23.855	24.042	24.232	24.425	24.621	
—.136		22.795	22.967	23.141	23.318	23.498	23.681	23.867	24.055	24.247	24.442	
—.135		22.628	22.798	22.972	23.148	23.326	23.508	23.692	23.879	24.069	24.263	
—.134		22.461	22.630	22.802	22.977	23.154	23.334	23.517	23.703	23.892	24.084	
—.133		22.294	22.462	22.633	22.806	22.982	23.161	23.342	23.527	23.714	23.905	
—.132		22.127	22.294	22.463	22.635	22.810	22.987	23.167	23.350	23.536	23.725	
—.131		21.960	22.125	22.293	22.464	22.637	22.814	22.992	23.174	23.359	23.546	
—.130		21.793	21.957	22.124	22.293	22.465	22.640	22.818	22.998	23.181	23.367	
—.129		21.626	21.789	21.954	22.123	22.293	22.467	22.643	22.822	23.003	23.188	
—.128		21.459	21.621	21.785	21.952	22.121	22.293	22.468	22.645	22.826	23.009	
—.127		21.292	21.452	21.615	21.781	21.949	22.120	22.293	22.469	22.648	22.830	
—.126		21.125	21.284	21.446	21.610	21.777	21.946	22.118	22.293	22.471	22.651	
—.125		20.958	21.116	21.276	21.439	21.605	21.773	21.943	22.117	22.293	22.472	
—.124		20.791	20.947	21.107	21.268	21.432	21.599	21.768	21.941	22.115	22.293	
—.123		....	20.779	20.937	21.097	21.260	21.426	21.594	21.764	21.938	22.114	
—.122		....	....	20.768	20.927	21.088	21.252	21.419	21.588	21.760	21.935	
—.121		....	....	....	20.756	20.916	21.079	21.244	21.412	21.582	21.756	
—.120		....	....	....	....	20.744	20.905	21.069	21.236	21.405	21.577	
—.119		....	....	....	....	....	20.732	20.894	21.059	21.227	21.398	
—.118		....	....	....	....	....	....	....	20.883	21.049	21.219	
—.117		....	....	....	....	....	....	....	....	20.872	21.040	
—.116		....	....	....	....	....	....	....	....	....	20.860	
		95.0°F	*94.5°F*	*94.0°F*	*93.5°F*	*93.0°F*	*92.5°F*	*92.0°F*	*91.5°F*	*91.0°F*	*90.5°F*	

TABLE 5.4.1—Page 7A

Barometer Total Correction Table

TEMP. 90.0–85.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.											Total Corr. in.
		90.0°F										
—.175		31.680	*89.5°F*									
—.174		31.499	......	*89.0°F*	......	......	......	......	......	......	......	
—.173		31.319	31.574	......	......	......	......	......	......	......	......	
—.172		31.138	31.392	31.651	*88.5°F*	......	......	......	......	......	......	
—.171		30.957	31.210	31.467	......	*88.0°F*	......	......	......	......	......	
—.170		30.777	31.028	31.284	31.543	......	......	......	......	......	......	
—.169		30.596	30.846	31.100	31.358	31.621	*87.5°F*	......	......	......	......	
—.168		30.416	30.664	30.917	31.173	31.434	......	*87.0°F*	......	......	......	
—.167		30.235	30.482	30.733	30.988	31.248	31.511	......	*86.5°F*	......	......	
—.166		30.055	30.301	30.550	30.803	31.061	31.323	31.590	......	......	......	
—.165		29.874	30.119	30.366	30.618	30.875	31.135	31.400	31.670	*86.0°F*	......	
—.164		29.694	29.937	30.183	30.433	30.688	30.947	31.211	31.479	......	*85.5°F*	
—.163		29.513	29.755	29.999	30.248	30.502	30.759	31.021	31.287	31.559	......	
—.162		29.333	29.573	29.816	30.063	30.315	30.571	30.831	31.096	31.366	31.640	
—.161		29.152	29.391	29.632	29.878	30.128	30.383	30.642	30.905	31.173	31.445	
—.160		28.972	29.209	29.449	29.693	29.942	30.195	30.452	30.713	30.980	31.250	
—.159		28.791	29.027	29.265	29.508	29.755	30.006	30.262	30.522	30.787	31.056	
—.158		28.611	28.845	29.082	29.323	29.569	29.818	30.072	30.331	30.593	30.861	
—.157		28.430	28.663	28.898	29.138	29.382	29.630	29.883	30.139	30.400	30.666	
—.156		28.250	28.481	28.715	28.953	29.196	29.442	29.693	29.948	30.207	30.471	
—.155		28.069	28.299	28.531	28.768	29.009	29.254	29.503	29.756	30.014	30.277	
—.154		27.889	28.117	28.348	28.583	28.823	29.066	29.313	29.565	29.821	30.082	
—.153		27.708	27.935	28.164	28.398	28.636	28.878	29.124	29.374	29.628	29.887	
—.152		27.528	27.753	27.981	28.213	28.449	28.689	28.934	29.182	29.435	29.693	
—.151		27.347	27.571	27.797	28.028	28.263	28.501	28.744	28.991	29.242	29.498	
—.150		27.167	27.389	27.614	27.843	28.076	28.313	28.554	28.800	29.049	29.303	
—.149		26.986	27.207	27.431	27.658	27.890	28.125	28.365	28.608	28.856	29.108	
—.148		26.806	27.025	27.247	27.473	27.703	27.937	28.175	28.417	28.663	28.914	
—.147		26.625	26.843	27.064	27.288	27.517	27.749	27.985	28.226	28.470	28.719	
—.146		26.445	26.661	26.880	27.103	27.330	27.561	27.796	28.034	28.277	28.524	
—.145		26.264	26.479	26.697	26.918	27.144	27.373	27.606	27.843	28.084	28.330	
—.144		26.084	26.297	26.513	26.733	26.957	27.184	27.416	27.651	27.891	28.135	
—.143		25.903	26.115	26.330	26.548	26.770	26.996	27.226	27.460	27.698	27.940	
—.142		25.723	25.933	26.146	26.363	26.584	26.808	27.037	27.269	27.505	27.746	
—.141		25.542	25.751	25.963	26.178	26.397	26.620	26.847	27.077	27.312	27.551	
—.140		25.362	25.569	25.779	25.993	26.211	26.432	26.657	26.886	27.119	27.356	
—.139		25.181	25.387	25.596	25.808	26.024	26.244	26.467	26.695	26.926	27.161	
—.138		25.001	25.205	25.412	25.623	25.838	26.056	26.278	26.503	26.733	26.967	
—.137		24.820	25.023	25.229	25.438	25.651	25.868	26.088	26.312	26.540	26.772	
—.136		24.640	24.841	25.045	25.253	25.465	25.679	25.898	26.121	26.347	26.577	
—.135		24.459	24.659	24.862	25.068	25.278	25.491	25.708	25.929	26.154	26.383	
—.134		24.278	24.477	24.678	24.883	25.091	25.303	25.519	25.738	25.961	26.188	
—.133		24.098	24.295	24.495	24.698	24.905	25.115	25.329	25.546	25.768	25.993	
—.132		23.917	24.113	24.311	24.513	24.718	24.927	25.139	25.355	25.575	25.798	
—.131		23.737	23.931	24.128	24.328	24.532	24.739	24.950	25.164	25.382	25.604	
—.130		23.556	23.749	23.944	24.143	24.345	24.551	24.760	24.972	25.189	25.409	
—.129		23.376	23.567	23.761	23.958	24.159	24.362	24.570	24.781	24.996	25.214	
—.128		23.195	23.385	23.577	23.773	23.972	24.174	24.380	24.590	24.803	25.020	
—.127		23.015	23.203	23.394	23.588	23.786	23.986	24.191	24.398	24.610	24.825	
		90.0°F	*89.5°F*	*89.0°F*	*88.5°F*	*88.0°F*	*87.5°F*	*87.0°F*	*86.5°F*	*86.0°F*	*85.5°F*	

TABLE 5.4.1—Page 7B

Barometer Total Correction Table

TEMP. 90.0–85.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*90.0°F*	*89.5°F*	*89.0°F*	*88.5°F*	*88.0°F*	*87.5°F*	*87.0°F*	*86.5°F*	*86.0°F*	*85.5°F*	Total Corr. in.
—.131		23.737	23.931	24.128	24.328	24.532	24.739	24.950	25.164	25.382	25.604	
—.130		23.556	23.749	23.944	24.143	24.345	24.551	24.760	24.972	25.189	25.409	
—.129		23.376	23.567	23.761	23.958	24.159	24.362	24.570	24.781	24.996	25.214	
—.128		23.195	23.385	23.577	23.773	23.972	24.174	24.380	24.590	24.803	25.020	
—.127		23.015	23.203	23.394	23.588	23.786	23.986	24.191	24.398	24.610	24.825	
—.126		22.834	23.021	23.210	23.403	23.599	23.798	24.001	24.207	24.417	24.630	
—.125		22.654	22.839	23.027	23.218	23.412	23.610	23.811	24.016	24.224	24.435	
—.124		22.473	22.657	22.843	23.033	23.226	23.422	23.621	23.824	24.031	24.241	
—.123		22.293	22.475	22.660	22.848	23.039	23.234	23.432	23.633	23.838	24.046	
—.122		22.112	22.293	22.476	22.663	22.853	23.046	23.242	23.441	23.645	23.851	
—.121		21.932	22.111	22.293	22.478	22.666	22.857	23.052	23.250	23.452	23.657	
—.120		21.751	21.929	22.109	22.293	22.480	22.669	22.862	23.059	23.259	23.462	
—.119		21.571	21.747	21.926	22.108	22.293	22.481	22.673	22.867	23.066	23.267	
—.118		21.390	21.565	21.742	21.923	22.107	22.293	22.483	22.676	22.873	23.073	
—.117		21.210	21.383	21.559	21.738	21.920	22.105	22.293	22.485	22.680	22.878	
—.116		21.029	21.201	21.376	21.553	21.733	21.917	22.104	22.293	22.487	22.683	
—.115		20.849	21.019	21.192	21.368	21.547	21.729	21.914	22.102	22.294	22.488	
—.114		....	20.837	21.009	21.183	21.360	21.540	21.724	21.911	22.101	22.294	
—.113		....	....	20.825	20.998	21.174	21.352	21.534	21.719	21.907	22.099	
—.112		....	....	....	20.813	20.987	21.164	21.345	21.528	21.714	21.904	
—.111		....	....	....	....	20.801	20.976	21.155	21.336	21.521	21.710	
—.110		....	....	....	....	....	20.788	20.965	21.145	21.328	21.515	
—.109		....	....	....	....	....	....	20.775	20.954	21.135	21.320	
—.108		....	....	....	....	....	....	....	20.762	20.942	21.125	
—.107		....	....	....	....	....	....	....	....	20.749	20.931	
—.106		....	....	....	....	....	....	....	....	....	20.736	
		90.0°F	*89.5°F*	*89.0°F*	*88.5°F*	*88.0°F*	*87.5°F*	*87.0°F*	*86.5°F*	*86.0°F*	*85.5°F*	

TABLE 5.4.1—Page 8A *Barometer Total Correction Table* **TEMP. 85.0–80.5°F**

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*85.0°F*										Total Corr. in.
—.161		31.722	*84.5°F*									
—.160		31.526	....	*84.0°F*			....	....	....	....	....	
—.159		31.329	31.608	....	....	....	....	....	....	....	....	
—.158		31.133	31.410	31.692	*83.5°F*	....	....	....	....	....	....	
—.157		30.936	31.212	31.492	....	*83.0°F*	....	....	....	....	....	
—.156		30.740	31.014	31.292	31.576	....	....	....	....	....	....	
—.155		30.544	30.816	31.092	31.374	31.661	*82.5°F*	....	....	....	....	
—.154		30.347	30.617	30.892	31.172	31.457	....	*82.0°F*	....	....	....	
—.153		30.151	30.419	30.692	30.971	31.254	31.542	....	....	....	....	
—.152		29.954	30.221	30.492	30.769	31.050	31.337	31.629	*81.5°F*	....	....	
—.151		29.758	30.023	30.292	30.567	30.846	31.131	31.421	....	*81.0°F*	....	
—.150		29.561	29.825	30.092	30.365	30.643	30.926	31.214	31.508	....	*80.5°F*	
—.149		29.365	29.627	29.892	30.164	30.439	30.720	31.007	31.298	31.595	....	
—.148		29.169	29.428	29.693	29.962	30.236	30.515	30.799	31.089	31.384	31.685	
—.147		28.972	29.230	29.493	29.760	30.032	30.309	30.592	30.880	31.173	31.472	
—.146		28.776	29.032	29.293	29.558	29.828	30.104	30.384	30.670	30.961	31.258	
—.145		28.579	28.834	29.093	29.356	29.625	29.898	30.177	30.461	30.750	31.045	
—.144		28.383	28.636	28.893	29.155	29.421	29.693	29.970	30.252	30.539	30.831	
—.143		28.186	28.437	28.693	28.953	29.218	29.487	29.762	30.042	30.327	30.618	
—.142		27.990	28.239	28.493	28.751	29.014	29.282	29.555	29.833	30.116	30.405	
—.141		27.794	28.041	28.293	28.549	28.810	29.076	29.347	29.624	29.905	30.191	
—.140		27.597	27.843	28.093	28.348	28.607	28.871	29.140	29.414	29.693	29.978	
—.139		27.401	27.645	27.893	28.146	28.403	28.665	28.932	29.205	29.482	29.765	
—.138		27.204	27.447	27.693	27.944	28.199	28.460	28.725	28.995	29.271	29.551	
—.137		27.008	27.248	27.493	27.742	27.996	28.255	28.518	28.786	29.059	29.338	
—.136		26.812	27.050	27.293	27.541	27.792	28.049	28.310	28.577	28.848	29.125	
—.135		26.615	26.852	27.093	27.339	27.589	27.844	28.103	28.367	28.637	28.911	
—.134		26.419	26.654	26.893	27.137	27.385	27.638	27.895	28.158	28.425	28.698	
—.133		26.222	26.456	26.693	26.935	27.181	27.433	27.688	27.949	28.214	28.484	
—.132		26.026	26.258	26.493	26.733	26.978	27.227	27.481	27.739	28.003	28.271	
—.131		25.829	26.059	26.293	26.532	26.774	27.022	27.273	27.530	27.791	28.058	
—.130		25.633	25.861	26.093	26.330	26.571	26.816	27.066	27.321	27.580	27.844	
—.129		25.437	25.663	25.893	26.128	26.367	26.611	26.858	27.111	27.369	27.631	
—.128		25.240	25.465	25.693	25.926	26.163	26.405	26.651	26.902	27.157	27.418	
—.127		25.044	25.267	25.494	25.725	25.960	26.200	26.444	26.693	26.946	27.204	
—.126		24.847	25.069	25.294	25.523	25.756	25.994	26.236	26.483	26.735	26.991	
—.125		24.651	24.870	25.094	25.321	25.553	25.789	26.029	26.274	26.523	26.777	
—.124		24.454	24.672	24.894	25.119	25.349	25.583	25.821	26.064	26.312	26.564	
—.123		24.258	24.474	24.694	24.918	25.145	25.378	25.614	25.855	26.100	26.351	
—.122		24.062	24.276	24.494	24.716	24.942	25.172	25.407	25.646	25.889	26.137	
—.121		23.865	24.078	24.294	24.514	24.738	24.967	25.199	25.436	25.678	25.924	
—.120		23.669	23.879	24.094	24.312	24.535	24.761	24.992	25.227	25.466	25.711	
—.119		23.472	23.681	23.894	24.111	24.331	24.556	24.784	25.018	25.255	25.497	
—.118		23.276	23.483	23.694	23.909	24.127	24.350	24.577	24.808	25.044	25.284	
—.117		23.079	23.285	23.494	23.707	23.924	24.145	24.370	24.599	24.832	25.070	
—.116		22.883	23.087	23.294	23.505	23.720	23.939	24.162	24.390	24.621	24.857	
—.115		22.687	22.889	23.094	23.303	23.516	23.734	23.955	24.180	24.410	24.644	
—.114		22.490	22.690	22.894	23.102	23.313	23.528	23.747	23.971	24.198	24.430	
—.113		22.294	22.492	22.694	22.900	23.109	23.323	23.540	23.762	23.987	24.217	
		85.0°F	*84.5°F*	*84.0°F*	*83.5°F*	*83.0°F*	*82.5°F*	*82.0°F*	*81.5°F*	*81.0°F*	*80.5°F*	

TABLE 5.4.1—Page 8B

Barometer Total Correction Table

TEMP. 85.0–80.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*85.0°F*	*84.5°F*	*84.0°F*	*83.5°F*	*83.0°F*	*82.5°F*	*82.0°F*	*81.5°F*	*81.0°F*	*80.5°F*	Total Corr. in.
—.117		23.079	23.285	23.494	23.707	23.924	24.145	24.370	24.599	24.832	25.070	
—.116		22.883	23.087	23.294	23.505	23.720	23.939	24.162	24.390	24.621	24.857	
—.115		22.687	22.889	23.094	23.303	23.516	23.734	23.955	24.180	24.410	24.644	
—.114		22.490	22.690	22.894	23.102	23.313	23.528	23.747	23.971	24.198	24.430	
—.113		22.294	22.492	22.694	22.900	23.109	23.323	23.540	23.762	23.987	24.217	
—.112		22.097	22.294	22.494	22.698	22.906	23.117	23.333	23.552	23.776	24.004	
—.111		21.901	22.096	22.294	22.496	22.702	22.912	23.125	23.343	23.564	23.790	
—.110		21.704	21.898	22.094	22.295	22.498	22.706	22.918	23.133	23.353	23.577	
—.109		21.508	21.700	21.894	22.093	22.295	22.501	22.710	22.924	23.142	23.364	
—.108		21.312	21.501	21.694	21.891	22.091	22.295	22.503	22.715	22.930	23.150	
—.107		21.115	21.303	21.494	21.689	21.888	22.090	22.296	22.505	22.719	22.937	
—.106		20.919	21.105	21.294	21.488	21.684	21.884	22.088	22.296	22.508	22.723	
—.105		20.722	20.907	21.095	21.286	21.480	21.679	21.881	22.087	22.296	22.510	
—.104		....	20.709	20.895	21.084	21.277	21.473	21.673	21.877	22.085	22.297	
—.103		....	....	....	20.882	21.073	21.268	21.466	21.668	21.874	22.083	
—.102		....	....	....	....	20.870	21.062	21.259	21.459	21.662	21.870	
—.101		....	....	....	....	....	20.857	21.051	21.249	21.451	21.657	
—.100		....	....	....	....	....	....	20.844	21.040	21.240	21.443	
—.099		....	....	....	....	....	....	....	20.831	21.028	21.230	
—.098		....	....	....	....	....	....	....	....	20.817	21.016	
—.097		....	....	....	....	....	....	....	....	....	20.803	
		85.0°F	*84.5°F*	*84.0°F*	*83.5°F*	*83.0°F*	*82.5°F*	*82.0°F*	*81.5°F*	*81.0°F*	*80.5°F*	

TABLE 5.4.1—Page 9A *Barometer Total Correction Table* **TEMP. 80.0–75.5°F**

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.											Total Corr. in.
		80.0°F										
—.147		31.776	*79.5°F*									
—.146		31.561										
—.145		31.346	31.652	*79.0°F*								
—.144		31.130	31.434		*78.5°F*							
—.143		30.915	31.217	31.525		*78.0°F*						
—.142		30.699	30.999	31.306	31.618							
—.141		30.484	30.782	31.086	31.396	31.712	*77.5°F*					
—.140		30.268	30.564	30.866	31.174	31.488		*77.0°F*				
—.139		30.053	30.347	30.647	30.952	31.264	31.582					
—.138		29.838	30.129	30.427	30.730	31.040	31.356	31.678	*76.5°F*			
—.137		29.622	29.912	30.207	30.508	30.816	31.130	31.450		*76.0°F*		
—.136		29.407	29.694	29.987	30.287	30.592	30.903	31.221	31.546			
—.135		29.191	29.477	29.768	30.065	30.368	30.677	30.992	31.314	31.643	*75.5°F*	
—.134		28.976	29.259	29.548	29.843	30.144	30.450	30.764	31.083	31.410		
—.133		28.760	29.041	29.328	29.621	29.920	30.224	30.535	30.852	31.176	31.508	
—.132		28.545	28.824	29.109	29.399	29.695	29.998	30.306	30.621	30.943	31.271	
—.131		28.329	28.606	28.889	29.177	29.471	29.771	30.077	30.390	30.709	31.035	
—.130		28.114	28.389	28.669	28.955	29.247	29.545	29.849	30.159	30.476	30.799	
—.129		27.899	28.171	28.450	28.733	29.023	29.318	29.620	29.928	30.242	30.563	
—.128		27.683	27.954	28.230	28.511	28.799	29.092	29.391	29.697	30.009	30.327	
—.127		27.468	27.736	28.010	28.290	28.575	28.866	29.162	29.466	29.775	30.091	
—.126		27.252	27.519	27.791	28.068	28.351	28.639	28.934	29.235	29.542	29.855	
—.125		27.037	27.301	27.571	27.846	28.127	28.413	28.705	29.003	29.308	29.619	
—.124		26.821	27.084	27.351	27.624	27.902	28.186	28.476	28.772	29.074	29.383	
—.123		26.606	26.866	27.131	27.402	27.678	27.960	28.248	28.541	28.841	29.147	
—.122		26.391	26.649	26.912	27.180	27.454	27.734	28.019	28.310	28.607	28.911	
—.121		26.175	26.431	26.692	26.958	27.230	27.507	27.790	28.079	28.374	28.675	
—.120		25.960	26.213	26.472	26.736	27.006	27.281	27.561	27.848	28.140	28.439	
—.119		25.744	25.996	26.253	26.515	26.782	27.054	27.333	27.617	27.907	28.203	
—.118		25.529	25.778	26.033	26.293	26.558	26.828	27.104	27.386	27.673	27.967	
—.117		25.313	25.561	25.813	26.071	26.334	26.602	26.875	27.155	27.440	27.731	
—.116		25.098	25.343	25.594	25.849	26.109	26.375	26.646	26.923	27.206	27.495	
—.115		24.882	25.126	25.374	25.627	25.885	26.149	26.418	26.692	26.973	27.259	
—.114		24.667	24.908	25.154	25.405	25.661	25.922	26.189	26.461	26.739	27.023	
—.113		24.452	24.691	24.935	25.183	25.437	25.696	25.960	26.230	26.506	26.787	
—.112		24.236	24.473	24.715	24.961	25.213	25.470	25.732	25.999	26.272	26.551	
—.111		24.021	24.256	24.495	24.739	24.989	25.243	25.503	25.768	26.039	26.315	
—.110		23.805	24.038	24.275	24.518	24.765	25.017	25.274	25.537	25.805	26.079	
—.109		23.590	23.820	24.056	24.296	24.541	24.790	25.045	25.306	25.571	25.843	
—.108		23.374	23.603	23.836	24.074	24.317	24.564	24.817	25.075	25.338	25.607	
—.107		23.159	23.385	23.616	23.852	24.092	24.338	24.588	24.844	25.104	25.371	
—.106		22.944	23.168	23.397	23.630	23.868	24.111	24.359	24.612	24.871	25.135	
—.105		22.728	22.950	23.177	23.408	23.644	23.885	24.130	24.381	24.637	24.899	
—.104		22.513	22.733	22.957	23.186	23.420	23.658	23.902	24.150	24.404	24.663	
—.103		22.297	22.515	22.738	22.964	23.196	23.432	23.673	23.919	24.170	24.427	
—.102		22.082	22.298	22.518	22.743	22.972	23.206	23.444	23.688	23.937	24.191	
—.101		21.866	22.080	22.298	22.521	22.748	22.979	23.215	23.457	23.703	23.955	
—.100		21.651	21.863	22.079	22.299	22.524	22.753	22.987	23.226	23.470	23.719	
—.099		21.435	21.645	21.859	22.077	22.299	22.526	22.758	22.995	23.236	23.483	
		80.0°F	*79.5°F*	*79.0°F*	*78.5°F*	*78.0°F*	*77.5°F*	*77.0°F*	*76.5°F*	*76.0°F*	*75.5°F*	

TABLE 5.4.1—Page 9B

Barometer Total Correction Table

TEMP. 80.0–75.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*80.0°F*	*79.5°F*	*79.0°F*	*78.5°F*	*78.0°F*	*77.5°F*	*77.0°F*	*76.5°F*	*76.0°F*	*75.5°F*	Total Corr. in.
—.103		22.297	22.515	22.738	22.964	23.196	23.432	23.673	23.919	24.170	24.427	
—.102		22.082	22.298	22.518	22.743	22.972	23.206	23.444	23.688	23.937	24.191	
—.101		21.866	22.080	22.298	22.521	22.748	22.979	23.215	23.457	23.703	23.955	
—.100		21.651	21.863	22.079	22.299	22.524	22.753	22.987	23.226	23.470	23.719	
—.099		21.435	21.645	21.859	22.077	22.299	22.526	22.758	22.995	23.236	23.483	
—.098		21.220	21.427	21.639	21.855	22.075	22.300	22.529	22.764	23.003	23.247	
—.097		21.005	21.210	21.419	21.633	21.851	22.074	22.301	22.532	22.769	23.011	
—.096		20.789	20.992	21.200	21.411	21.627	21.847	22.072	22.301	22.536	22.775	
—.095		....	20.775	20.980	21.189	21.403	21.621	21.843	22.070	22.302	22.539	
—.094		....	....	20.760	20.967	21.179	21.394	21.614	21.839	22.068	22.303	
—.093		....	....	....	20.746	20.955	21.168	21.386	21.608	21.835	22.067	
—.092		....	....	....	....	20.731	20.942	21.157	21.377	21.601	21.831	
—.091		....	....	....	....	....	20.715	20.928	21.146	21.368	21.595	
—.090		....	....	....	....	....	....	20.699	20.915	21.134	21.359	
—.089		....	....	....	....	....	....	....	20.684	20.901	21.123	
—.088		....	....	....	....	....	....	....	....	20.667	20.887	
		80.0°F	*79.5°F*	*79.0°F*	*78.5°F*	*78.0°F*	*77.5°F*	*77.0°F*	*76.5°F*	*76.0°F*	*75.5°F*	

TABLE 5.4.1—Page 10A

Barometer Total Correction Table

TEMP. 75.0–70.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*75.0°F*										Total Corr. in.
—.132		31.607	*74.5°F*									
—.131		31.368	31.709	*74.0°F*	....	....	....	....	....	....	....	
—.130		31.130	31.468	....	*73.5°F*	....	....	....	....	....	....	
—.129		30.891	31.227	31.569	....	....	....	....	....	....	....	
—.128		30.653	30.985	31.325	31.673	*73.0°F*	....	....	....	....	....	
—.127		30.414	30.744	31.081	31.426	....	*72.5°F*	....	....	....	....	
—.126		30.176	30.503	30.838	31.180	31.529	....	*72.0°F*	....	....	....	
—.125		29.937	30.262	30.594	30.933	31.280	31.635	....	....	....	....	
—.124		29.698	30.021	30.350	30.687	31.031	31.383	31.743	*71.5°F*	....	....	
—.123		29.460	29.780	30.106	30.440	30.782	31.131	31.488	....	*71.0°F*	....	
—.122		29.221	29.539	29.863	30.194	30.533	30.879	31.233	31.596	....	....	
—.121		28.983	29.298	29.619	29.947	30.283	30.627	30.978	31.338	31.707	*70.5°F*	
—.120		28.744	29.056	29.375	29.701	30.034	30.375	30.724	31.080	31.446	....	
—.119		28.506	28.815	29.131	29.454	29.785	30.123	30.469	30.822	31.185	31.555	
—.118		28.267	28.574	28.887	29.208	29.536	29.871	30.214	30.564	30.924	31.291	
—.117		28.029	28.333	28.644	28.961	29.286	29.619	29.959	30.306	30.663	31.027	
—.116		27.790	28.092	28.400	28.715	29.037	29.366	29.704	30.048	30.402	30.763	
—.115		27.552	27.851	28.156	28.469	28.788	29.114	29.449	29.791	30.141	30.499	
—.114		27.313	27.610	27.912	28.222	28.539	28.862	29.194	29.533	29.880	30.235	
—.113		27.074	27.368	27.669	27.976	28.289	28.610	28.939	29.275	29.619	29.971	
—.112		26.836	27.127	27.425	27.729	28.040	28.358	28.684	29.017	29.358	29.707	
—.111		26.597	26.886	27.181	27.483	27.791	28.106	28.429	28.759	29.097	29.443	
—.110		26.359	26.645	26.937	27.236	27.542	27.854	28.174	28.501	28.836	29.179	
—.109		26.120	26.404	26.693	26.990	27.292	27.602	27.919	28.243	28.575	28.915	
—.108		25.882	26.163	26.450	26.743	27.043	27.350	27.664	27.985	28.314	28.651	
—.107		25.643	25.922	26.206	26.497	26.794	27.098	27.409	27.727	28.053	28.386	
—.106		25.405	25.680	25.962	26.250	26.545	26.846	27.154	27.469	27.792	28.122	
—.105		25.166	25.439	25.718	26.004	26.295	26.594	26.899	27.211	27.531	27.858	
—.104		24.928	25.198	25.475	25.757	26.046	26.342	26.644	26.953	27.270	27.594	
—.103		24.689	24.957	25.231	25.511	25.797	26.089	26.389	26.695	27.009	27.330	
—.102		24.450	24.716	24.987	25.264	25.548	25.837	26.134	26.437	26.748	27.066	
—.101		24.212	24.475	24.743	25.018	25.298	25.585	25.879	26.179	26.487	26.802	
—.100		23.973	24.234	24.499	24.771	25.049	25.333	25.624	25.922	26.226	26.538	
—.099		23.735	23.993	24.256	24.525	24.800	25.081	25.369	25.664	25.965	26.274	
—.098		23.496	23.751	24.012	24.278	24.551	24.829	25.114	25.406	25.704	26.010	
—.097		23.258	23.510	23.768	24.032	24.301	24.577	24.859	25.148	25.443	25.746	
—.096		23.019	23.269	23.524	23.785	24.052	24.325	24.604	24.890	25.182	25.482	
—.095		22.781	23.028	23.280	23.539	23.803	24.073	24.349	24.632	24.921	25.218	
—.094		22.542	22.787	23.037	23.292	23.554	23.821	24.094	24.374	24.661	24.954	
—.093		22.304	22.546	22.793	23.046	23.304	23.569	23.839	24.116	24.400	24.690	
—.092		22.065	22.305	22.549	22.799	23.055	23.317	23.584	23.858	24.139	24.426	
—.091		21.826	22.063	22.305	22.553	22.806	23.065	23.329	23.600	23.878	24.161	
—.090		21.588	21.822	22.062	22.306	22.557	22.812	23.074	23.342	23.617	23.897	
—.089		21.349	21.581	21.818	22.060	22.307	22.560	22.819	23.084	23.356	23.633	
—.088		21.111	21.340	21.574	21.813	22.058	22.308	22.564	22.826	23.095	23.369	
—.087		20.872	21.099	21.330	21.567	21.809	22.056	22.309	22.568	22.834	23.105	
—.086		....	20.858	21.086	21.320	21.560	21.804	22.054	22.311	22.573	22.841	
—.085		....	....	20.843	21.074	21.310	21.552	21.800	22.053	22.312	22.577	
—.084		....	....	....	20.827	21.061	21.300	21.545	21.795	22.051	22.313	
		75.0°F	*74.5°F*	*74.0°F*	*73.5°F*	*73.0°F*	*72.5°F*	*72.0°F*	*71.5°F*	*71.0°F*	*70.5°F*	

TABLE 5.4.1—Page 10B

Barometer Total Correction Table

TEMP. 75.0–70.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*75.0°F*	*74.5°F*	*74.0°F*	*73.5°F*	*73.0°F*	*72.5°F*	*72.0°F*	*71.5°F*	*71.0°F*	*70.5°F*	Total Corr. in.
—.088		21.111	21.340	21.574	21.813	22.058	22.308	22.564	22.826	23.095	23.369	
—.087		20.872	21.099	21.330	21.567	21.809	22.056	22.309	22.568	22.834	23.105	
—.086		....	20.858	21.086	21.320	21.560	21.804	22.054	22.311	22.573	22.841	
—.085		....	....	20.843	21.074	21.310	21.552	21.800	22.053	22.312	22.577	
—.084		....	....	....	20.827	21.061	21.300	21.545	21.795	22.051	22.313	
—.083		....	....	....	....	20.812	21.048	21.290	21.537	21.790	22.049	
—.082		....	....	....	....	....	20.796	21.035	21.279	21.529	21.785	
—.081		....	....	....	....	....	....	20.780	21.021	21.268	21.521	
—.080		....	....	....	....	....	....	....	20.763	21.007	21.257	
—.079		....	....	....	....	....	....	....	....	20.746	20.993	
—.078		....	....	....	....	....	....	....	....	....	20.729	
		75.0°F	*74.5°F*	*74.0°F*	*73.5°F*	*73.0°F*	*72.5°F*	*72.0°F*	*71.5°F*	*71.0°F*	*70.5°F*	

TABLE 5.4.1—Page 11

Barometer Total Correction Table

TEMP. 70.0–65.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*70.0°F*										Total Corr. in.
—.118		31.668	*69.5°F*									
—.117		31.401	....	*69.0°F*	....	....	....	....	....	....	....	
—.116		31.133	31.513	....	*68.5°F*	....	....	....	....	....	....	
—.115		30.866	31.242	31.627	....	....	....	....	....	....	....	
—.114		30.599	30.972	31.354	31.745	*68.0°F*	....	....	....	....	....	
—.113		30.332	30.701	31.080	31.468	....	*67.5°F*	....	....	....	....	
—.112		30.064	30.431	30.806	31.191	31.585	....	....	....	....	....	
—.111		29.797	30.160	30.532	30.914	31.304	31.706	*67.0°F*	....	....	....	
—.110		29.530	29.890	30.258	30.636	31.024	31.421	....	*66.5°F*	....	....	
—.109		29.263	29.619	29.984	30.359	30.743	31.137	31.541	....	*66.0°F*	....	
—.108		28.995	29.349	29.711	30.082	30.462	30.853	31.253	31.664	....	....	
—.107		28.728	29.078	29.437	29.805	30.181	30.568	30.965	31.372	31.790	*65.5°F*	
—.106		28.461	28.808	29.163	29.527	29.901	30.284	30.677	31.081	31.495	....	
—.105		28.194	28.537	28.889	29.250	29.620	30.000	30.389	30.789	31.199	31.621	
—.104		27.926	28.267	28.615	28.973	29.339	29.715	30.101	30.497	30.903	31.321	
—.103		27.659	27.996	28.341	28.695	29.058	29.431	29.813	30.205	30.607	31.021	
—.102		27.392	27.726	28.068	28.418	28.778	29.147	29.525	29.913	30.312	30.721	
—.101		27.125	27.455	27.794	28.141	28.497	28.862	29.237	29.621	30.016	30.422	
—.100		26.858	27.185	27.520	27.864	28.216	28.578	28.949	29.330	29.720	30.122	
—.099		26.590	26.914	27.246	27.586	27.935	28.293	28.661	29.038	29.425	29.822	
—.098		26.323	26.644	26.972	27.309	27.655	28.009	28.373	28.746	29.129	29.523	
—.097		26.056	26.373	26.698	27.032	27.374	27.725	28.084	28.454	28.833	29.223	
—.096		25.789	26.103	26.425	26.755	27.093	27.440	27.796	28.162	28.537	28.923	
—.095		25.521	25.832	26.151	26.477	26.812	27.156	27.508	27.870	28.242	28.623	
—.094		25.254	25.562	25.877	26.200	26.532	26.872	27.220	27.578	27.946	28.324	
—.093		24.987	25.291	25.603	25.923	26.251	26.587	26.932	27.287	27.650	28.024	
—.092		24.720	25.021	25.329	25.646	25.970	26.303	26.644	26.995	27.354	27.724	
—.091		24.452	24.750	25.055	25.368	25.689	26.019	26.356	26.703	27.059	27.424	
—.090		24.185	24.480	24.782	25.091	25.408	25.734	26.068	26.411	26.763	27.125	
—.089		23.918	24.209	24.508	24.814	25.128	25.450	25.780	26.119	26.467	26.825	
—.088		23.651	23.939	24.234	24.537	24.847	25.165	25.492	25.827	26.172	26.525	
—.087		23.383	23.668	23.960	24.259	24.566	24.881	25.204	25.536	25.876	26.226	
—.086		23.116	23.398	23.686	23.982	24.285	24.597	24.916	25.244	25.580	25.926	
—.085		22.849	23.127	23.412	23.705	24.005	24.312	24.628	24.952	25.284	25.626	
—.084		22.582	22.857	23.139	23.428	23.724	24.028	24.340	24.660	24.989	25.326	
—.083		22.314	22.586	22.865	23.150	23.443	23.744	24.052	24.368	24.693	25.027	
—.082		22.047	22.316	22.591	22.873	23.162	23.459	23.764	24.076	24.397	24.727	
—.081		21.780	22.045	22.317	22.596	22.882	23.175	23.476	23.785	24.101	24.427	
—.080		21.513	21.775	22.043	22.319	22.601	22.891	23.188	23.493	23.806	24.127	
—.079		21.245	21.504	21.769	22.041	22.320	22.606	22.900	23.201	23.510	23.828	
—.078		20.978	21.234	21.496	21.764	22.039	22.322	22.612	22.909	23.214	23.528	
—.077		20.711	20.963	21.222	21.487	21.759	22.037	22.323	22.617	22.918	23.228	
—.076		....	20.693	20.948	21.210	21.478	21.753	22.035	22.325	22.623	22.929	
—.075		....	....	20.674	20.932	21.197	21.469	21.747	22.033	22.327	22.629	
—.074		....	....	....	20.655	20.916	21.184	21.459	21.742	22.031	22.329	
—.073		....	....	....	....	20.636	20.900	21.171	21.450	21.736	22.029	
—.072		....	....	....	....	....	20.616	20.883	21.158	21.440	21.730	
—.071		....	....	....	....	....	....	....	20.866	21.144	21.430	
—.070		....	....	....	....	....	....	....	....	20.848	21.130	
		70.0°F	*69.5°F*	*69.0°F*	*68.5°F*	*68.0°F*	*67.5°F*	*67.0°F*	*66.5°F*	*66.0°F*	*65.5°F*	

TABLE 5.4.1—Page 12 *Barometer Total Correction Table* **TEMP. 65.0–60.5°F**

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*65.0°F*										Total Corr. in.
—.104		31.750	*64.5°F*									
—.103		31.446	......	*64.0°F*	......	......	......	......	......	......	......	
—.102		31.142	31.575	......	......	......	......	......	......	......	......	
—.101		30.838	31.266	31.707	*63.5°F*	......	......	......	......	......	......	
—.100		30.534	30.958	31.395	......	*63.0°F*	......	......	......	......	......	
—.099		30.231	30.650	31.082	31.526	......	*62.5°F*	......	......	......	......	
—.098		29.927	30.342	30.770	31.209	31.662	......	......	......	......	......	
—.097		29.623	30.034	30.457	30.892	31.340	31.801	*62.0°F*	......	......	......	
—.096		29.319	29.726	30.145	30.576	31.019	31.475	......	*61.5°F*	......	......	
—.095		29.015	29.418	29.833	30.259	30.698	31.149	31.614	......	......	......	
—.094		28.711	29.110	29.520	29.942	30.376	30.823	31.283	31.757	*61.0°F*	......	
—.093		28.408	28.802	29.208	29.625	30.055	30.497	30.952	31.421	......	*60.5°F*	
—.092		28.104	28.494	28.895	29.308	29.733	30.171	30.621	31.085	31.564	......	
—.091		27.800	28.186	28.583	28.991	29.412	29.844	30.290	30.749	31.223	31.711	
—.090		27.496	27.878	28.271	28.675	29.090	29.518	29.959	30.413	30.882	31.364	
—.089		27.192	27.570	27.958	28.358	28.769	29.192	29.628	30.077	30.540	31.018	
—.088		26.888	27.262	27.646	28.041	28.447	28.866	29.297	29.741	30.199	30.671	
—.087		26.585	26.954	27.334	27.724	28.126	28.540	28.966	29.405	29.858	30.325	
—.086		26.281	26.646	27.021	27.407	27.805	28.214	28.635	29.069	29.517	29.978	
—.085		25.977	26.338	26.709	27.090	27.483	27.887	28.304	28.733	29.175	29.632	
—.084		25.673	26.030	26.396	26.773	27.162	27.561	27.973	28.397	28.834	29.285	
—.083		25.369	25.722	26.084	26.457	26.840	27.235	27.642	28.061	28.493	28.938	
—.082		25.065	25.414	25.772	26.140	26.519	26.909	27.311	27.725	28.152	28.592	
—.081		24.762	25.105	25.459	25.823	26.197	26.583	26.980	27.389	27.810	28.245	
—.080		24.458	24.797	25.147	25.506	25.876	26.257	26.649	27.053	27.469	27.899	
—.079		24.154	24.489	24.834	25.189	25.554	25.930	26.318	26.717	27.128	27.552	
—.078		23.850	24.181	24.522	24.872	25.233	25.604	25.987	26.380	26.787	27.206	
—.077		23.546	23.873	24.210	24.555	24.912	25.278	25.656	26.044	26.446	26.859	
—.076		23.242	23.565	23.897	24.239	24.590	24.952	25.325	25.708	26.104	26.512	
—.075		22.939	23.257	23.585	23.922	24.269	24.626	24.993	25.372	25.763	26.166	
—.074		22.635	22.949	23.272	23.605	23.947	24.299	24.662	25.036	25.422	25.819	
—.073		22.331	22.641	22.960	23.288	23.626	23.973	24.331	24.700	25.081	25.473	
—.072		22.027	22.333	22.648	22.971	23.304	23.647	24.000	24.364	24.739	25.126	
—.071		21.723	22.025	22.335	22.654	22.983	23.321	23.669	24.028	24.398	24.780	
—.070		21.420	21.717	22.023	22.337	22.661	22.995	23.338	23.692	24.057	24.433	
—.069		21.116	21.409	21.711	22.021	22.340	22.669	23.007	23.356	23.716	24.086	
—.068		20.812	21.101	21.398	21.704	22.019	22.342	22.676	23.020	23.374	23.740	
—.067		......	20.793	21.086	21.387	21.697	22.016	22.345	22.684	23.033	23.393	
—.066		......	......	20.773	21.070	21.376	21.690	22.014	22.348	22.692	23.047	
—.065		......	......	......	20.753	21.054	21.364	21.683	22.012	22.351	22.700	
—.064		......	......	......	......	20.733	21.038	21.352	21.676	22.009	22.354	
—.063		......	......	......	......	......	20.712	21.021	21.340	21.668	22.007	
—.062		......	......	......	......	......	......	20.690	21.003	21.327	21.660	
—.061		......	......	......	......	......	......	......	20.667	20.986	21.314	
—.060		......	......	......	......	......	......	......	......	20.644	20.967	
—.059		......	......	......	......	......	......	......	......	......	20.621	
		65.0°F	*64.5°F*	*64.0°F*	*63.5°F*	*63.0°F*	*62.5°F*	*62.0°F*	*61.5°F*	*61.0°F*	*60.5°F*	

TABLE 5.4.1—Page 13

Barometer Total Correction Table

TEMP. 60.0-55.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.											Total Corr. in.
		60.0°F										
—.090		31.863	*59.5°F*									
—.089		31.510		*59.0°F*								
—.088		31.158	31.662									
—.087		30.806	31.304	31.818	*58.5°F*							
—.086		30.454	30.946	31.454		*58.0°F*						
—.085		30.102	30.588	31.090	31.609							
—.084		29.750	30.231	30.727	31.240	31.770	*57.5°F*					
—.083		29.398	29.873	30.363	30.870	31.394		*57.0°F*				
—.082		29.046	29.515	29.999	30.500	31.018	31.554		*56.5°F*			
—.081		28.694	29.157	29.636	30.130	30.642	31.171	31.719				
—.080		28.342	28.800	29.272	29.761	30.266	30.789	31.330	31.890	*56.0°F*		
—.079		27.990	28.442	28.908	29.391	29.890	30.406	30.940	31.494		*55.5°F*	
—.078		27.638	28.084	28.545	29.021	29.514	30.024	30.551	31.098	31.664		
—.077		27.286	27.726	28.181	28.652	29.138	29.641	30.162	30.701	31.261	31.841	
—.076		26.933	27.369	27.818	28.282	28.762	29.259	29.773	30.305	30.857	31.430	
—.075		26.581	27.011	27.454	27.912	28.386	28.876	29.384	29.909	30.454	31.019	
—.074		26.229	26.653	27.090	27.543	28.010	28.494	28.994	29.513	30.051	30.608	
—.073		25.877	26.295	26.727	27.173	27.634	28.111	28.605	29.117	29.647	30.197	
—.072		25.525	25.937	26.363	26.803	27.258	27.729	28.216	28.721	29.244	29.787	
—.071		25.173	25.580	25.999	26.433	26.882	27.346	27.827	28.325	28.841	29.376	
—.070		24.821	25.222	25.636	26.064	26.506	26.964	27.438	27.928	28.437	28.965	
—.069		24.469	24.864	25.272	25.694	26.130	26.581	27.048	27.532	28.034	28.554	
—.068		24.117	24.506	24.908	25.324	25.754	26.199	26.659	27.136	27.630	28.143	
—.067		23.765	24.149	24.545	24.955	25.378	25.816	26.270	26.740	27.227	27.732	
—.066		23.413	23.791	24.181	24.585	25.002	25.434	25.881	26.344	26.824	27.321	
—.065		23.061	23.433	23.818	24.215	24.626	25.051	25.492	25.948	26.420	26.911	
—.064		22.709	23.075	23.454	23.845	24.250	24.669	25.102	25.551	26.017	26.500	
—.063		22.356	22.718	23.090	23.476	23.874	24.287	24.713	25.155	25.614	26.089	
—.062		22.004	22.360	22.727	23.106	23.498	23.904	24.324	24.759	25.210	25.678	
—.061		21.652	22.002	22.363	22.736	23.122	23.522	23.935	24.363	24.807	25.267	
—.060		21.300	21.644	21.999	22.367	22.746	23.139	23.546	23.967	24.404	24.856	
—.059		20.948	21.287	21.636	21.997	22.370	22.757	23.156	23.571	24.000	24.445	
—.058		20.596	20.929	21.272	21.627	21.994	22.374	22.767	23.175	23.597	24.035	
—.057			20.571	20.909	21.258	21.618	21.992	22.378	22.778	23.193	23.624	
—.056				20.545	20.888	21.242	21.609	21.989	22.382	22.790	23.213	
—.055						20.866	21.227	21.600	21.986	22.387	22.802	
—.054							20.844	21.211	21.590	21.983	22.391	
—.053								20.821	21.194	21.580	21.980	
—.052									20.798	21.177	21.569	
—.051										20.773	21.159	
—.050											20.748	
		60.0°F	*59.5°F*	*59.0°F*	*58.5°F*	*58.0°F*	*57.5°F*	*57.0°F*	*56.5°F*	*56.0°F*	*55.5°F*	

Barometer Total Correction Table

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*55.0°F*	*54.5°F*									Total Corr. in.
—.075		31.606	---------	---------	---------	---------	---------	---------	---------	---------	---------	
—.074		31.187	31.788	*54.0°F*	---------	---------	---------	---------	---------	---------	---------	
—.073		30.769	31.362	---------	*53.5°F*	---------	---------	---------	---------	---------	---------	
—.072		30.350	30.935	31.543	---------	*53.0°F*	---------	---------	---------	---------	---------	
—.071		29.931	30.508	31.108	31.732	---------	---------	---------	---------	---------	---------	
—.070		29.513	30.081	30.673	31.288	31.928	*52.5°F*	---------	---------	---------	---------	
—.069		29.094	29.655	30.238	30.844	31.476	---------	*52.0°F*	---------	---------	---------	
—.068		28.675	29.228	29.803	30.400	31.023	31.671	---------	---------	---------	---------	
—.067		28.257	28.801	29.368	29.957	30.570	31.208	31.874	*51.5°F*	---------	---------	
—.066		27.838	28.375	28.933	29.513	30.117	30.746	31.402	---------	*51.0°F*	---------	
—.065		27.420	27.948	28.498	29.069	29.664	30.284	30.930	31.605	---------	---------	
—.064		27.001	27.521	28.062	28.625	29.211	29.821	30.458	31.122	31.816	*50.5°F*	
—.063		26.582	27.095	27.627	28.181	28.758	29.359	29.986	30.640	31.323	---------	
—.062		26.164	26.668	27.192	27.738	28.305	28.897	29.513	30.157	30.830	31.533	
—.061		25.745	26.241	26.757	27.294	27.852	28.434	29.041	29.675	30.336	31.028	
—.060		25.326	25.815	26.322	26.850	27.400	27.972	28.569	29.192	29.843	30.524	
—.059		24.908	25.388	25.887	26.406	26.947	27.510	28.097	28.710	29.350	30.019	
—.058		24.489	24.961	25.452	25.962	26.494	27.047	27.624	28.227	28.856	29.515	
—.057		24.071	24.534	25.017	25.518	26.041	26.585	27.152	27.745	28.363	29.010	
—.056		23.652	24.108	24.582	25.075	25.588	26.123	26.680	27.262	27.870	28.506	
—.055		23.233	23.681	24.147	24.631	25.135	25.660	26.208	26.780	27.377	28.001	
—.054		22.815	23.254	23.712	24.187	24.682	25.198	25.736	26.297	26.883	27.497	
—.053		22.396	22.828	23.277	23.743	24.229	24.735	25.263	25.814	26.390	26.992	
—.052		21.977	22.401	22.841	23.299	23.776	24.273	24.791	25.332	25.897	26.488	
—.051		21.559	21.974	22.406	22.856	23.323	23.811	24.319	24.849	25.403	25.983	
—.050		21.140	21.548	21.971	22.412	22.871	23.348	23.847	24.367	24.910	25.479	
—.049		20.722	21.121	21.536	21.968	22.418	22.886	23.374	23.884	24.417	24.974	
—.048		---------	20.694	21.101	21.524	21.965	22.424	22.902	23.402	23.924	24.469	
—.047		---------	---------	20.666	21.080	21.512	21.961	22.430	22.919	23.430	23.965	
—.046		---------	---------	---------	20.637	21.059	21.499	21.958	22.437	22.937	23.460	
—.045		---------	---------	---------	---------	20.606	21.037	21.486	21.954	22.444	22.956	
—.044		---------	---------	---------	---------	---------	20.574	21.013	21.472	21.951	22.451	
—.043		---------	---------	---------	---------	---------	---------	20.541	20.989	21.457	21.947	
—.042		---------	---------	---------	---------	---------	---------	---------	20.507	20.964	21.442	
—.041		---------	---------	---------	---------	---------	---------	---------	---------	20.471	20.938	
—.040		---------	---------	---------	---------	---------	---------	---------	---------	---------	20.433	
		55.0°F	*54.5°F*	*54.0°F*	*53.5°F*	*53.0°F*	*52.5°F*	*52.0°F*	*51.5°F*	*51.0°F*	*50.5°F*	

TABLE 5.4.1—Page 15

Barometer Total Correction Table

TEMP. 50.0–45.5°F

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.	*50.0°F*	*49.5°F*									Total Corr. in.
—.061		31.753	....	....	....	....	....	....	....	....	....	
—.060		31.236	31.983	*49.0°F*	....	....	....	....	....	....	....	
—.059		30.720	31.455	....	*48.5°F*	....	....	....	....	....	....	
—.058		30.204	30.926	31.683	....	....	....	....	....	....	....	
—.057		29.687	30.397	31.142	31.924	*48.0°F*	....	....	....	....	....	
—.056		29.171	29.869	30.600	31.369	....	*47.5°F*	....	....	....	....	
—.055		28.655	29.340	30.059	30.813	31.607	....	....	....	....	....	
—.054		28.139	28.811	29.517	30.258	31.038	31.858	*47.0°F*	....	....	....	
—.053		27.622	28.283	28.975	29.703	30.468	31.274	....	*46.5°F*	....	....	
—.052		27.106	27.754	28.434	29.148	29.899	30.689	31.523	....	*46.0°F*	....	
—.051		26.590	27.225	27.892	28.593	29.329	30.105	30.923	31.786	....	....	
—.050		26.073	26.697	27.351	28.037	28.760	29.520	30.322	31.169	32.000	*45.5°F*	
—.049		25.557	26.168	26.809	27.482	28.190	28.936	29.722	30.552	31.430	....	
—.048		25.041	25.639	26.267	26.927	27.621	28.351	29.121	29.935	30.795	31.706	
—.047		24.524	25.111	25.726	26.372	27.051	27.766	28.521	29.317	30.160	31.052	
—.046		24.008	24.582	25.184	25.816	26.482	27.182	27.921	28.700	29.525	30.398	
—.045		23.492	24.053	24.643	25.261	25.912	26.597	27.320	28.083	28.890	29.745	
—.044		22.975	23.525	24.101	24.706	25.343	26.013	26.720	27.466	28.255	29.091	
—.043		22.459	22.996	23.559	24.151	24.773	25.428	26.119	26.849	27.620	28.437	
—.042		21.943	22.467	23.018	23.596	24.204	24.844	25.519	26.231	26.985	27.783	
—.041		21.426	21.939	22.476	23.040	23.634	24.259	24.918	25.614	26.350	27.130	
—.040		20.910	21.410	21.935	22.485	23.065	23.675	24.318	24.997	25.715	26.476	
—.039		20.394	20.881	21.393	21.930	22.495	23.090	23.717	24.380	25.080	25.822	
—.038		....	....	20.851	21.375	21.926	22.505	23.117	23.762	24.445	25.168	
—.037		....	....	....	20.820	21.356	21.921	22.516	23.145	23.810	24.515	
—.036		....	....	....	....	20.787	21.336	21.916	22.528	23.175	23.861	
—.035		....	....	....	....	....	20.752	21.316	21.911	22.540	23.207	
—.034		....	....	....	....	....	....	20.715	21.294	21.906	22.554	
—.033		....	....	....	....	....	....	....	20.676	21.271	21.900	
—.032		....	....	....	....	....	....	....	....	20.636	21.246	
—.031		....	....	....	....	....	....	....	....	....	20.592	
		50.0°F	*49.5°F*	*49.0°F*	*48.5°F*	*48.0°F*	*47.5°F*	*47.0°F*	*46.5°F*	*46.0°F*	*45.5°F*	

TABLE 5.4.1—Page 16 *Barometer Total Correction Table* **TEMP 45.0–40.5°F**

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.											Total Corr. in.
		45.0°F										
—.047		31.999	*44.5°F*									
—.046		31.325		*44.0°F*								
—.045		30.652	31.616									
—.044		29.978	30.921	31.925	*43.5°F*							
—.043		29.304	30.226	31.208		*43.0°F*						
—.042		28.631	29.531	30.490	31.514		*42.5°F*					
—.041		27.957	28.836	29.773	30.773	31.842						
—.040		27.283	28.142	29.055	30.031	31.074	32.000	*42.0°F*				
—.039		26.610	27.447	28.338	29.290	30.307	31.398		*41.5°F*			
—.038		25.936	26.752	27.621	28.548	29.540	30.603	31.746				
—.037		25.262	26.057	26.903	27.807	28.772	29.808	30.921	32.000	*41.0°F*		
—.036		24.589	25.362	26.186	27.065	28.005	29.013	30.097	31.265		*40.5°F*	
—.035		23.915	24.667	25.468	26.323	27.238	28.219	29.272	30.408	31.636		
—.034		23.241	23.972	24.751	25.582	26.471	27.424	28.448	29.552	30.744	32.000	
—.033		22.568	23.277	24.033	24.840	25.703	26.629	27.623	28.695	29.853	31.109	
—.032		21.894	22.583	23.316	24.099	24.936	25.834	26.799	27.838	28.962	30.180	
—.031		21.220	21.888	22.599	23.357	24.169	25.039	25.974	26.982	28.071	29.252	
—.030		20.547	21.193	21.881	22.616	23.402	24.244	25.149	26.125	27.180	28.323	
—.029			20.498	21.164	21.874	22.634	23.449	24.325	25.269	26.289	27.394	
—.028				20.446	21.133	21.867	22.654	23.500	24.412	25.397	26.466	
—.027					20.391	21.100	21.859	22.676	23.555	24.506	25.537	
—.026						20.332	21.064	21.851	22.699	23.615	24.609	
—.025							20.270	21.026	21.842	22.724	23.680	
—.024								20.202	20.986	21.833	22.751	
—.023									20.129	20.942	21.823	
—.022										20.051	20.894	
		45.0°F	*44.5°F*	*44.0°F*	*43.5°F*	*43.0°F*	*42.5°F*	*42.0°F*	*41.5°F*	*41.0°F*	*40.5°F*	

TABLE 5.4.1—Page 17 *Barometer Total Correction Table* **TEMP. 40.0–28.5°F**

[For Fortin barometers, scale true at 62° F.]

Barometer No. .... Sum of Corrections .... Date ....

Attached Thermometer readings (°F) appear at head of columns.

Tabular values are barometer readings (inches of mercury).

Temp. Corr. in.	Total Corr. in.											Total Corr. in.
		40.0°F										
—.033		32.000	*39.5°F*									
—.032		31.506	......	*39.0°F*	......	......	......	......	......	......	......	
—.031		30.537	31.940	......	......	......	......	......	......	......	......	
—.030		29.567	30.926	32.000	*38.5°F*	......	......	......	......	......	......	
—.029		28.598	29.912	31.353	......	*38.0°F*	......	......	......	......	......	
—.028		27.628	28.898	30.290	31.823	......	......	......	......	......	......	
—.027		26.659	27.884	29.227	30.706	32.000	*37.5°F*	......	......	......	......	
—.026		25.690	26.870	28.164	29.589	31.167	......	*37.0°F*	......	......	......	
—.025		24.720	25.856	27.101	28.473	29.991	31.680	......	......	......	......	
—.024		23.751	24.842	26.039	27.356	28.815	30.437	32.000	*36.5°F*	......	......	
—.023		22.781	23.828	24.976	26.240	27.639	29.195	30.937	......	*36.0°F*	......	
—.022		21.812	22.814	23.913	25.123	26.462	27.953	29.621	31.501	......	*35.5°F*	
—.021		20.842	21.800	22.850	24.006	25.286	26.710	28.304	30.101	32.000	......	
—.020		......	20.786	21.787	22.890	24.110	25.468	26.988	28.701	30.647	32.000	
—.019		......	......	20.724	21.773	22.934	24.226	25.671	27.301	29.152	31.272	
—.018		......	......	......	20.657	21.758	22.983	24.355	25.901	27.657	29.668	
—.017		......	......	......	......	20.582	21.741	23.038	24.501	26.162	28.064	
—.016		......	......	......	......	......	20.498	21.722	23.101	24.667	26.461	
—.015		......	......	......	......	......	......	20.405	21.701	23.172	24.857	
—.014		......	......	......	......	......	......	......	20.301	21.677	23.253	
—.013		......	......	......	......	......	......	......	......	20.182	21.650	
—.012		......	......	......	......	......	......	......	......	......	20.046	
		40.0°F	*39.5°F*	*39.0°F*	*38.5°F*	*38.0°F*	*37.5°F*	*37.0°F*	*36.5°F*	*36.0°F*	*35.5°F*	
		35.0°F	*34.5°F*				......	......	......	......	......	
—.018		31.995	......	......	......	......	......	......	......	......	......	
—.017		30.266	32.000	*34.0°F*	......	......	......	......	......	......	......	
—.016		28.536	30.966	......	*33.5°F*	......	......	......	......	......	......	
—.015		26.807	29.089	31.796	......	......	......	......	......	......	......	
—.014		25.077	27.212	29.744	32.000	*33.0°F*	......	......	......	......	......	
—.013		23.348	25.335	27.693	30.535	......	*32.5°F*	......	......	......	......	
—.012		21.618	23.459	25.642	28.273	31.506	......	*32.0°F*	......	......	......	
—.011		19.889	21.582	23.590	26.011	28.986	32.000		......	......	......	
—.010		......	19.705	21.539	23.749	26.465	29.883	32.000	*31.5°F*	......	......	
—.009		......	......	19.487	21.487	23.945	27.037	31.047	......	*31.0°F*	......	
—.008		......	......	......	19.225	21.424	24.191	27.779	32.000	......	......	
—.007		......	......	......	......	18.903	21.345	24.510	28.779	32.000	*30.5°F*	
—.006		......	......	......	......	......	18.499	21.242	24.942	30.203	......	
—.005		......	......	......	......	......	......	17.974	21.105	25.556	32.000	
—.004		......	......	......	......	......	......	......	17.267	20.909	26.499	
—.003		......	......	......	......	......	......	......	......	16.263	20.610	
		35.0°F	*34.5°F*	*34.0°F*	*33.5°F*	*33.0°F*	*32.5°F*	*32.0°F*	*31.5°F*	*31.0°F*	*30.5°F*	
		30.0°F										
—.004		32.000	*29.5°F*	......	......	......	......	......	......	......	......	
—.003		28.131	......	*29.0°F*	......	......	......	......	......	......	......	
—.002		20.093	31.640	......	*28.5°F*	......	......	......	......	......	......	
—.001		......	18.984	32.000	......	......	......	......	......	......	......	
—.000		......	......	14.878	32.000	......	......	......	......	......	......	
		30.0°F	*29.5°F*	*29.0°F*	*28.5°F*							

TABLE 7.1

Table of Additive Reduction Constants, in Inches of Mercury, To Be Applied to Station Pressure in Order to Obtain Pressure Reduced to Sea Level, for Stations Having Elevations of 50 ft. (16 gpm) or Less; or Having Small Temperature Variations at Slightly Higher Elevations

Station elevation H_{pg} (gpm.)	Mean annual normal value of virtual temperature, in ° F. at the station								
	−40°	−30°	−20°	−10°	0°	10°	20°	30°	40°
	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$
0	0	0	0	0	0	0	0	0	0
1	.004	.004	.004	.004	.004	.004	.004	.004	.004
2	.009	.009	.008	.008	.008	.008	.008	.008	.007
3	.013	.013	.013	.012	.012	.012	.012	.011	.011
4	.018	.017	.017	.016	.016	.016	.015	.015	.015
5	.022	.021	.021	.020	.020	.020	.019	.019	.018
6	.026	.026	.025	.025	.024	.024	.023	.023	.022
7	.031	.030	.029	.029	.028	.027	.027	.026	.026
8	.035	.034	.034	.033	.032	.031	.031	.030	.030
9	.040	.039	.038	.037	.036	.035	.035	.034	.033
10	.044	.043	.042	.041	.040	.039	.038	.038	.037
11	.048	.047	.046	.045	.044	.043	.042	.041	.041
12	.053	.051	.050	.049	.048	.047	.046	.045	.044
13	.057	.056	.055	.053	.052	.051	.050	.049	.048
14	.061	.060	.059	.057	.056	.055	.054	.053	.052
15	.066	.064	.063	.061	.060	.059	.058	.056	.055
16	.070	.069	.067	.066	.064	.063	.061	.060	.059
17	.075	.073	.071	.070	.068	.067	.065	.064	.063
18	.079	.077	.075	.074	.072	.071	.069	.068	.066
19	.083	.082	.080	.078	.076	.075	.073	.072	.070
20	.088	.086	.084	.082	.080	.079	.077	.075	.074
21	.092	.090	.088	.086	.084	.082	.081	.079	.077
22	.097	.094	.092	.090	.088	.086	.085	.083	.081
23	.101	.099	.096	.094	.092	.090	.088	.087	.085
24	.105	.103	.101	.098	.096	.094	.092	.090	.089
25	.110	.107	.105	.102	.100	.098	.096	.094	.092
26	.114	.112	.109	.107	.104	.102	.100	.098	.096
27	.119	.116	.113	.111	.108	.106	.104	.102	.100
28	.123	.120	.117	.115	.112	.110	.108	.105	.103
29	.127	.124	.121	.119	.116	.114	.111	.109	.107
30	.132	.129	.126	.123	.120	.118	.115	.113	.111

TABLE 7.1 (CONTINUED)

Table of Additive Reduction Constants, in Inches of Mercury, To Be Applied to Station Pressure in Order to Obtain Pressure Reduced to Sea Level, for Stations Having Elevations of 50 ft. (16 gpm) or Less; or Having Small Temperature Variations at Slightly Higher Elevations

Station elevation H_{pg} (gpm.)	Mean annual normal value of virtual temperature, in ° F. at the station								
	40°	50°	60°	70°	80°	90°	100°	110°	120°
	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$	(in. Hg)$_n$
0	0	0	0	0	0	0	0	0	0
1	.004	.004	.004	.003	.003	.003	.003	.003	.003
2	.007	.007	.007	.007	.007	.007	.007	.006	.006
3	.011	.011	.011	.010	.010	.010	.010	.010	.010
4	.015	.014	.014	.014	.014	.013	.013	.013	.013
5	.018	.018	.018	.017	.017	.017	.016	.016	.016
6	.022	.022	.021	.021	.020	.020	.020	.019	.019
7	.026	.025	.025	.024	.024	.023	.023	.023	.022
8	.030	.029	.028	.028	.027	.027	.026	.026	.025
9	.033	.033	.032	.031	.031	.030	.030	.029	.029
10	.037	.036	.035	.035	.034	.034	.033	.032	.032
11	.041	.040	.039	.038	.038	.037	.036	.036	.035
12	.044	.043	.043	.042	.041	.040	.040	.039	.038
13	.048	.047	.046	.045	.044	.044	.043	.042	.041
14	.052	.051	.050	.049	.048	.047	.046	.045	.045
15	.055	.054	.053	.052	.051	.050	.049	.049	.048
16	.059	.058	.057	.056	.055	.054	.053	.052	.051
17	.063	.061	.060	.059	.058	.057	.056	.055	.054
18	.066	.065	.064	.063	.061	.060	.059	.058	.057
19	.070	.069	.067	.066	.065	.064	.063	.061	.060
20	.074	.072	.071	.070	.068	.067	.066	.065	.064
21	.077	.076	.074	.073	.072	.070	.069	.068	.067
22	.081	.080	.078	.077	.075	.074	.072	.071	.070
23	.085	.083	.082	.080	.079	.077	.076	.074	.073
24	.089	.087	.085	.084	.082	.080	.079	.078	.076
25	.092	.090	.089	.087	.085	.084	.082	.081	.080
26	.096	.094	.092	.090	.089	.087	.086	.084	.083
27	.100	.098	.096	.094	.092	.091	.089	.087	.086
28	.103	.101	.099	.097	.096	.094	.092	.091	.089
29	.107	.105	.103	.101	.099	.097	.096	.094	.092
30	.111	.109	.106	.104	.102	.101	.099	.097	.095

TABLE 7.1.1

Minimum and Maximum Virtual Temperature (Min. and Max., in ° F) Corresponding to Positive and Negative Deviations of 0.2 mb. in the Constant for Reduction of Pressure to Sea Level with Respect to the Constant Based on the Annual Normal Temperature (t_n, in ° F)

t_n		Geopotential of station, H_{pg}, in gpm.					
		5	10	15	20	25	30
° F		° F	° F	° F	° F	° F	° F
−20	Min.	−116.6	− 74.3	− 57.7	− 48.9	− 43.5	− 39.7
	Max.	+152.4	+ 52.1	+ 25.6	+ 13.3	+ 6.3	+ 1.7
−10	Min.	−110.6	− 66.6	− 49.4	− 40.2	− 34.5	− 30.6
	Max.	+172.0	+ 65.7	+ 37.8	+ 24.9	+ 17.5	+ 12.7
0	Min.	−104.6	− 59.0	− 41.1	− 31.5	− 25.6	− 21.5
	Max.	+191.9	+ 79.4	+ 50.0	+ 36.5	+ 28.8	+ 23.7
+10	Min.	− 98.6	− 51.4	− 32.8	− 22.9	− 16.7	− 12.4
	Max.	+212.2	+ 93.2	+ 62.4	+ 48.2	+ 40.1	+ 34.8
20	Min.	− 92.8	− 43.9	− 24.6	− 14.2	− 7.8	− 3.4
	Max.	+232.8	+106.1	+ 74.8	+ 59.9	+ 51.4	+ 45.9
30	Min.	− 86.9	− 36.4	− 16.4	− 5.6	+ 1.1	+ 5.7
	Max.	+253.9	+121.1	+ 87.2	+ 71.7	+ 62.8	+ 57.0
40	Min.	− 81.2	− 29.0	− 8.2	+ 3.0	+ 9.9	+ 14.7
	Max.	+275.3	+135.2	+ 99.7	+ 83.5	+ 74.2	+ 68.2
50	Min.	− 75.5	− 21.5	+ 0.0	+ 11.5	+ 18.8	+ 23.7
	Max.	+297.2	+149.5	+112.3	+ 95.3	+ 85.6	+ 79.3
60	Min.	− 69.8	− 14.2	+ 8.1	+ 20.1	+ 27.6	+ 32.7
	Max.	+319.4	+163.8	+124.9	+107.2	+ 97.1	+ 90.5
70	Min.	− 64.2	− 6.8	+ 16.2	+ 28.6	+ 36.3	+ 41.6
	Max.	+342.1	+178.3	+137.6	+119.1	+108.6	+101.8
80	Min.	− 58.7	+ 0.4	+ 24.2	+ 37.1	+ 45.1	+ 50.6
	Max.	+365.2	+192.8	+150.3	+131.1	+120.1	+113.0
90	Min.	− 53.2	+ 7.7	+ 32.2	+ 45.5	+ 53.8	+ 59.5
	Max.	+388.8	+207.5	+163.1	+143.1	+131.7	+124.3
100	Min.	− 47.7	+ 14.9	+ 40.2	+ 54.0	+ 62.5	+ 68.4
	Max.	+412.9	+222.3	+176.0	+155.1	+143.2	+135.6

TABLE 7.1.2

NORMAL AND EXTREMES OF TEMPERATURE

State and station	Lat. north		Long. west		Elev. of ground	Annual normal temp.[1]	Absolute extremes of temp.[2]		
							Length of record	Record highest	Record lowest
	°	′	°	′	feet	° F	years	° F	° F
ALABAMA							71	112	−18*
Birmingham	33	34	86	45	610	62.5	59	107	−10
Mobile	30	41	88	15	211	67.3	13	104	11
Montgomery	32	18	86	24	198	65.4	82	107	−5
ALASKA (Northern)							69	100	−76
Anchorage	61	10	149	59	92	35.3	32	86	−38
Barrow	71	18	156	47	22	10.1	34	78	−56
Bethel	60	47	161	43	10	29.6	31	90	−52
Fairbanks	64	49	147	52	436	26.2	25	91	−66
Kotzebue	66	52	162	38	10	20.6	12	82	−48
McGrath	62	58	155	37	334	25.5	14	89	−64
Nome	64	30	165	24	13	26.3	38	84	−47
Northway	62	58	141	58	1713	22.4	12	88	−72
ALASKA (Southern)							72	99	−51
Annette	55	02	131	34	110	45.6	14	90	−4
Cordova	60	29	145	30	40	38.6	11	84	−33
Juneau	58	22	134	35	15	40.6	11	83	−21
St. Paul Island	57	09	170	13	22	35.2	37	64	−26
Yakutat	59	31	139	40	28	39.3	8	79	−22
ARIZONA							60	127	−33
Flagstaff	35	08	111	40	6993	44.6	56	94	−30
Phoenix	33	26	112	01	1114	69.4	59	118	16
Prescott	34	39	112	26	5014	55.2	12	102	−5
Tucson	32	08	110	57	2558	67.6	14	110	16
Winslow	35	01	110	44	4880	55.0	23	104	−18
Yuma	32	40	114	36	199	74.7	77	123	22
ARKANSAS							64	120	−29
Fort Smith	35	20	94	22	458	62.0	73	113	−15
Little Rock	34	44	92	14	257	62.4	75	110	−13
Texarkana	33	27	94	00	361	65.1	12	106	−3
CALIFORNIA							70	134	−45
Bakersfield	35	25	119	03	489	65.0	48	118	13
Bishop	37	22	118	22	4108	56.0	19	109	−15
Blue Canyon	39	17	120	42	5280	50.1	11	93	5
Burbank	34	12	118	22	699	62.8	23	111	21
Eureka CO	40	48	124	10	43	52.3	68	85	20
Fresno	36	46	119	42	331	63.0	67	115	17
Los Angeles CO	34	03	118	14	312	63.9	77	109	28
Los Angeles	33	56	118	23	99	60.9	(3)	(3)	(3)
Mt. Shasta CO	41	19	122	19	3544	49.3	41	101	−8
Oakland	37	44	122	12	3	56.5	26	102	23
Red Bluff	40	09	122	15	341	63.2	76	115	17
Sacramento CO	38	35	121	30	25	60.9	77	114	17
San Diego	32	44	117	10	19	62.4	83	110	25
San Francisco CO	37	47	122	25	52	56.7	83	101	27
San Francisco	37	37	122	23	1	55.6	27	104	20
Sandberg CO	34	45	118	44	4517	55.3	22	102	3
Santa Maria	34	54	120	27	238	57.1	12	104	22

See reference notes at end of table.

TABLE 7.1.2 (CONTINUED)

NORMAL AND EXTREMES OF TEMPERATURE

State and station	Lat. north		Long. west		Elev. of ground	Annual normal temp.[1]	Absolute extremes of temp.[2]		
							Length of record	Record highest	Record lowest
	°	′	°	′	feet	° F	years	° F	° F
COLORADO							67	118	—60
Alamosa	37	27	105	52	7536	41.4	9	91	—50
Colorado Springs	38	49	104	42	6173	49.1	6	100	—27
Denver	39	46	104	53	5292	49.8	83	105	—29
Grand Junction	39	07	108	32	4849	52.1	63	105	—21
Pueblo	38	17	104	31	4639	51.5	66	105	—31
CONNECTICUT							67	105	—32
Bridgeport	41	10	73	08	7	50.5	54	102	—20
Hartford	41	56	72	41	169	50.1	50	101	—24
New Haven	41	16	72	53	6	49.7	82	101	—15
DELAWARE							62	110	—17
Wilmington	39	40	75	36	73	54.2	7	102	2
DIST. OF COLUMBIA									
Washington CO	38	54	77	03	72	56.8	83	106	—15
Washington	38	51	77	02	14	56.5	13	103	1
FLORIDA							65	109	— 2
Apalachicola CO	29	44	84	59	13	68.8	32	102	18
Daytona Beach	29	11	81	03	31	70.5	20	102	18
Fort Myers	26	35	81	52	15	73.9	35	101	[4]29
Jacksonville CO	30	20	81	39	18	69.8	83	104	10
Jacksonville	30	25	81	39	24	69.3	(3)	(3)	(3)
Key West CO	24	33	81	48	9	77.6	60	95	43
Lakeland CO	28	02	81	59	214	72.2	40	101	23
Miami CO	25	47	80	11	8	75.3	44	95	27
Miami	25	48	80	16	7	75.7	(3)	(3)	(3)
Miami Beach	25	47	80	08	9	76.6	13	98	35
Orlando	28	33	81	20	106	72.5	12	102	26
Pensacola CO	30	25	87	13	13	68.0	75	103	7
Tallahassee	30	26	84	20	64	67.7	15	103	15
Tampa	27	58	82	32	19	72.3	65	98	19
West Palm Beach	26	41	80	06	15	75.0	17	101	31
GEORGIA							63	112	—17
Athens	33	57	83	19	798	62.7	11	105	7
Atlanta	33	39	84	25	975	62.2	76	103	— 9
Augusta	33	22	81	58	143	65.4	81	106	3
Columbus	32	31	84	56	385	64.2	9	104	10
Macon	32	42	83	39	356	66.1	55	106	7
Rome	34	21	85	10	637	61.3	9	106	3
Savannah	32	08	81	12	48	66.8	84	105	8
HAWAII							50	100	18
Hilo	19	44	155	04	31	73.0	8	93	55
Honolulu CO	21	19	157	52	12	75.2	50	88	56
Honolulu	21	20	157	56	7	75.9	(3)	(3)	(3)
Lihue	21	59	159	21	115	74.0	4	87	52
IDAHO							62	118	—60
Boise	43	34	116	13	2842	50.8	15	109	—17
Idaho Falls 46W CO	43	32	112	57	4933	42.3	5	99	—26
Idaho Falls 43NW CO	43	51	112	42	4780	41.1	4	102	—26
Lewiston	46	23	117	01	1413	52.1	8	105	—22
Pocatello	42	55	112	36	4444	47.2	16	103	—31

See reference notes at end of table.

TABLE 7.1.2 (CONTINUED)

NORMAL AND EXTREMES OF TEMPERATURE

State and station	Lat. north		Long. west		Elev. of ground	Annual normal temp.[1]	Absolute extremes of temp.[2] Length of record	Record highest	Record lowest
	°	′	°	′	feet	° F	years	° F	° F
ILLINOIS							65	117	−35
Cairo CO	37	00	89	10	314	59.8	83	106	−16
Chicago	41	47	87	45	610	50.1	84	105	−23
Moline	41	27	90	31	589	50.2	22	106	−23
Peoria	40	40	89	41	654	51.0	99	113	−27
Springfield	39	50	89	40	589	52.4	76	112	−24
INDIANA							68	116	−35
Evansville	38	03	87	32	383	56.9	58	108	−23
Fort Wayne	41	00	85	12	801	49.9	43	106	−24
Indianapolis	39	44	86	16	793	52.5	84	107	−25
South Bend	41	42	86	19	768	49.1	61	109	−22
IOWA							82	118	−47
Burlington	40	47	91	07	694	51.3	57	111	−27
Davenport	41	31	90	34	568	51.4	82	111	−27
Des Moines	41	32	93	39	948	50.2	76	110	−30
Dubuque	42	24	90	42	1065	47.0	80	110	−32
Sioux City	42	24	96	23	1094	48.6	65	111	−35
KANSAS							68	121	−40
Concordia CO	39	34	97	40	1375	54.5	69	116	−25
Dodge City	37	46	99	58	2594	55.0	80	109	−26
Goodland	39	22	101	42	3645	49.9	34	111	−22
Topeka CO	39	03	95	41	926	55.9	68	114	−25
Wichita	37	39	97	25	1321	57.0	66	114	−22
KENTUCKY							67	114	−33
Lexington	38	02	84	36	979	55.4	71	108	−20
Louisville CO	38	15	85	46	457	57.3	(3)	(3)	(3)
Louisville	38	11	85	44	474	56.5	82	107	−20
LOUISIANA							64	114	−16
Baton Rouge	30	32	91	09	64	67.5	10	103	13
Lake Charles	30	13	93	09	12	68.3	16	104	12
New Orleans CO	29	57	90	04	9	70.4	81	102	7
New Orleans	29	59	90	15	3	69.1	(3)	(3)	(3)
Shreveport	32	28	93	49	252	66.4	81	110	− 5
MAINE							67	105	−48
Caribou	46	52	68	01	624	37.2	16	96	−32
Portland	43	39	70	19	61	44.5	83	103	−39
MARYLAND							60	109	−40
Baltimore CO	39	17	76	37	14	57.1	81	107	− 7
Baltimore	39	11	76	40	146	54.7	(3)	(3)	(3)
Frederick	39	25	77	23	294	54.7	13	102	− 8
MASSACHUSETTS							67	106	−30
Blue Hill Obs.	42	13	71	07	640	47.3	70	101	−21
Boston	42	22	71	01	15	50.7	83	104	−18
Nantucket	41	15	70	04	43	48.8	68	95	− 6
Pittsfield	42	26	73	17	1153	44.5	16	95	−25

See reference notes at end of table.

TABLE 7.1.2 (CONTINUED)

NORMAL AND EXTREMES OF TEMPERATURE

State and station	Lat. north		Long. west		Elev. of ground	Annual normal temp.[1]	Absolute extremes of temp.[2]		
							Length of record	Record highest	Record lowest
	°	′	°	′	feet	° F	years	° F	° F
MICHIGAN							67	112	−51
Alpena CO	45	04	83	26	587	43.5	82	104	−28
Detroit	42	24	83	00	619	49.3	84	105	−24
Detroit Willow Run	42	14	83	32	722	49.2	8	100	−13
East Lansing CO	42	44	84	29	856	47.3	55	102	−25
Escanaba CO	45	48	87	05	594	41.9	81	100	−32
Grand Rapids CO	42	58	85	40	638	49.3	63	108	−24
Grand Rapids	42	54	85	40	681	47.1	(3)	(3)	(3)
Marquette CO	46	34	87	24	677	42.2	80	108	−27
Muskegon	43	10	86	14	627	46.8	13	97	−14
Sault Ste. Marie	46	28	84	22	721	39.3	66	98	−37
MINNESOTA							68	114	−59
Duluth CO	46	47	92	06	1162	39.2	80	106	−41
International Falls	48	34	93	23	1179	36.3	15	97	−41
Minneapolis	44	53	93	13	830	45.6	64	108	−34
Rochester	44	00	92	27	1017	44.5	42	108	−42
St. Cloud	45	35	94	11	1034	41.9	61	107	−42
MISSISSIPPI							67	115	−16
Jackson	32	20	90	13	315	65.4	59	107	− 5
Meridian	32	20	88	45	294	64.5	65	105	− 7
Vicksburg CO	32	21	90	53	234	66.1	81	104	− 1
MISSOURI							67	118	−40
Columbia	38	58	92	22	778	54.6	65	113	−26
Kansas City	39	07	94	35	741	56.1	66	113	−22
St. Joseph	39	46	94	55	809	54.5	45	110	−24
St. Louis CO	38	38	90	12	465	57.3	84	112	−22
St. Louis	38	45	90	23	552	56.3	(3)	(3)	(3)
Springfield	37	14	93	23	1265	55.7	67	113	−29
MONTANA							88	117	−70
Billings	45	48	108	32	3568	47.2	20	106	−38
Glasgow CO	48	11	106	38	2090	42.7	11	108	−50
Great Falls	47	29	111	21	3664	45.1	17	105	−35
Havre CO	48	34	109	40	2488	43.6	75	108	−57
Helena	46	36	112	00	3893	43.0	75	103	−42
Kalispell	48	18	114	16	2965	43.2	5	97	−38
Miles City	46	26	105	52	2629	45.4	63	111	−49
Missoula	46	55	114	05	3200	44.1	19	105	−26
NEBRASKA							79	118	−47
Grand Island	40	58	98	19	1841	51.0	24	117	−26
Lincoln CO	40	49	96	42	1184	52.7	68	115	−29
Norfolk	41	59	97	26	1544	48.3	9	113	−26
North Platte	41	08	100	41	2779	49.5	80	112	−35
Omaha	41	18	95	54	978	51.6	82	114	−32
Scottsbluff	41	52	103	36	3950	48.2	63	110	−45
Valentine CO	42	53	100	33	2581	47.9	66	110	−38
NEVADA							66	122	−50
Elko	40	50	115	47	5075	45.7	59	107	−43
Ely	39	17	114	51	6257	45.2	16	99	−27
Las Vegas	36	05	115	10	2162	66.8	18	117	8
Reno	39	30	119	47	4397	49.5	67	106	−19
Winnemucca	40	54	117	48	4299	49.1	74	108	−36

See reference notes at end of table.

TABLE 7.1.2 (CONTINUED)

NORMAL AND EXTREMES OF TEMPERATURE

State and station	Lat. north		Long. west		Elev. of ground	Annual normal temp.[1]	Absolute extremes of temp.[2] Length of record	Record highest	Record lowest
	°	′	°	′	feet	° F	years	° F	° F
NEW HAMPSHIRE							79	106	−46
Concord	43	12	71	30	339	44.8	84	102	−37
Mt. Washington	44	16	71	18	6262	27.0	22	71	−46
NEW JERSEY							70	110	−34
Atlantic City CO	39	22	74	25	8	54.1	81	104	− 9
Newark	40	42	74	10	11	52.9	24	105	−14
Trenton CO	40	13	74	46	56	53.5	82	106	−14
NEW MEXICO							63	116	−50
Albuquerque	35	03	106	37	5310	56.6	23	102	− 6
Clayton	36	27	103	09	4969	53.1	40	105	−18
Roswell	33	24	104	32	3612	59.8	60	110	−29
NEW YORK							65	108	−52
Albany	42	45	73	48	277	47.2	81	104	−26
Binghamton CO	42	06	75	55	858	48.4	64	103	−28
Buffalo	42	56	78	44	693	47.5	81	99	−21
New York CO	40	42	74	01	10	53.4	84	102	−14
New York, Central Pk.	40	47	73	58	132	54.0	86	106	−15
New York	40	46	73	52	19	53.9	15	103	− 7
Rochester	43	07	77	40	543	47.5	83	102	−22
Schenectady CO	42	50	73	55	217	47.2	(3)	(3)	(3)
Syracuse	43	07	76	07	424	48.8	52	102	−26
NORTH CAROLINA							68	109	−21
Asheville CO	35	36	82	32	2203	56.3	52	99	− 6
Charlotte	35	13	80	56	727	60.5	76	104	− 5
Greensboro	36	05	79	57	891	58.1	26	102	− 7
Hatteras CO	35	13	75	41	4	63.1	80	97	8
Raleigh	35	52	78	47	438	59.9	68	105	− 2
Wilmington	34	16	77	55	30	63.8	84	104	5
Winston-Salem	36	08	80	14	967	58.5	55	104	−10
NORTH DAKOTA							63	121	−60
Bismarck	46	46	100	45	1650	41.7	80	114	−45
Devils Lake CO	48	07	98	52	1471	38.7	50	112	−46
Fargo	46	54	96	48	895	40.9	74	114	−48
Williston CO	48	09	103	37	1877	41.3	76	110	−50
OHIO							81	113	−39
Akron	40	55	81	26	1210	49.7	68	104	−20
Cincinnati Obs.	39	09	84	31	761	54.9	39	109	−17
Cincinnati	39	04	84	40	869	53.6	(3)	(3)	(3)
Cleveland CO	41	30	81	42	651	51.5	(3)	(3)	(3)
Cleveland	41	24	81	51	787	50.6	84	103	−17
Columbus CO	39	58	83	00	724	53.4	(3)	(3)	(3)
Columbus	40	00	82	53	815	52.0	76	106	−20
Dayton	39	54	84	12	1002	52.2	40	106	−16
Portsmouth CO	39	00	83	00	670	54.1	34	107	−25
Sandusky CO	41	25	82	40	603	51.3	77	105	−16
Toledo	41	34	83	28	622	49.4	84	105	−16
Youngstown	41	16	80	40	1178	49.8	11	100	−11

See reference notes at end of table.

TABLE 7.1.2 (CONTINUED)

NORMAL AND EXTREMES OF TEMPERATURE

State and station	Lat. north		Long. west		Elev. of ground	Annual normal temp.[1]	Absolute extremes of temp.[2] Length of record	Record highest	Record lowest
	°	′	°	′	feet	° F	years	° F	° F
OKLAHOMA							63	120	-27
Oklahoma City	35	24	97	36	1280	60.4	15	109	-10
Tulsa	36	11	95	54	672	60.6	19	112	- 8
OREGON							65	119	-54
Astoria	46	09	123	53	8	51.4	1	88	24
Burns CO	43	35	119	03	4140	46.8	16	103	-20
Eugene	44	07	123	13	361	52.4	12	105	- 3
Meacham	45	30	118	24	4050	43.5	10	97	-15
Medford	42	22	122	52	1312	54.0	43	115	-10
Pendleton	45	41	118	51	1492	52.7	19	110	-18
Portland CO	45	32	122	40	30	54.6	80	107	- 2
Portland	45	36	122	36	22	53.0	(3)	(3)	(3)
Roseburg CO	43	13	123	20	479	54.6	76	109	- 6
Salem	44	55	123	01	195	53.1	61	108	-10
Sexton Summit	42	37	123	22	3836	48.1	10	100	8
PENNSYLVANIA							67	111	-42
Allentown	40	39	75	26	376	50.9	11	102	-10
Harrisburg	40	13	76	51	335	53.0	66	104	-14
Philadelphia CO	39	57	75	09	26	55.7	84	106	-11
Philadelphia	39	53	75	15	13	54.3	(3)	(3)	(3)
Pittsburgh CO	40	27	80	00	749	53.9	(3)	(3)	(3)
Pittsburgh	40	30	80	13	1151	50.6	80	103	-20
Reading CO	40	20	75	58	266	53.7	57	105	-14
Scranton CO	41	25	75	40	746	50.1	54	103	-19
Williamsport	41	15	76	55	527	50.7	59	106	-18
RHODE ISLAND							67	102	-23
Block Island	41	10	71	35	110	49.9	74	95	-10
Providence	41	44	71	26	55	49.4	50	102	-17
SOUTH CAROLINA							70	111	-13
Charleston CO	32	47	79	56	9	66.6	84	104	7
Charleston	32	54	80	02	41	65.2	(3)	(3)	(3)
Columbia	33	57	81	07	217	64.0	67	107	- 2
Florence	34	11	79	43	146	63.6	73	108	- 1
Greenville	34	51	82	21	1018	61.0	37	104	4
Spartanburg	34	55	81	57	801	61.2	24	104	5
SOUTH DAKOTA							65	120	-58
Huron	44	23	98	13	1282	45.7	73	111	-43
Rapid City	44	02	103	03	3165	46.1	55	109	-33
Sioux Falls	43	34	96	44	1420	45.8	62	110	-42
TENNESSEE							72	113	-32
Bristol	36	29	82	24	1519	56.4	17	102	-10
Chattanooga	35	02	85	12	670	60.0	76	106	-10
Knoxville	35	49	83	59	950	59.3	84	104	-16
Memphis CO	35	09	90	03	271	62.4	(3)	(3)	(3)
Memphis	35	03	89	59	263	61.8	80	106	-11
Nashville	36	07	86	41	577	60.1	84	107	-13
Oak Ridge CO	36	02	84	14	905	57.8	7	105	0
Oak Ridge Area	----	----	----	----	886	58.1	10	103	1

See reference notes at end of table.

TABLE 7.1.2 (CONTINUED)

NORMAL AND EXTREMES OF TEMPERATURE

State and station	Lat. north		Long. west		Elev. of ground	Annual normal temp.[1]	Absolute extremes of temp.[2]		
							Length of record	Record highest	Record lowest
	°	′	°	′	feet	° F	years	° F	° F
TEXAS							77	120	−23
Abilene	32	26	99	41	1759	64.1	69	111	− 9
Amarillo	35	14	101	42	3590	56.6	63	108	−16
Austin	30	18	97	42	615	68.2	57	109	− 2
Brownsville	25	54	97	26	16	73.6	73	104	12
Corpus Christi	27	46	97	27	40	70.8	68	105	11
Dallas	32	51	96	51	487	66.5	41	111	− 3
Del Rio	29	22	100	49	1091	69.8	49	111	11
El Paso	31	48	106	24	3920	63.3	68	107	− 6
Fort Worth	32	50	97	03	544	66.0	56	112	− 8
Galveston CO	29	18	94	50	7	70.1	84	101	8
Galveston	29	16	94	52	5	70.1	(3)	(3)	(3)
Houston CO	29	46	95	22	41	70.0	65	108	5
Houston	29	39	95	17	50	68.9	(3)	(3)	(3)
Laredo	27	32	99	28	500	74.3	18	115	18
Lubbock	33	39	101	50	3243	59.5	8	106	− 9
Port Arthur	29	58	94	01	16	68.1	10	102	13
San Angelo	31	22	100	30	1903	66.2	7	107	1
San Antonio	29	32	98	28	792	68.8	70	107	0
Victoria	28	47	97	05	110	71.2	51	110	9
Waco	31	37	97	13	500	67.3	67	111	− 5
Wichita Falls	33	59	98	31	1027	63.1	11	110	−12
UTAH							64	116	−50
Milford	38	26	113	01	5028	49.0	37	104	−34
Salt Lake City	40	46	111	58	4220	51.3	26	106	−30
VERMONT							67	105	−50
Burlington	44	28	73	09	331	44.5	71	101	−29
VIRGINIA							63	110	−29
Lynchburg	37	20	79	12	947	56.6	83	106	− 7
Norfolk	36	53	76	12	26	59.2	84	105	2
Richmond	37	30	77	20	162	57.7	57	107	[5]− 3
Roanoke	37	19	79	58	1174	56.6	52	105	−12
WASHINGTON							88	118	−42
Olympia	46	58	122	54	190	50.0	13	103	− 1
Seattle CO	47	36	122	20	14	53.2	64	100	3
Seattle	47	32	122	18	14	52.1	(3)	(3)	(3)
Seattle-Tacoma	47	27	122	18	379	50.7	(3)	(3)	(3)
Spokane	47	37	117	31	2357	47.1	73	108	−30
Stampede Pass	47	17	121	20	3958	39.9	11	88	−11
Tatoosh	48	23	124	44	101	49.3	65	88	7
Walla Walla CO	46	02	118	20	949	54.2	82	113	−29
Yakima	46	34	120	32	1061	50.2	45	111	−25
WEST VIRGINIA							63	112	−37
Charleston	38	22	81	36	960	55.8	46	108	−17
Elkins	38	53	79	51	1970	50.4	56	99	−28
Huntington CO	38	25	82	27	565	57.4	14	105	−10
Parkersburg CO	39	16	81	34	615	54.9	66	106	−27

See reference notes at end of table.

TABLE 7.1.2 (CONTINUED)

NORMAL AND EXTREMES OF TEMPERATURE

State and station	Lat. north		Long. west		Elev. of ground	Annual normal temp.[1]	Absolute extremes of temp.[2] Length of record	Record highest	Record lowest
	°	′	°	′	feet	° F	years	° F	° F
WISCONSIN							64	114	−54
Green Bay	44	29	88	08	689	43.6	68	104	−36
La Crosse	43	52	91	15	652	46.2	82	108	−43
Madison CO	43	05	89	24	938	46.9	86	107	−29
Madison	43	08	89	20	857	46.6	(3)	(3)	(3)
Milwaukee	42	57	87	54	674	46.8	84	105	−25
WYOMING							95	114	−63
Casper	42	55	106	28	5322	45.1	15	104	−40
Cheyenne	41	09	104	49	6131	44.9	82	100	−38
Lander	42	48	108	43	5563	43.2	63	102	−40
Sheridan	44	46	106	58	3942	44.5	47	106	−41
CARIBBEAN									
Swan Island	17	24	83	56	28	80.7	12	92	64
PUERTO RICO							55	103	40
San Juan CO	18	28	66	06	47	78.0	56	94	62
San Juan	18	27	66	06	9	78.0	(3)	(3)	(3)
PACIFIC AREA[6]									
Canton Island	2	46 S	171	43 W	9	83.7	8	98	70
Koror CO	7	21 N	134	29 E	94	80.9	5	93	69
Ponape CO	6	58 N	158	13 E	112	81.0	4	96	68
Truk (Moen Island)	7	27 N	151	50 E	8	80.8	4	94	70
Wake Island	19	17 N	166	39 E	11	79.9	7	91	64
Yap CO	9	31 N	138	08 E	53	81.6	6	97	70

Data from airport or combined city office records unless otherwise indicated.

CO after station name indicates City Office data.

*On the line opposite the name of each state there are indicated the values of highest and lowest temperatures ever recorded in the given state, together with the length of record on whose basis the specified state-wide extremes were obtained. In determining these extremes the pertinent data for discontinued stations and for climatological substations, as well as for the places listed, were considered.

[1] Normal values are based on the period 1921-1950, and are means adjusted to represent observations taken at the present standard location.

[2] Data for this table are based on records through 1954.

[3] Data not available.

[4] Prior to 1920 when observations were made at Cooperative Stations at Fort Myers, Florida, a minimum of 24° F. occurred.

[5] Richmond, Virginia, City Office data through 1952, Airport thereafter. Record lowest at the Airport −12; Jan. 1940.

[6] See also Hawaii.

TABLE 7.1.3

Means and Extremes of Temperature

The annual mean and absolute extreme temperatures for available periods of record for stations outside the United States and its possessions contained in this table were obtained from sources shown on page 23 at the end of this table.

A table of contents and index of countries are presented as aids in locating data.

Temperature data are arranged alphabetically as follows:

1. According to continent or ocean.
2. According to country, island group, or other appropriate subdivision.
3. According to station name.

TABLE OF CONTENTS: Continents and Oceans

1. AFRICA

INDEX OF COUNTRIES

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
1. AFRICA	°	′	°	′	feet	years	° F	years	° F	° F
ALGERIA										
Adrar	27	53 N	0	20 W	938	8	76.5	8	131	—
Alger (Algiers)	36	37 N	3	04 E	126	—	60.6	36	112	28
Beni Abbes	30	08 N	2	11 W	1640	7	73.6	7	124	—
Biskra	34	51 N	5	44 E	407	—	71.2	18	119	28
El-Goléa	30	33 N	3	42 E	1247	—	70.7	19	124	22
El Oued	33	22 N	6	51 E	230	11	71.4	11	135	—
Géryville	33	41 N	1	00 E	4298	—	56.3	28	108	1
Ghardaïa	32	28 N	3	40 E	1739	14	70.3	14	126	—
In Salah	27	08 N	2	27 E	919	13	77.4	14	133	25
Laghouat (Laghout)	33	48 N	2	51 E	2559	17	64.2	36	120	—
BECHUANALAND										
Mahalapye (Myalapye)	23	06 S	26	40 E	3296	10	68.7	15	105	20
BELGIAN CONGO										
Elizabethville	11	39 S	27	28 E	4055	—	68.9	9	97	34
Usumbura	3	23 S	29	20 E	2625	—	—	8	94	54
BRITISH EAST AFRICA										
Berbera, Somaliland	10	27 N	45	02 E	31	—	85.0	15	117	52
Dar-es-Salaam	6	29 S	39	18 E	249	17	77.5	17	95	60
Eldama Ravine	0	03 S	35	30 E	7239	—	60.9	6	90	37
Entebbe	0	05 N	32	29 E	3842	19	70.0	16	92	51
Fort Portal	0	40 N	30	17 E	5229	—	—	2	86	50
Mombasa	4	02 S	39	37 E	50	—	78.5	—	98	60
Nairobi	1	16 S	36	48 E	5971	10	62.6	8+	89	34
Tabora	5	03 S	32	53 E	4151	10	72.5	10	98	49
Tandala	9	23 S	34	14 E	6629	—	—	5	86	31
EGYPT										
Alexandria	31	12 N	29	53 E	98	53	68.5	20	111	37
Aswân	24	02 N	32	53 E	327	—	—	20	124	36
Helwan	29	52 N	31	20 E	379	19	70.2	42	118	34
ERITREA										
Massawa (Massaua)	15	37 N	39	27 E	63	—	—	8	112	65
ETHIOPIA										
Addis Ababa (Adis Abeba)	9	02 N	38	45 E	8005	—	62.1	9	93	32
Gambela	8	15 N	34	35 E	1345	—	—	12	111	47
FRENCH EQUATORIAL AFRICA										
Brazzaville	4	17 S	15	16 E	951	—	—	16	101	53
Fort-Lamy	12	07 N	15	00 E	886	—	—	8	118	46
Libreville	0	23 N	09	26 E	115	—	—	22	99	60

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
FRENCH WEST AFRICA										
Bobo-Dioulasso, Haute-Volta	11	10 N	4	19 W	1509	—	—	6	107	46
Dakar, Senegal	14	40 N	17	25 W	98	—	—	15	104	55
Kayes, French Sudan	14	26 N	11	26 W	197	—	84.9	15	118	48
Port-Etienne, Mauretania	20	54 N	17	03 W	90	—	—	6	107	46
Tombouctou (Timbuctu) French Sudan	16	46 N	3	02 W	820	—	84.4	12	122	41
GHANA										
Accra	5	12 N	0	12 W	60	29	78.7	4	95	59
ITALIAN SOMALILAND										
Mogadiscio	2	05 N	45	25 E	59	—	—	2	93	61
LIBYA										
Bengazi (Benia)	32	06 N	20	04 E	82	—	—	7	109	38
Tripoli	32	54 N	13	11 E	59	—	66.2	20	113	35
MOROCCO										
Agadir	30	28 N	9	39 W	705	—	—	8	119	35
Bekrit	33	10 N	4	50 W	6266	—	—	5	100	5
Cape Spartel (Tanger)	35	47 N	05	55 W	192	27	63.3	28	107	30
Marrakech	31	38 N	7	59 W	1509	—	—	10	118	24
Rabat	34	00 N	6	20 W	210	—	—	10	115	34
Tata	29	45 N	7	59 W	2953	6	75.6	6	121	—
NIGERIA										
Calabar	4	58 N	8	19 E	170	10	77.3	16	100	59
Debundja	4	05 N	8	59 E	16	—	—	2	92	64
Lagos	6	27 N	3	24 E	22	29	80.5	19	104	63
Lokoja	7	48 N	6	44 E	320	—	—	16	103	52
Sokoto	13	02 N	5	15 E	1160	—	—	18	114	45
NORTHERN RHODESIA										
Livingstone	17	51 S	25	51 E	3000	—	73.1	4	103	37
NYASALAND										
Zomba	15	22 S	35	18 E	3130	—	69.4	28	102	41
PORTUGUESE EAST AFRICA (MOZAMBIQUE)										
Beira	19	50 S	34	51 E	30	—	—	20	108	48
Lourenço Marques	25	58 S	32	36 E	194	—	72.0	18	112	46
PORTUGUESE WEST AFRICA (ANGOLA)										
Huambo	12	45 S	15	40 E	5771	—	—	4	90	33
Luanda	8	49 S	13	13 E	167	—	—	24	91	57
SIERRA LEONE										
Freetown	8	29 N	13	09 W	224	42	80.7	34	101	61

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
SOUTHERN RHODESIA										
Bulawayo	20	09 S	28	40 E	4440	27	66.5	24	99	25
Salisbury	17	48 S	31	05 E	4860	27	65.3	28	102	30
SUDAN										
El Fasher	13	32 N	25	18 E	2395	—	—	5	113	33
Gallabat	12	48 N	36	10 E	2502	—	—	16	111	43
Khartoum	15	37 N	32	33 E	1280	22	84.6	21	117	41
Mogalla	05	11 N	31	47 E	1440	—	79.0	18	110	52
Wadi Halfa	21	55 N	31	19 E	421	—	75.7	19	126	28
TUNISIA										
Tunis	36	48 N	10	10 E	69	29	63.1	42	122	28
UNION OF SOUTH AFRICA										
Aliwal (North)	30	41 S	26	40 E	4352	44	59.3	29	99	14
Cape Town	33	56 S	18	29 E	40	68	62.3	48	104	31
Durban	29	51 S	31	00 E	260	36	70.5	50	111	41
East London	33	02 S	27	52 E	33	—	65.0	38+	106	34
Johannesburg	26	11 S	28	04 E	5925	20	59.6	20	90	23
Kimberley (Kimberly)	28	42 S	24	47 E	4042	27	63.6	31+	109	20
Okiep	29	36 S	17	52 E	3035	25	63.2	25	103	28
Port Elizabeth	33	59 S	25	37 E	181	40	63.6	51	107	36
Port Nolloth	29	14 S	16	51 E	25	—	57.6	14	104	32
Swakopmund	22	41 S	14	31 E	26	—	59.4	10	104	34
2. ANTARCTICA										
Little America	78	34 S	163	56 W	46	2	12.7	2	38	−72
Marguerite Bay	(68	20 S	67	00 W)*	28	—	—	5	47	−39
McMurdo Sound	77	51 S	166	45 E	—	5	0.7	4	42	−59

*Estimated.

Means and Extremes of Temperature

3. ASIA

INDEX OF COUNTRIES

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
3. ASIA										
AFGHANISTAN										
Kabul	34	30 N	69	13 E	5955	38	55.6	37	112	– 7
ARABIA										
Aden, Aden	12	46 N	45	03 E	94	40	82.9	33–50	109	61
Muscat, Oman	23	37 N	58	35 E	20	—	—	34	114	53
BURMA										
Akyab	20	07 N	92	57 E	20	43	78.8	60	100	47
Mergui	12	26 N	98	36 E	66	10	79.9	43	99	43
Rangoon	16	47 N	96	13 E	18	45	81.1	51	107	55
CEYLON										
Colombo	6	54 N	79	53 E	24	51	81.0	25	97	62
Hambantota	6	07 N	81	08 E	61	20	80.6	29	98	65
Nuwara Eliya	6	59 N	80	46 E	6188	50	59.1	28	80	27
Trincomalee	8	34 N	81	14 E	99	51	82.9	64	104	65
CHINA (NATIONALIST)										
Taipei (Taihoku), Formosa	25	02 N	121	31 E	30	34	70.9	33	101	32
CHINESE MAINLAND										
Chungking (Sha Ping Peh)	29	34 N	106	31 E	755	—	—	25	111	29
Hankow	30	35 N	114	17 E	121	22	62.2	29	106	13
Harbin	45	46 N	126	50 E	494	—	—	26	102	–40
Hsiying (Fort Bayard)	21	03 N	110	28 E	46	20	74.3	25	102	36
Hulun (Hailar)	49	14 N	119	43 E	1997	—	—	19	104	–57
Kashgar (Shufu)	39	30 N	75	53 E	4255	—	54.6	35	110	– 8
Kunming (Yunnanfu)	25	07 N	102	54 E	6211	20	60.6	10	91	24
Lanchow	36	02 N	103	50 E	5105	—	—	5	100	– 6
Minhow (Foochow)	25	59 N	119	27 E	66	—	—	14	102	29
Mukden (Shen Yang)	41	48 N	123	23 E	144	15	44.2	22	103	–27
Nanking	32	03 N	118	47 E	223	17	59.9	27	109	7
Paan (Batang)	30	00 N	99	30 E	8399	6	55.6	5	96	—
Shanghai (Zi-Ka-Wei)	31	11 N	121	25 E	23	48	60.4	53	103	10
Suchow (Kiuchuan)	39	50 N	99	07 E	5577	—	—	2	100	—
Tengueh (Tengchung)	24	45 N	98	14 E	5358	—	—	10	85	22
Tientsin (Tiensin)	39	10 N	117	10 E	13	21	53.6	21	109	– 3
HONG KONG (VICTORIA)										
Royal Observatory	22	18 N	114	10 E	109	37	71.8	67	97	32

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature: Length of record	Annual mean temperature: Mean	Absolute extremes of temperature: Length of record	Absolute extremes of temperature: Record highest	Absolute extremes of temperature: Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
INDIA										
Allahabad	25	28 N	81	54 E	307	45	78.5	10	120	36
Banaras (Benares)	25	30 N	83	00 E	250	—	77.2	51	120	30
Bangalore	12	58 N	77	37 E	3021	46	74.5	50	101	46
Bombay (Colaba)	18	55 N	72	54 E	37	43	80.6	51	100	56
Calcutta (Alipore)	22	32 N	88	24 E	21	44	78.8	51	111	44
Cochin	9	58 N	76	17 E	9	46	81.3	43+	100	61
Delhi	28	39 N	77	17 E	718	—	77.1	51	118	32
Gauhati	26	11 N	91	48 E	196	30	75.4	27	103	38
Hyderabad	17	20 N	78	30 E	1719	—	—	37	112	47
Jaipur	26	55 N	75	52 E	1431	40	78.0	—	—	—
Khatmandu, Nepal	27	43 N	85	21 E	4388	—	—	26	99	27
Kodaikanal	10	14 N	77	28 E	7688	20	58.3	29	79	35
Madras	13	04 N	80	15 E	22	46	83.1	58	113	57
Nagpur	21	09 N	79	09 E	1017	46	80.3	7	117	39
Shillong	25	34 N	91	56 E	4920	34	61.7	26	84	27
Simla	31	06 N	77	13 E	7232	45	55.9	37	94	17
Visokhapatnam (Waltair)	17	42 N	83	19 E	38	33	81.3	23	111	60
IRAN										
Bushehr (Bushire)	29	00 N	49	50 E	14	44	75.2	53	115	32
Esfahan (Isfahan)	32	38 N	51	38 E	5817	27	59.8	34	107	—
Jask	25	45 N	57	45 E	13	48	80.0	38	113	42
Kerman	30	21 N	57	05 E	6099	7	62.4	7	112	7
Kermanshah	34	19 N	47	04 E	4860	7	56.3	7	106	—
Mashad (Meshed)	36	17 N	59	38 E	3104	38	56.2	19	112	− 8
Tehran	35	41 N	51	25 E	4002	—	61.7	27	109	− 4
IRAQ										
Baghdad	33	20 N	44	22 E	125	42	72.9	34+	123	10
Basra (Busrah)	30	34 N	47	47 E	22	31	75.4	20	122	24
JAPAN										
Hakodate	41	47 N	140	43 E	13	—	—	52	92	− 7
Kagoshima	31	34 N	130	33 E	16	—	61.5	—	95	21
Kanazawa	36	32 N	136	39 E	94	—	—	42	101	15
Kyoto (Kioto)	35	01 N	135	44 E	161	40	56.7	44	100	11
Miyako	39	38 N	141	59 E	89	37	50.0	44	99	1
Nagasaki	32	44 N	129	52 E	436	42	60.3	47	98	22
Nemuro	43	20 N	145	35 E	89	37	41.9	44	90	− 9
Sapporo	42	49 N	141	40 E	56	—	44.2	—	93	−14
Tokyo	35	41 N	139	45 E	69	45	56.8	52	98	15
KASHMIR										
Dras	34	26 N	75	46 E	10059	24	35.2	29	92	−49
Gilgit	35	55 N	74	23 E	4892	28	62.7	33	113	—
Leh	34	09 N	77	34 E	11503	43	42.4	51	93	−19
Skardu	35	18 N	75	37 E	7507	24	51.5	32	102	—
KOREA										
Chemulpo (Zinsen)	37	19 N	126	32 E	222	26	51.1	30	98	− 6
Joshin (Zvosin)	40	40 N	129	11 E	13	25	46.2	24	100	−12
Fusan (Husan)	35	06 N	129	01 E	16	29	56.0	15	96	7
Woon-gi (Unggi) (Yuki)	42	20 N	130	24 E	64	15	43.1	15	98	−12

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
LAOS										
Luang-Prabang	19	50 N	102	04 E	1148	—	—	18	113	33
PAKISTAN										
Chaman	30	55 N	66	28 E	4311	26	65.9	34	112	—
Drosh	35	34 N	71	47 E	4723	17	62.3	17	110	—
Hyderabad	25	23 N	68	24 E	96	41	80.8	—	—	—
Jacobabad	28	17 N	68	29 E	187	43	80.7	60	127	—
Kalat	29	02 N	66	35 E	6616	26	55.1	24	106	—
Karachi	24	48 N	66	59 E	13	10	77.8	51	118	39
Lahore	31	34 N	74	21 E	702	45	75.9	51	120	29
Parachinar	33	54 N	70	07 E	6000	22	59.1	24	101	—
Peshawar (Peshwar)	34	01 N	71	34 E	1164	43	72.4	51	122	—
Quetta	30	12 N	67	00 E	5502	43	58.9	51–60	104	3
SINGAGPORE										
Singapore	1	17 N	103	51 E	10	29	81.0	26	97	66
THAILAND (SIAM)										
Bangkok	13	44 N	100	29 E	26	10	82.6	12	106	52
TIBET										
Gartok	31	45 N	80	21 E	15099	6	30.6	6	81	−32
Gyantse (Gyangtse)	28	56 N	89	36 E	13110	12	42.1	9	85	−20
Lhasa	29	48 N	91	02 E	12238	4	48.7	4	84	—
Yatung (Chumbi)	27	29 N	88	55 E	9800	20	46.5	32	76	—
USSR										
Akmolinsk	51	12 N	71	23 E	1152	30	34.5	28	99	−56
Alma Ata (Verniy)	43	16 N	76	53 E	2543	35	45.1	35–47	100	−30
Barguzin	53	37 N	109	38 E	1595	8–11	27.8	8–11	—	−58
Barnaul	53	20 N	83	47 E	517	35	33.4	33	96	−61
Berezov (Berezovo)	63	56 N	65	04 E	130	30	24.4	15–44	90	−65
Blagoveshchensk	50	15 N	127	31 E	459	30	31.5	20–32	104	−41
Blagovyeshtchensky Priisk	58	10 N	114	19 E	902	33	19.9	26	—	−66
Burr	58	00 N	106	00 E	1414	9	22.1	9	—	−72
Chita (Tachita)	52	02 N	113	30 E	2231	30	26.6	19	100	−57
Chkalov (Orenburg)	51	45 N	55	06 E	374	30	38.8	—	105	−44
Dickson (Ostrov Dikson)	73	30 N	80	24 E	43	20	12.6	12–18	73	−55
Dolinsk (Ochaia)	47	20 N	142	44 E	22	23	35.2	—	—	—
Doudinka (Dudinka)	69	23 N	86	04 E	66	14	13.1	17	83	−70
Elgiai	62	46 N	116	56 E	443	13	17.6	13	—	−75
Ft. Shevichenko	44	30 N	50	16 E	79	33	51.6	24–42	107	− 7
Guryev (Guriev)	47	07 N	51	55 E	−60	—	—	26	105	−34
Jakutsk (Yakutsk)	62	01 N	129	43 E	354	77	12.7	33	102	−84
Kazalinsk	45	46 N	62	07 E	219	20	46.6	—	108	−27
Kirensk	57	47 N	108	07 E	842	27	25.3	18	—	−71
Kiusiur (Bulum)	70	45 N	127	47 E	98	7	7.0	7–12	85	−75
Krasnovodsk	40	00 N	52	59 E	68	30	60.3	—	108	1
Malye Karmakuly	72	23 N	52	42 E	50	20	24.1	37–38	76	−47
Markovo On Anadyr	64	45 N	170	50 E	85	21	15.6	17	—	−75
Minusinsk	53	43 N	91	41 E	814	33	32.7	21	104	−59
Molotov (Perm)	58	01 N	56	16 E	535	33	34.0	18–26	94	−47
Naryn	41	30 N	76	02 E	6611	36	37.2	35	94	−33
Narynskoye	41	26 N	67	02 E	6713	28	36.7	—	—	—
Nerchinsky zavod	51	19 N	119	37 E	2034	33	25.3	8	—	−59

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
USSR (CONT.)										
Nikolayevsk	53	08 N	140	45 E	107	34	27.7	—	92	−51
Nizhne Kolymsk	68	32 N	160	59 E	16	—	—	5	82	−57
Novo Mariinsky (Anadyr)	64	45 N	177	33 E	9	13	17.6	16	75	−50
Obdorsk (Sale-Khard)	66	31 N	66	35 E	86	33	19.2	18	—	−65
Okhotsk	59	21 N	143	17 E	20	23	22.3	—	77	−50
Olekminsk	60	22 N	120	26 E	479	35	19.9	23	95	−76
Omsk	54	58 N	73	20 E	286	46	32.5	23–25	102	−56
Ostrov Vaigach	70	24 N	58	47 E	36	19	21.7	—	—	—
Pamir Post (Pamirski Post)	38	11 N	74	02 E	11942	—	30.4	26+	87	−52
Petropavlovsk Na Kamchatke	52	53 N	158	42 E	335	43	33.2	—	84	−25
Petrovskiy zavod	51	17 N	108	51 E	2628	29	24.1	18	—	−67
Sofyiski Priisk	52	27 N	134	07 E	3002	12	18.9	11	—	−59
Surgut	61	15 N	73	24 E	138	30	25.3	18	—	−67
Sverdlovsk (Ekaterinburg)	56	50 N	60	38 E	922	35	33.8	18–28	94	−44
Tashkent	41	20 N	68	18 E	1569	35	55.8	—	109	−19
Tobolsk	58	12 N	68	14 E	322	48	32.2	—	95	−51
Tomsk	56	30 N	84	58 E	399	35	30.4	—	95	−60
Turgay (Turgai)	49	38 N	63	27 E	407	31	40.1	6–7	104	−40
Turukhansk	65	55 N	87	38 E	131	46	18.7	13	—	−78
Ust Maia (Ust Maya)	60	25 N	134	29 E	525	27	14.4	17	—	−76
Ust-Tsilma (Ust-Zylma)	65	27 N	52	10 E	82	25	27.4	31	89	−61
Verkhoiansk	67	33 N	133	24 E	400	38	3.4	33+	94	−90
Vladivostok	43	07 N	131	54 E	56	35	40.3	—	96	−22
Voroshilov-Ussuryiskiy	43	52 N	131	57 E	152	26	37.4	3–7	91	−49
Yeniseysk (Yeniseisk)	58	27 N	92	11 E	262	35	28.9	34	96	−65
Yrkutsk (Irkutsk)	52	16 N	104	19 E	1532	40	29.7	34+	94	−58
Zlatoust	55	10 N	59	41 E	1503	—	—	—	93	−51
VIET-NAM (INDO CHINA)										
Moncay	21	31 N	107	51 E	30	24	73.6	—	—	—
Nhatrang (Naha Trang)	12	15 N	109	12 E	12	24	80.1	31	103	58
Phu Lien	20	48 N	106	37 E	379	24	73.8	31	107	43
Saigon	10	47 N	106	42 E	36	23	81.7	30+	104	57
4. AUSTRALIA (Including British New Guinea)										
Adelaide	34	56 S	138	35 E	140	69	63.0	75	116	32
Alice Springs	23	38 S	133	37 E	1926	46	69.6	46	117	23
Bourke	30	13 S	145	58 E	361	—	68.5	49	127	25
Brisbane	27	28 S	153	02 E	125	38	68.9	45	109	36
Darwin	12	28 S	130	51 E	97	43	82.6	43	104	56
Derby	17	18 S	123	40 E	53	—	—	28	114	42
Eucla	31	46 S	128	50 E	15	—	63.5	47	123	28
Georgetown	18	22 S	143	32 E	991	—	—	15	108	33
Halls Creek	18	13 S	127	46 E	1224	—	—	26	112	32
Hobart, Tasmania	42	53 S	147	20 E	37	9	54.4	25	105	29
Laverton	28	40 S	122	23 E	1529	—	—	24	115	24
Mein	13	13 S	142	47 E	400	—	—	15	104	43
Melbourne	37	49 S	144	58 E	115	—	58.3	76	111	27
Mitchell	26	32 S	147	52 E	1102	—	—	15	111	19
Onslow	21	43 S	114	57 E	14	—	75.4	28	117	38
Perth	31	57 S	115	50 E	197	—	64.0	35	108	34
Port Moresby, British New Guinea	9	29 S	147	09 E	126	43	80.0	6	98	68
Rockhampton	23	24 S	150	30 E	37	—	—	15	112	35
Sydney	33	52 S	151	13 E	138	66	63.2	73+	108	35

For New Zealand see South Pacific Ocean.

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

5. EUROPE (Including Middle East)

INDEX OF COUNTRIES

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	°F	years	°F	°F
5. EUROPE (Including Middle East)										
AUSTRIA										
Obir	46	30 N	14	29 E	6706	73	32.7	44	75	−17
Sonnblick	47	03 N	12	57 E	10192	50	20.6	50	—	−35
Wien (Vienna)	48	15 N	16	22 E	664	146	49.3	—	102	−14
BULGARIA										
Sofia	42	42 N	23	20 E	1804	—	50.0	37	102	−24
DENMARK										
København (Copenhagen)	55	41 N	12	36 E	16	139	44.4	61	91	−13
FINLAND										
Helsinki (Helsingfors)	60	10 N	24	57 E	38	92	39.6	44	88	−23
FRANCE										
Bordeaux	44	50 N	0	42 W	242	—	54.3	48	107	3
Brest	48	23 N	4	30 W	213	—	—	63	100	12
Lyon (Bron)	45	41 N	4	47 E	650	18	52.3	78	101	−4
Marseille	43	18 N	5	23 E	246	50	57.4	68+	100	11
Nantes	47	15 N	1	34 W	121	40	52.0	48	102	5
Paris	48	48 N	2	30 E	164	50	50.3	172	101	−14
GERMANY										
Berlin	52	33 N	13	21 E	160	150	48.2	82+	100	−25
Dresden	51	07 N	13	41 E	394	—	—	28	100	−18
Frankfurt A. Main	50	07 N	8	41 E	335	86	49.3	51	100	−7
Hannover	52	27 N	9	42 E	186	—	47.1	45	98	−13
München (Munich)	48	08 N	11	42 E	1727	—	46.2	54	97	−14

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
GREECE										
Athínai (Athens)	37	58 N	23	43 E	351	36	63.5	70	109	20
Kerkyra (Corfu)	39	37 N	19	57 E	105	—	63.9	36	102	23
HUNGARY										
Budapest	47	31 N	19	02 E	425	—	49.8	30	103	−10
IRELAND (EIRE)										
Dublin	53	21 N	6	16 W	155	—	49.9	41	85	4
Valentia (Valencia)	51	56 N	10	15 W	45	52	50.9	58	81	20
ISRAEL, STATE OF										
Jerusalem	31	47 N	35	13 E	2200	—	60.6	20	108	25
ITALY										
Cagliari, Sardinia	39	14 N	9	06 E	246	—	—	17	102	25
Catania	37	30 N	15	05 E	213	32	64.0	41	107	31
Milano (Milan)	45	28 N	9	11 E	482	59	55.2	29–30	101	6
Palermo	38	07 N	13	19 E	230	—	63.1	36	114	29
Roma (Rome)	41	54 N	12	29 E	207	114	59.7	73+	103	16
Sassari, Sardinia	40	44 N	8	35 E	735	42	59.9	40	107	26
Torino	45	04 N	7	41 E	902	—	—	46	96	4
Venezia (Venice)	45	26 N	12	20 E	69	—	—	56	97	14
LEBANON										
Beyrouth (Beirut)	33	54 N	35	28 E	111	20	70.8	30	102	30
LUXEMBOURG, GRAND DUCHY OF										
Luxembourg	49	37 N	6	03 E	1096	—	—	112	99	−10
NETHERLANDS										
De Bilt (Utrecht)	52	06 N	5	11 E	10	72	49.5	81	96	− 5
NORWAY										
Bergen II (Fredriksberg)	60	24 N	5	19 E	57	20	45.7	55	89	5
Bodø (Bordo)	67	17 N	14	24 E	7	53	39.6	55	85	− 4
Oslo (Kristiania) (Christiania)	59	55 N	10	43 E	82	55	42.4	55	95	−26
Tromsø	69	42 N	19	01 E	147	—	36.3	55	82	− 1
Trondheim (Trondhjem)	63	26 N	10	25 E	194	—	40.5	45	95	−15
Vardø	70	22 N	31	08 E	39	—	33.1	55	78	−11
POLAND										
Gdansk (Danzig)	54	24 N	18	40 E	16	—	—	51	96	−16
Warszawa (Warsaw)	52	13 N	21	01 E	396	36	46.2	44	98	−28
Wroclaw (Breslau)	51	07 N	17	02 E	482	70	47.3	50	98	−26
PORTUGAL										
Lisboa (Lisbon)	38	43 N	9	08 W	312	57	60.3	53	103	30

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
RUMANIA										
Bucuresti (Bucharest)	44	25 N	26	06 E	269	68	51.1	48	105	−23
Iasi (Jassy)	47	10 N	27	37 E	328	—	—	31	104	−20
Sulina	45	09 N	29	40 E	7	50	52.0	—	—	—
SPAIN										
Granada	37	09 N	3	35 W	2350	—	—	25	109	15
Madrid	40	24 N	3	41 W	2149	60	56.8	64	112	10
Oviedo	43	23 N	5	49 W	801	—	—	56	100	13
Palma (Island of Mallorca)	39	33 N	2	42 E	75	55	62.8	42	102	26
Sevilla (Seville)	37	23 N	5	59 W	98	—	67.3	57	124	22
Valencia	39	28 N	0	23 W	59	—	—	55	109	18
SWEDEN										
Haparanda	65	50 N	24	09 E	30	62	32.7	57	91	−40
Stensele	65	04 N	17	10 E	1078	—	—	44	84	−49
Stockholm	59	21 N	18	04 E	146	—	42.1	57	92	−22
SWITZERLAND										
Basel	47	33 N	7	35 E	1043	—	49.1	23	101	−11
Säntis	47	15 N	9	20 E	8202	38	27.7	—	66	−26
Zurich	47	23 N	8	33 E	1565	57	47.5	23	98	−12
TURKEY										
Istanbul	41	02 N	28	47 E	246	—	56.8	28	100	17
Izmir (Smyrna)	38	27 N	27	15 E	33	—	—	26	111	12
Sivas	39	44 N	37	00 E	4330	—	—	10	104	−22
Trabzon (Trebizond)	41	00 N	39	44 E	92	—	—	9	95	25
UNITED KINGDOM										
Aberdeen	57	10 N	2	06 W	94	50	46.0	65	86	4
Edinburgh	55	55 N	3	11 W	250	167	47.0	57	88	5
London	51	30 N	0	08 W	149	—	49.7	90	100	4
USSR (IN EUROPE)										
Arkhangelsk (Archangel)	64	35 N	40	36 E	22	35	32.4	—	94	−49
Astrakhan (Astrachan)	46	21 N	48	02 E	−45	35	48.6	—	110	−22
Baku	40	21 N	49	50 E	−43	—	57.0	—	99	—
Chernovitsy (Cernauti)	48	17 N	25	56 E	738	46	46.2	44	103	−21
Kaliningrad (Königsberg)	54	43 N	20	30 E	20	70	44.6	49–50	97	−24
Kazan (Kasan)	55	47 N	49	08 E	266	35	37.9	47–52	103	−44
Kharkov	50	00 N	36	14 E	381	—	—	—	99	−34
Kyev (Kiew) (Kiev)	50	27 N	30	30 E	600	35	44.4	20	98	−24
Leningrad	59	56 N	30	16 E	20	45	39.2	36+	97	−41
Lvov (Lemberg)	49	50 N	24	01 E	978	—	45.5	46	99	−28
Minsk	53	54 N	27	33 E	738	—	—	—	91	−27
Moscow	55	50 N	37	33 E	538	35	38.5	—	100	−44
Nikolaewskoe	51	27 N	45	27 E	633	35	39.6	18–30	104	−44
Noworossijek	44	44 N	37	49 E	121	35	54.7	52	102	−17
Odessa	46	29 N	30	44 E	213	35	49.8	27	95	−19
Riga	56	57 N	24	06 E	23	—	43.0	25	92	−20
Rostov	47	12 N	39	41 E	157	—	—	—	102	−19

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
USSR (IN EUROPE) (CONT.)										
Sebastopol	44	37 N	33	32 E	164	—	—	25	98	− 6
Tiflis	41	43 N	44	48 E	1325	35	54.3	38–61	101	0
Vilnius (Vilnyus) (Wilno)	54	41 N	25	18 E	486	135	43.7	12–37	91	−31
Vologda	59	15 N	39	50 E	400	—	—	—	93	−42
Vyatka	58	36 N	49	40 E	538	—	—	—	92	−43
YUGOSLAVIA										
Boegrad (Belgrad)	44	48 N	20	27 E	453	34	52.2	8	107	− 9
Hvar (Lesina)	43	10 N	16	26 E	66	59	61.0	60	99	19

6. INDIAN OCEAN (Including East Indies)

INDEX OF COUNTRIES

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
6. INDIAN OCEAN (Including East Indies)										
ANDAMAN ISLAND										
Port Blair	11	41 N	92	45 E	59	53	81.8	—	99	60
CHRISTMAS ISLAND										
Christmas Island	10	25 S	105	43 E	18	20	80.3	36–37	95	67
LACCADIVE ISLANDS										
Amini Devi	11	07 N	72	44 E	13	39	82.4	21	99	65
Minicoy, Maldive	8	18 N	73	00 E	9	10	82.0	14–15	98	63
MADAGASCAR										
Tamatave	18	09 S	49	26 E	13	—	74.5	15	100	55
Tananarive Antanarivo)	18	55 S	47	32 E	4600	35	65.7	24	93	35
MAURITIUS										
Royal Alfred Observatory	20	05 S	57	32 E	181	20	73.3	40	95	50

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
SEYCHELLES										
Mahe (Port Victoria)	4	37 S	55	27 E	126	47	79.7	27	89	68
EAST INDIES										
JAVA										
Djakarta (Batavia)	6	11 S	106	50 E	23	58	79.0	62+	96	65
Pasuruan (Pasoeroean)	7	38 S	112	55 E	16	10	80.2	17	96	58
NEW GUINEA										
Manokwari	0	52 S	134	20 E	62	—	—	4	91	70
NORTH BORNEO										
Sandakan	5	49 N	118	12 E	104	33	81.3	14	97	69
SUMATRA										
Medan	3	35 N	98	41 E	82	10	78.8	16+	97	60
TIMOR										
Kupang (Koepang)	10	16 S	123	34 E	7	—	—	14	101	60

Means and Extremes of Temperature

7. NORTH AMERICA (Including Central America)

INDEX OF COUNTRIES

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* Some data for Canadian stations are enclosed in parentheses to identify them as estimated. These estimations were based on maps published in the "Climatological Atlas of Canada"; prepared by Morley K. Thomas, a joint publication of the Meteorological Division, Department of Transportation, and the Division of Building Research, National Research Council: Ottawa, Canada (1953).

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
7. NORTH AMERICA (Including Central America)										
CANADA										
ALBERTA								46	108	−77
Banff	51	10 N	115	34 W	4521	41	35.4	33	93	(−58)
Beaverlodge	55	13 N	119	20 W	2500	30	36.0	31	98	−54
Calgary	51	02 N	114	02 W	3540	50	38.7	55	97	−49
Edmonton	53	33 N	113	30 W	2159	51	36.7	40	98	−57
Fort Chipewyan	58	43 N	111	09 W	722	45	26.1	45	93	−60
Fort Vermilion	58	27 N	116	03 W	950	39	29.0	46+	103	−77
McMurray (Fort)	56	39 N	111	13 W	1216	30	30.0	46	(103)	−64
Medicine Hat	50	01 N	110	37 W	2365	50	42.2	40	108	−51
BRITISH COLUMBIA									(107)	(−72)
Atlin	59	35 N	133	38 W	2240	26	33.0	22	86	−58
Barkerville	53	02 N	121	35 W	4180	42	35.4	40	93	−48
Bella Coola	52	20 N	126	52 W	10	35	44.6	—	(103)	(−20)
Bull Harbour	50	55 N	127	57 W	15	27	48.0	9–10	79	9
Clayoquot	49	09 N	125	55 W	26	33	48.2	42	90	10
Glacier	51	14 N	117	29 W	3776	35	36.0	—	(103)	(−40)
Hudson Hope	56	05 N	121	55 W	1606	23	35.0	—	(100)	(−65)
Kamloops	50	41 N	120	29 W	1263	34	47.1	34	102	−31
Lower Post	(59	55 N	128	37 W)	—	—	—	46	(92)	−61
Massett	54	02 N	132	08 W	10	34	45.7	27	84	− 2
Nelson	49	29 N	117	21 W	2234	33	45.0	39	103	−17
Prince George	53	50 N	122	48 W	1870	22	38.5	27	102	−57
Port Simpson	54	34 N	130	25 W	—	22	44.8	—	88	−10
Stewart	56	01 N	130	01 W	213	20	41.4	—	(93)	(−30)
Victoria	48	24 N	123	19 W	230	43	49.5	—	95	− 2
MANITOBA								—	(113)	(−63)
Churchill	58	46 N	94	13 W	43	45	17.7	45	96	−57
Flin Flon	54	45 N	101	50 W	968	23	31.0	—	(102)	(−63)
Norway House	53	58 N	97	52 W	722	32	28.9	21	90	−58
Port Nelson	57	00 N	92	51 W	49	15	20.9	15+	92	−55
Waskada	(49	06 N	100	47 W)	—	—	—	46	(111)	−61
Winnipeg	49	53 N	97	07 W	760	60	35.1	43	103	−46
NEW BRUNSWICK								46	(103)	−52
Chatham	47	03 N	65	29 W	98	50	40.1	50	102	−43
Chipman	46	11 N	65	54 W	—	—	—	46	(103)	−52
St. John	45	17 N	66	04 W	118	49	41.2	52	92	−21
NEWFOUNDLAND AND LABRADOR									(97)	(−61)
Belle Isle	51	53 N	55	22 W	436	53	30.4	66	72	−31
Cape Race	46	39 N	53	04 W	99	30	40.0	28	87	−15
Fogo	49	43 N	54	17 W	25	26	38.0	29	86	−18
Hebron, Laborador	58	12 N	62	37 W	49	20	23.0	19	87	−42
Hoffenthal, Labrador	55	27 N	60	12 W	25	20	26.0	17	84	−36
Port aux Basques	47	35 N	59	10 W	10	37	38.3	19	80	−14

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
NORTHWEST TERRITORIES									(101)	−80
Chesterfield	63	20 N	90	43 W	13	29	11.0	9	84	−55
Fort Good Hope	66	15 N	128	38 W	251	30	18.0	46	95	−79
Fort McPherson	67	26 N	134	53 W	150	30	17.0	46	92	−62
Fort Norman	64	54 N	125	30 W	300	25	21.0	21	92	−62
Fort Reliance	62	43 N	109	06 W	539	5	19.0	—	(93)	−80
Fort Simpson	61	52 N	121	21 W	415	27	25.0	46	(97)	−66
Fort Smith	60	01 N	111	58 W	665	30	26.0	16–46	93	−71
Hay River	60	51 N	115	46 W	529	29	25.0	36	96	−62
Lake Harbour, Baffin Island	62	50 N	69	55 W	69	45	16.0	24	74	−45
Nottingham Island	63	07 N	77	56 W	54	21	16.0	8–10	73	−42
Pond Inlet	72	43 N	77	30 W	10	21	7.0	6	77	−54
NOVA SCOTIA									99	−42
Halifax	44	39 N	63	36 W	240	50	43.9	53	99	−21
Sable Island	43	57 N	60	06 W	25	43	44.7	47–48	86	− 3
Sydney	46	09 N	60	12 W	49	50	42.3	69	98	−25
Upper Stewiacke	(45	24 N	62	59 W)	—	—	—	46	(97)	−42
Yarmouth	43	50 N	66	02 W	102	40	43.7	40	86	−12
ONTARIO									(108)	−73
Fort Hope	51	33 N	87	49 W	1100	30	28.8	30	99	−54
Halibury	47	29 N	79	39 W	705	24	33.4	—	102	−48
Iroquois Falls	48	46 N	80	42 W	—	—	—	46	(102)	−73
Kenora	49	48 N	94	32 W	1102	31	35.4	—	(108)	(−60)
London	42	59 N	81	13 W	—	43	45.4	43	106	−26
Moose Factory	51	16 N	80	30 W	29	33	30.4	38	97	−54
Ottawa	45	24 N	75	43 W	236	40	41.7	40	98	−33
Parry Sound	45	19 N	80	00 W	636	40	41.3	—	100	−39
Port Arthur	48	27 N	89	12 W	643	55	36.1	40	99	−51
Southampton	44	30 N	81	21 W	656	58	43.3	10	92	−34
Toronto	43	40 N	79	24 W	381	94	45.0	87	103	−28
White River	48	35 N	85	16 W	1243	49	32.5	42	97	−60
PRINCE EDWARD ISLAND									(99)	(−31)
Charlottetown	46	14 N	63	07 W	49	50	41.5	40	92	−23
QUEBEC									(102)	−66
Anticosti Island S.W. Point	49	24 N	63	33 W	30	50	35.1	40	85	−40
Cape Hopes Advance	61	05 N	69	33 W	240	—	—	46	(81)	−66
Clark City	50	12 N	66	38 W	315	14	33.1	7	89	−50
Doucet	48	13 N	76	37 W	1236	17	31.0	—	(98)	(−62)
Father Point	48	31 N	68	10 W	20	44	35.1	20	90	−32
Fort George	53	50 N	79	05 W	320	23	25.0	13	94	−52
Harrington Harbour	50	32 N	59	30 W	30	23	32.3	—	83	−37
Mistassini Post	50	30 N	73	55 W	1255	30	29.0	7	91	−56
Port Harrison	58	27 N	78	08 W	66	26	19.0	46	(80)	−59
Quebec	46	48 N	71	13 W	295	50	38.5	52	97	−52
SASKATCHEWAN									(112)	−70
Fond du Lac	59	20 N	107	24 W	690	24	22.4	24	90	−61
Prince Albert	53	10 N	105	38 W	1430	49	32.7	43	96	−70
Qu'Appelle	50	31 N	103	47 W	2146	50	34.9	42	102	−55

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
YUKON									100	−81
Carcross	60	11 N	134	34 W	2171	30	29.0	13–17	(93)	−67
Dawson	64	04 N	139	29 W	1062	38	22.8	34	95	−68
Mayo Landing	63	35 N	135	51 W	1625	26	26.0	14–15	(96)	−71
Snag	62	22 N	140	24 W	1925	10	22.0	—	(94)	−81
Watson Lake	60	07 N	128	48 W	2248	12	28.0	7–10	(92)	−74
CENTRAL AMERICA										
BRITISH HONDURAS										
Belize	17	30 N	88	11 W	17	—	79.3	22	99	46
CANAL ZONE										
Balboa Heights	8	58 N	79	33 W	118	—	—	20	97	63
Colon (Christobal)	9	21 N	79	54 W	36	38	80.7	20	95	66
COSTA RICA										
San Jose	9	56 N	84	07 W	3760	—	67.5	12	94	47
EL SALVADOR										
San Salvador	13	42 N	89	12 W	2238	33	74.8	5	103	45
GUATEMALA										
Chimax Bei Coban	15	37 N	90	21 W	—	21	65.7	11	91	36
Guatemala Ciudad	14	37 N	90	31 W	4855	—	64.8	13	90	41
MEXICO										
Camargo	27	40 N	105	12 W	4026	5	69.1	5	118	—
Casas Grandes	30	23 N	107	51 W	4774	13–17	62.1	13–17	119	—
Cerritos	22	25 N	100	15 W	3691	5	75.0	5	120	—
Chihuahua	28	38 N	106	04 W	4669	—	—	12	103	11
Ciudad Guerrero	28	33 N	107	29 W	6562	7–8	55.6	7–8	113	—
Guadalajara	20	41 N	103	20 W	5184	—	—	29	99	24
Ixmiquilpan	20	29 N	99	13 W	5676	5	65.5	5	106	—
La Paz	24	10 N	110	21 W	59	—	—	11	114	35
León	21	07 N	101	41 W	5935	28	65.8	—	—	—
Lerdo	25	30 N	103	32 W	3740	—	—	13	105	23
Mazatlán	23	12 N	106	25 W	256	32	75.9	30	95	42
Mexico City	19	26 N	99	08 W	7411	47	59.9	18	92	24
Monterrey	25	40 N	100	18 W	1733	27	71.4	24	118	21
Oaxaca	17	04 N	96	43 W	5128	22	68.5	—	100	36
Progreso	21	17 N	89	40 W	46	—	—	12	102	53
Santa Ana	30	34 N	111	08 W	2254	5	70.0	5	126	—
Veracruz	19	12 N	96	08 W	52	—	76.6	12	96	49
Zacatecas	22	47 N	102	34 W	8570	—	—	15	84	21

TABLE 7.1.3 (CONTINUED)

Means and Extremes of Temperature

8. NORTH ATLANTIC (Including West Indies)

INDEX OF COUNTRIES

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
AÇORES (AZORES)										
Horta	38	32 N	28	38 W	213	44	63.6	25	87	42
Ponta Delgada	37	44 N	25	40 W	73	30	63.1	32	82	42
BERMUDA										
St. George (Prospect)	32	18 N	64	46 W	151	55	70.6	32	94	39
CANARY ISLANDS										
La Laguna	28	28 N	16	20 W	1667	36	61.8	—	—	—
Las Palmas	28	07 N	15	26 W	39	—	67.8	34	99	46
CABO VERDE (CAPE VERDE) ISLANDS										
São Thiago (Santiago)	14	54 N	23	31 W	112	15	76.6	16	92	56
São Vicente (St. Vincent)	16	53 N	25	00 W	36	20	74.8	10	96	50
FAEROES										
Thorshavn (Højvig)	62	03 N	6	45 W	84	48	43.3	50	70	8
GREENLAND										
Angmagssalik (Angmagsalik)	65	37 N	37	33 W	104	45	29.6	24	77	−23
Eismitte	70	54 N	40	42 W	9000	—	—	1	—	−85
Godthåb (Godthaab)	64	11 N	51	43 W	30	45	28.4	—	76	−20
Grønnedal (Ivigtut)	61	12 N	48	10 W	16	45	33.1	48	86	−20
Jakobshavn (Jacobshavn)	69	13 N	51	02 W	41	47	21.7	—	71	−46
Upernavik (Upernivik)	72	47 N	56	07 W	62	46	16.5	—	69	−44

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
ICELAND										
Akureyri	65	41 N	18	05 W	23	10	40.5	—	—	—
Grimsey	66	33 N	18	01 W	72	48	35.6	59	79	—23
Stykkisholmur	65	05 N	22	46 W	82	48	39.2	59	73	—21
Tiegarhorn (Berufjordur) (Berufjord)	64	41 N	14	22 W	59	40	39.0	29	79	—10
Vestmannaeyjar (Vestmanno)	63	24 N	20	17 W	43	40	42.3	34	71	— 6
MADEIRA ISLAND										
Funchal	32	37 N	16	54 W	82	41	64.8	30	103	40
SPITSBERGEN (SVALBARD IS.)										
Green Harbour	78	02 N	14	14 E	35	19	18.5	17	61	—57
WEST INDIES										
ANTIGUA										
St. John's	17	06 N	61	50 W	—	—	—	11	93	60
BAHAMAS										
Nassau	25	05 N	77	21 W	25	42	77.2	40	94	51
BARBADOS										
Bridgetown	13	06 N	59	37 W	181	—	79.3	18	91	61
CUBA										
Camaguey	21	19 N	77	55 W	344	—	—	13	102	45
Habana (Havana)	23	08 N	82	22 W	79	55	77.4	21	95	50
GRENADA										
Richmond Hill	12	05 N	61	46 W	507	30	78.8	12	93	68
HAITI										
Port au Prince	18	34 N	72	22 W	123	44	79.0	25	100	59
JAMAICA										
Kingston	18	01 N	76	48 W	24	—	78.8	16	98	57
MARTINIQUE										
Fort-de-France	14	37 N	61	04 W	479	10	77.9	17	93	59
ST. CROIX										
Christiansted	17	45 N	64	42 W	23	45	80.2	40	96	64
TRINIDAD										
Port of Spain	10	40 N	61	32 W	41	57	77.3	36	101	56

TABLE 7.1.3 (CONTINUED)

Means and Extremes of Temperature

9. NORTH PACIFIC

INDEX OF COUNTRIES

For additional Pacific area stations see Table 7.1.2.

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
9. NORTH PACIFIC										
BONIN ISLAND										
Omura	27	05 N	142	11 E	9	10	72.3	—	95	45
FANNING ISLAND										
Fanning Island	3	54 N	159	23 W	17	—	—	8	100	69
HAWAII										
Midway Island	28	13 N	177	22 W	19	20	71.6	9	91	46
MARIANA ISLAND										
Guam (Ladrone Island)	13	24 N	144	38 E	61	19	81.7	17	93	64
PHILIPPINES										
Aparri	18	22 N	121	38 E	16	38	78.8	27	101	59
Iloilo	10	42 N	122	32 E	46	38	80.0	27	98	64
Legaspi	13	09 N	123	45 E	18	38	80.6	27	99	62
Manila	14	35 N	120	59 E	47	36	79.9	49	101	58
RYUKYU ISLAND (OKINAWA)										
Naha, Okinawa	26	13 N	127	41 E	34	30	71.8	30	96	41

Means and Extremes of Temperature

10. SOUTH AMERICA

INDEX OF COUNTRIES

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
10. SOUTH AMERICA										
ARGENTINA										
Año Nuevo	54	39 S	64	10 W	174	17	41.0	—	—	—
Bahia Blanca	38	43 S	62	15 W	82	53	59.7	50	108	18
Buenos Aires	34	36 S	58	22 W	82	69	61.0	50+	103	23
Cipolletti	38	57 S	67	59 W	870	10	57.0	17	106	9
Cordoba	31	25 S	64	12 W	1388	52	62.4	49	114	13
Deseado	47	46 S	65	55 W	26	8	49.8	8	102	1
Goya	29	09 S	59	15 W	85	48	67.8	10	109	28
Humahuaca	23	11 S	65	26 W	9925	11	56.1	11	93	—
La Quiaca	22	06 S	65	36 W	11355	23	48.7	19	90	0
Mar del Plata	38	02 S	57	33 W	45	10	56.8	17	103	22
Mendoza	32	53 S	68	50 W	2477	10	59.5	31	109	15
Puerto Madryn	42	49 S	64	58 W	46	24	56.3	8	102	11
Salta	24	46 S	65	28 W	3865	24	63.7	18	101	15
Santa Cruz	50	11 S	68	21 W	39	19	47.1	17	93	5
Santiago	27	47 S	64	15 W	613	—	71.1	36	115	24
Sarmiento	45	30 S	69	00 W	899	21	51.3	13	99	−27
Tinogasta	28	07 S	67	32 W	4653	11	64.3	11	110	—
Victorica	36	10 S	65	21 W	1027	—	—	17	113	4
BOLIVIA										
Aguas Calientes	17	48 S	66	37 W	11657	12	55.6	14	93	—
La Paz	16	30 S	68	08 W	12001	23	49.3	13+	80	27
Parotani	17	34 S	66	21 W	8038	12	65.7	12	102	—
Sucre	19	03 S	65	16 W	9344	—	54.3	6	82	25
Tolapalca	19	10 S	66	26 W	12815	12	50.7	14	91	—
Uyuni (Uyana)	20	32 S	66	52 W	12037	7	45.3	7	100	—
Yacuiba	22	02 S	63	40 W	2041	17	68.0	—	—	—
BRAZIL										
Barra do Cordo	5	30 S	45	16 W	266	—	—	17	103	54
Belem	1	27 S	48	29 W	42	—	—	18	95	64
Bella Vista	22	06 S	56	22 W	628	—	—	10	108	28
Caetité	14	03 S	42	37 W	2881	10	70.7	22	99	46
Corumbá	19	00 S	57	39 W	476	10	77.2	8	106	33
Cuiaba (Cuyaba)	15	36 S	56	06 W	541	25	79.7	9+	99	43
Curitiba	25	25 S	49	17 W	2979	33	61.5	—	—	—
Goyaz (Goiás)	15	55 S	50	08 W	1706	—	—	12	104	36
Igarapava	20	01 S	47	46 W	1886	30	72.7	12	104	30
Iguape	24	42 S	47	30 W	33	36	70.5	27	104	41
Manaus (Manaos)	3	08 S	60	01 W	146	10	79.9	14	101	66
Morro do Chapéo	11	33 S	41	14 W	3543	—	—	10	91	44
Passo Fundo	28	16 S	52	24 W	2198	—	—	17	101	21
Pelotas	31	42 S	52	23 W	23	7	64.0	7	102	28
Pirapóra	17	21 S	44	57 W	1548	—	—	16	100	37
Porto Nacional	10	39 S	48	20 W	778	—	—	9	104	50
Quixéramobim	5	16 S	39	15 W	679	25	81.3	35	99	64
Recife	8	04 S	34	52 W	97	—	—	11	94	67
Rio de Janeiro	22	54 S	43	10 W	201	55	72.9	49+	102	50
Salvador (Bahai)	13	00 S	38	31 W	210	29	76.8	22	95	62
Santarém (Taperinha)	2	25 S	54	42 W	66	27	78.3	11	96	65
São Paulo	23	34 S	46	55 W	2690	54	64.0	31	101	28
Terezina (Therezina)	5	05 S	42	49 W	230	—	—	12	102	57
Turiacú (Turi-assú)	1	43 S	45	24 W	18	29	79.2	8	100	59
Uaupés (São Gabriel do Rio Negro)	0	08 S	67	05 W	279	10	77.4	—	—	—
Uruguaiana (Uruguayana)	29	45 S	57	05 W	184	—	—	15	108	27

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
BRITISH GUIANA										
Dadanawa	2	48 N	59	26 W	—	—	—	4	103	66
Georgetown	6	50 N	58	12 W	6	38	80.6	17	92	68
CHILE										
Caldera	27	03 S	70	53 W	92	—	—	24	86	39
Coquimbo (Punta Tortuga)	29	55 S	71	22 W	82	40	58.6	25	80	37
I. Evangelistas	52	24 S	75	36 W	180	24	42.8	—	60	24
Iquique	20	12 S	70	11 W	30	25	64.4	25	92	43
Isla Guafo	43	34 S	74	45 W	459	31	49.3	12	85	32
Isla Juan Fernández	33	37 S	78	52 W	20	36	59.7	11–12	82	38
Ovalle	30	36 S	71	12 W	820	—	—	12	97	33
Punta Angeles (Valparaiso)	33	01 S	71	38 W	134	—	—	25	94	36
Punta Arenas	53	10 S	70	54 W	92	34	43.6	19	81	15
Punta Dungenes	52	24 S	68	26 W	16	—	—	—	80	19
Santiago (Tobalabo)	33	27 S	70	42 W	1703	62	56.4	21	99	24
Valdivia	39	48 S	73	14 W	30	—	52.9	11	95	25
ECUADOR										
Quito	0	10 S	78	35 W	9350	13	54.6	4	79	35
FRENCH GUIANA										
Cayenne	4	56 N	52	21 W	20	—	—	23	97	65
PARAGUAY										
Asunción	25	16 S	57	38 W	210	27	72.3	20	109	33
PERU										
Arequipa	16	22 S	71	33 W	8041	31	58.1	13	82	36
Cailloma	15	08 S	71	52 W	12992	19	39.7	17	82	−10
Cuzco (Cusco)	13	31 S	72	03 W	11309	—	—	14	80	28
El Mista (Summit)	16	21 S	71	26 W	19200	2	17.7	3	52	0
Lambayeque	6	42 S	79	54 W	52	10	71.8	—	—	—
Limatambo (Lima)	12	04 S	77	02 W	420	10	65.3	6	90	40
Mollendo	17	05 S	72	02 W	80	—	—	10	90	50
Vincocaya	15	41 S	71	05 W	14370	8	37.8	3	70	—
SURINAM (DUTCH GUIANA)										
Paramaribo	5	49 N	55	09 W	12	10	81.5	26	99	62
URUGUAY										
Montevideo	34	52 S	56	13 W	96	43	60.8	20+	109	20
VENEZUELA										
Caracas	10	30 N	66	55 W	3420	—	67.3	16	91	45
Ciudad Bolivar	8	09 N	63	33 W	125	—	80.6	7	97	66
Maracaibo	10	38 N	71	36 W	20	—	—	9	102	68
Mérida	8	36 N	71	09 W	5384	—	—	9	85	52

TABLE 7.1.3 (CONTINUED)

Means and Extremes of Temperature

11. SOUTH ATLANTIC

INDEX OF COUNTRIES

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature: Length of record	Annual mean temperature: Mean	Absolute extremes of temperature: Length of record	Absolute extremes of temperature: Record highest	Absolute extremes of temperature: Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
11. SOUTH ATLANTIC										
FALKLAND										
Cape Pembroke	51	41 S	57	42 W	70	25	42.9	10	75	19
SAINT HELENA										
Saint Helena	15	57 S	5	40 W	1980	29	61.1	6–8	93	58
SOUTH GEORGIA ISLANDS										
Grytviken	54	13 S	36	33 W	13	42	35.1	15	80	− 3
SOUTH ORKNEYS										
Laurie Island	60	44 S	44	39 W	23	41	23.5	13	51	−40

Means and Extremes of Temperature

12. SOUTH PACIFIC

INDEX OF COUNTRIES

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature: Length of record	Annual mean temperature: Mean	Absolute extremes of temperature: Length of record	Absolute extremes of temperature: Record highest	Absolute extremes of temperature: Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
12. SOUTH PACIFIC										
COOK ISLANDS										
Alofi Niue	19	02 S	169	55 W	65	20	76.8	20	98	54
FIJI ISLANDS										
Suva	18	08 S	178	26 E	12	19	77.2	33	98	57

TABLE 7.1.3 (CONTINUED)

MEANS AND EXTREMES OF TEMPERATURE

Location and station	Lat.		Long.		Elev. of ground	Annual mean temperature		Absolute extremes of temperature		
						Length of record	Mean	Length of record	Record highest	Record lowest
	°	′	°	′	feet	years	° F	years	° F	° F
GILBERT ISLANDS										
Ocean Island	0	52 S	169	35 E	177	10	82.9	12	96	68
NEW CALEDONIA										
Nouméa	22	16 S	166	27 E	30	—	—	24	99	52
NEW ZEALAND										
Auckland	36	50 S	174	50 E	125	60	59.1	50	90	32
Dunedin	45	52 S	170	32 E	240	60	50.7	65	94	23
Wellington	41	16 S	174	46 E	10	60	55.3	65	88	29
PHOENIX ISLANDS										
Canton	2	46 S	171	43 W	9	30	83.7	8	98	70
SAMOA										
Apia	13	48 S	171	46 W	6	31	78.4	29	96	61
SOCIETY ISLANDS										
Papeete (Papeiti)	17	32 S	149	34 W	20	—	—	8	93	61
SOLOMON ISLANDS										
Tulagi	9	05 S	160	08 E	7	—	—	9	97	70
SOUTHERN LINE ISLANDS										
Malden Island	4	01 S	155	01 W	21	28	84.8	24	98	21

Means and Extremes of Temperature

Sources of Data

The annual mean and absolute extreme temperatures for available periods of record for stations outside the United States and its possessions were obtained from the following sources:

H. H. Clayton, "World Weather Records," Smithsonian Institution, Washington, D.C. Miscellaneous Collections, volume 79, 1927; volume 90, 1944; and volume 105, 1947.

U.S. Department of Agriculture, "Climate and Man," 1941 Yearbook of Agriculture (pages 672 to 684), U.S. Government Printing Office, Washington, D.C.

W. Köppen and R. Geiger, "Handbuch der Klimatologie," volume II, part J, "The Climates of North America—Canada" by A. J. Conner. Berlin, 1938.

Canada, Bureau of Statistics, "The Canada Year Book," editions of 1927-1928, and 1930. Ottawa, Canada. (See section on Meteorological Tables.)

W. G. Kendrew, "The Climates of the Continents," 3d edition, Clarendon Press, Oxford, 1942.

Meteorological Division, Department of Transport, Canada, "Addendum to volume 1 of 'Climatic Summaries for Selected Meteorological Stations in Canada.'" Toronto, Canada, 1954.

John R. Theaman, "Minimum Temperatures for the Dominion of Canada." Publication No. 23. Indianapolis, Indiana, 1946.

TABLE 7.1.4

Sea-Level Pressure and Altimeter-Setting Constants for Low Stations[*]

[All tabular constants are positive unless preceded by minus (—) sign.]

Symbols Indicating Type of Station

The types of stations referred to in Table 7.1.4 are designated by the following symbols:

WBAS	Weather Bureau Airport Station
WBO	Weather Bureau Office, not at an airport
FAA	Federal Aviation Agency
CG	US Coast Guard
A	Aviation reporting, second order
S	Synoptic, second order
SAWR	Supplementary Aviation Weather Reporting
C	Cooperative.

In cases where there are at least two airport weather reporting stations located near a given city, the name of the specific airport to which the reduction constants pertain is given after a slant mark following the name of the city.

State and station	Type of station	Station elevation H_p	Altimeter-setting reduction constant	Sea-level pressure reduction constants	
		feet	in. Hg	in. Hg	mb
ALASKA					
Barrow	WBAS	13	0.003	0.016	0.5
Gustavus	FAA	29	.021	.033	1.1
Juneau	WBAS	24	.015	.027	0.9
Kotzebue	WBAS	16	.006	.019	0.6
Moses Point	FAA	16	.006	.019	0.6
Nome	WBAS	22	.013	.025	0.8
Platinum	A	22	.013	.025	0.8
St. Paul Island	WBAS	28	.019	.032	1.1
Unalakleet	FAA	21	.012	.024	0.8
Yakataga	FAA	26	.017	.029	1.0
Yakutat	WBAS	31	.023	.035	1.2
CALIFORNIA					
Crescent City	FAA	57	.051	.062	2.1
Eureka	WBO	60	.054	.066	2.2
Long Beach	WBAS	40	.032	.043	1.5
Oakland	WBAS	7	—0.003	.008	0.3
Point Piedras Blancas	CG	69	#	.075	2.5
Sacramento	WBAS	25	.016	.027	0.9
SanDiego/Lindbergh	WBAS	28	.019	.030	1.0
San Francisco	WBAS	18	.009	.020	0.7
Santa Barbara	FAA	20	.011	.022	0.7
Stockton	FAA	27	.018	.029	1.0
CONNECTICUT					
Bridgeport	WBAS	17	.008	.019	0.6
New Haven	WBAS	13	.003	.014	0.5

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[*] Since the correction in each case depends upon the pertinent value of the station elevation H_p, the official in charge should verify that the proper value of H_p for his station is given in the table. If a different value of H_p than that listed in the table is adopted for any station after July 1, 1962, the corrections indicated in the table for the station under consideration are invalid; and under such circumstances new corrections which are appropriate for the current value of H_p should be obtained and applied.

[#] Determine altimeter setting by means of altimeter-setting table in which the station pressure is used as an argument, or by means of a Pressure Reduction Computer if one is available.

TABLE 7.1.4 (CONTINUED)

*Sea-Level Pressure and Altimeter-Setting Constants for Low Stations**

[All tabular constants are positive unless preceded by minus (—) sign]

State and station	Type of station	Station elevation H_p	Altimeter-setting reduction constant	Sea-level pressure reduction constants	
		feet	in. Hg	in. Hg	mb
FLORIDA					
Apalachicola	WBO	35	.027	.037	1.3
Clewiston	S	28	.019	.029	1.0
Daytona Beach	WBAS	41	.034	.043	1.5
Fort Myers	WB-FAA	12	.002	.013	0.4
Jacksonville	WBAS	31	.023	.033	1.1
Key West	WBO	21	.012	.022	0.7
Melbourne	FAA	27	.018	.028	0.9
Miami/International	WBAS	12	.002	.013	0.4
Tampa	WBAS	11	.001	.012	0.4
Vero Beach	FAA	28	.019	.029	1.0
W. Palm Beach	WBAS	21	.012	.022	0.7
GEORGIA					
Brunswick	FAA	24	.015	.025	0.8
HAWAII					
French Frigate Shoals	CG	6	—0.004	.006	0.2
Hana (Maui)	SAWR	85	#	.089	3.0
Hilo	WBAS	36	.028	.038	1.3
Honolulu	WBAS	15	.005	.016	0.5
Kahului	WBAS	67	#	.070	2.4
Kona	SAWR	23	.014	.024	0.8
LOUISIANA					
Burrwood	WBO	17	.008	.018	0.6
Lake Charles	WBAS	32	.024	.033	1.1
New Orleans/Moisant	WBAS	30	.022	.031	1.0
MASSACHUSETTS					
Boston	WBAS	29	.021	.032	1.1
Nantucket	WBAS	12	.002	.014	0.5
NEW JERSEY					
Newark	WBAS	30	.022	.032	1.1
NEW YORK					
New York/International	WBAS	22	.013	.024	0.8
NORTH CAROLINA					
Cape Hatteras	WBO	11	.001	.012	0.4
Elizabeth City	FAA	13	.003	.014	0.5
New Bern	FAA	24	.015	.026	0.9
Wilmington	WBAS	38	.030	.041	1.4
OREGON					
Astoria	WBAS	22	.013	.024	0.8
North Bend	FAA	17	.008	.019	0.6
PENNSYLVANIA					
Philadelphia/International	WBAS	28	.019	.030	1.0
TEXAS					
Brownsville	WBAS	20	.011	.021	0.7
Galveston	WBAS	9	—0.001	.010	0.3
Palacios	FAA	15	.005	.016	0.5
Port Arthur	WBAS	22	.013	.023	0.8
VIRGINIA					
Cape Henry	WBO	18	.009	.019	0.6
Norfolk	WBAS	30	.022	.032	1.1

Determine altimeter setting by means of altimeter-setting table in which the station pressure is used as an argument, or by means of a Pressure Reduction Computer if one is available.

TABLE 7.1.4 (CONTINUED)

*Sea-Level Pressure and Altimeter-Setting Constants for Low Stations**

[All tabular constants are positive unless preceded by minus (—) sign]

State and station	Type of station	Station elevation H_p	Altimeter-setting reduction constant	Sea-level pressure reduction constants	
		feet	in. Hg	in. Hg	mb
WASHINGTON					
Hoquiam	FAA	15	.005	.016	0.5
Port Angeles	CG	29	.021	.032	1.1
Seattle/Boeing	WBAS	30	.022	.033	1.1
CARIBBEAN AND WEST INDIES					
Abrahama Bay, Mayaguana Is., Bahamas	C	9	—0.001	0.009	0.3
Basseterre, Saint Kitts	S	29	.021	.030	1.0
Charlotte Amalie, St. Thomas, Virgin Is.	FAA	15	.005	.015	0.5
Christiansted, Saint Croix, Virgin Is.	FAA	55	.049	.057	1.9
Grand Turk, Turks Island	C	22	.013	.023	0.8
Green Turtle Cay, Abaco Is., Bahamas	C	45	.038	.047	1.6
Mangrove Cay, Andros Is., Bahamas	C	15	.005	.015	0.5
Mayaguez, Puerto Rico	SAWR	28	.019	.029	1.0
Ponce, Puerto Rico	S	36	.028	.037	1.3
San Juan, Puerto Rico	WBAS	62	#	.064	2.2
Swan Island, W. I.	WBO	35	.027	.036	1.2
West End, Grand Bahama Is., Bahamas	C	10	.000	.010	0.3
PACIFIC ISLANDS					
Canton Island, Phoenix Group	WBAS	11	.001	.011	0.4
Eniwetok, Marshall Is.	WBAS	21	.012	.022	0.7
Falalop, Ulithi Atoll, Caroline Islands	CG	16	.006	.016	0.5
Johnston Island	WBAS	17	.008	.018	0.6
Koror, Caroline Is.	WBO	109	#	.112	3.8
Kwajalein, Marshall Is.	WBAS	26	.017	.027	0.9
Lele Island, Kusaie, Caroline Is.	S	13	.003	.013	0.4
Majuro, Marshall Is.	WBAS	10	.000	.010	0.3
Ponape, East Caroline Is.	WBO	151	#	.155	5.2
Tafuna, Samoa	C	10	.000	.010	0.3
Truk, Moen, Caroline Is.	WBAS	8	—0.002	.008	0.3
Wake Island	WBAS	12	.002	.012	0.4
Yap, West Caroline Is.	WBO	56	.050	.057	1.9
(See also Hawaii)					

Determine altimeter setting by means of altimeter-setting table in which the station pressure is used as an argument, or by means of a Pressure Reduction Computer if one is available.

TABLE 7.2.1

Table of Mean Vapor Pressure, e_s, (in mb.) as a Function of Station Temperature Argument, t_s, in ° F. for Continental U.S. Stations[1] [2]

Station No.	State and station	Station elev. (H_p)	Station temperature argument, t_s, in °F.												
			0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
		feet	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
	ALABAMA														
228	Birmingham	630	[3]1.0	[3]1.7	[3]2.8	[3]4.4	[3]6.2	8.4	11.8	17.4	[4]25.8	[5]26.5	[5]21.3	[5]15.8	....
	ARIZONA														
274	Tucson	2555	......	[3]1.7	[3]2.6	[3]3.7	[3]5.3	6.1	6.4	7.5	12.0	[5]18.8	[5]19.0	[5]13.0	[5]10.0
280	Yuma	206	[3]1.0	[3]1.7	[3]2.6	[3]3.7	[3]4.7	[3]5.9	7.3	9.3	12.5	18.3	[5]20.7	[5]16.0	[5]10.0
372	Prescott	5022	[3]1.0	[3]1.7	[3]2.7	[3]3.7	4.6	5.4	6.3	9.2	[5]15.2	[5]16.6	[5]14.2	[5]10.9	....
	ARKANSAS														
344	Fort Smith	463	[3]1.0	[3]1.7	[3]2.8	[3]4.4	6.1	8.1	11.5	16.8	23.5	[5]26.2	[5]21.3	[5]17.6	....
	CALIFORNIA														
290	San Diego	28	......	[3]1.7	[3]2.8	[3]4.5	[3]6.3	[3]8.6	12.4	19.4	[5]22.7	[5]22.1	[5]20.2	[5]16.9	....
384	Bakersfield	492	[3]1.0	[3]1.7	[3]2.8	[3]4.5	[3]6.7	8.7	9.9	10.8	11.9	[5]14.1	[5]13.5	[5]11.6	[5]10.3
389	Fresno	327	......	[3]1.7	[3]2.8	[3]4.5	[3]7.0	8.9	10.5	11.6	13.0	[5]14.2	[5]13.0	[5]10.8	....
394	Santa Maria	238	[3]1.0	[3]1.8	[3]3.0	[3]4.5	[3]6.4	8.8	13.1	[5]18.0	[5]18.5	[5]17.0	[5]14.5	....	....
493	Oakland	7	[3]1.0	[3]1.7	[3]2.8	[3]4.5	[3]6.8	9.3	12.9	[5]15.8	[5]15.4	[5]14.0	[5]11.9	[5]10.8	....
594	Eureka	60	[3]1.0	[3]1.8	[3]2.9	[3]4.5	[3]6.7	10.1	[4]14.7	[5]17.0	[5]16.8	[5]14.9	[5]12.5	....	....
595	Mount Shasta	3587	[3]1.0	[3]1.7	[3]3.0	[3]4.5	6.0	7.7	9.5	[4]11.4	[5]12.5	[5]11.4	[5]9.4	[5]8.0	....

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[1] Except for Canadian stations, data not marked with any footnote sign in the body of Tables 7.2.1–7.2.5 will be understood to be obtained from the correlation of 30-year normal monthly station temperature (t_{30}) *with* mean monthly vapor pressure (e_s) derived from mean monthly relative humidity based on four standard synoptic hours and saturation vapor pressure corresponding to t_{30}. A curve was drawn by eye estimate for each station to give best fit to the points representing the correlation between e_s and t_s. In the case of Canadian stations, data were based on temperature and humidity values published in "Handbuch der Klimatologie," edited by W. Köppen, and R. Geiger, Band II, Teil J (Zweite Lieferung), The Climates of North America, Canada, by A. J. Conner, Berlin 1938; tables 2 and 5.

[2] Data based on the assumption that at temperatures of −10°F. and below, the mean relative humidity with respect to ice is 80%, yielding a curve of e_s versus t_s for the lowest temperature range. On this basis, for the temperature range from −70°F. to −10°F., use the following data in regard to the correlation between t_s (in °F.) and e_s (in mb.):

−70°, 0.013; −60°, 0.03; −50°, 0.05; −40°, 0.10; −30°, 0.19;
−20°, 0.34; −10°, 0.60.

[3] Data based on a curve constructed by smooth interpolation between the lowest extremity of the curve mentioned in footnote 1 and the uppermost extremity of the curve mentioned in footnote 2.

[4] Data determined by a small amount of extrapolation, involving a temperature departure of not more than 3° F. from the uppermost extremity of the curve mentioned in footnote 1.

[5] Data obtained by estimate and extrapolation of the curve of e_s versus t_s for temperatures higher than those referred to under footnote 4. Some guidance in regard to the configuration of the extrapolated curve was secured by means of a special, extensive, statistical investigation of detailed data based on hourly dewpoint observations correlated with the corresponding temperatures at the high end of the range, in the case of a small selection of representative stations.

TABLE 7.2.1

Table of Mean Vapor Pressure, e_s, (in mb.) as a Function of Station Temperature Argument, t_s, in ° F. for Continental U.S. Stations[1] [2]

Station No.	State and station	Station elev. (H_p)	Station temperature argument, t_s, in °F. 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
		feet	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
	COLORADO														
469	Denver	5332	^{3}1.0	^{3}1.6	^{3}2.2	3.0	4.3	6.0	8.6	12.0	^{5}16.2	^{5}17.6	^{5}16.8	^{5}13.5	......
476	Gr. Junction	4839	^{3}1.0	^{3}1.7	^{3}2.6	3.7	4.6	5.6	7.0	8.8	^{4}12.6	^{5}12.6	^{5}11.2	^{5}9.8	......
	FLORIDA														
201	Key West	21	......	......	^{3}2.9	^{3}4.6	^{3}7.0	^{3}10.5	^{3}14.8	^{3}19.8	26.8	^{5}30.2	^{5}23.6	......	......
206	Jacksonville	31	^{3}1.0	^{3}1.7	^{3}2.8	^{3}4.5	^{3}6.7	^{3}9.6	13.5	18.5	26.8	^{5}28.4	^{5}21.6	......	......
211	Tampa	11	^{3}1.0	^{3}1.7	^{3}2.8	^{3}4.5	^{3}6.8	^{3}9.9	13.6	18.3	27.0	^{5}30.2	^{5}23.0	......	......
	GEORGIA														
217	Macon	362	^{3}1.0	^{3}1.7	^{3}2.8	^{3}4.2	^{3}6.2	8.7	11.9	16.9	25.0	^{5}27.3	^{5}21.3	^{5}15.8	......
	IDAHO														
578	Pocatello	4478	^{3}1.0	^{3}1.8	2.9	4.1	5.3	6.5	8.1	9.4	^{5}10.7	^{5}11.3	^{5}10.8	^{5}8.8	......
	ILLINOIS														
534	Chicago	623	^{3}1.0	^{3}1.7	^{3}2.8	4.2	5.9	8.3	11.9	17.6	^{5}21.6	^{5}21.4	^{5}19.2	^{5}16.5	......
	INDIANA														
432	Evansville	388	^{3}1.0	^{3}1.7	^{3}2.8	^{3}4.3	5.9	8.4	12.0	17.0	^{4}23.7	^{5}24.6	^{5}21.4	^{5}18.0	......
	KANSAS														
450	Wichita	1392	^{3}1.0	^{3}1.7	^{3}2.7	^{3}4.0	5.6	7.8	11.3	16.3	22.0	^{5}24.2	^{5}21.6	^{5}18.5	......
465	Goodland	3688	^{3}1.0	^{3}1.7	^{3}2.7	3.7	5.1	7.2	10.5	15.0	^{5}20.5	^{5}21.7	^{5}20.3	^{5}17.4	......
	LOUISIANA														
231	New Orleans	53	^{3}1.0	^{3}1.7	^{3}2.8	^{3}4.5	^{3}6.7	9.5	13.2	18.1	26.2	^{5}27.3	^{5}21.6	^{5}15.8	......
248	Shreveport	259	^{3}1.0	^{3}1.7	^{3}2.8	^{3}4.5	^{3}6.5	8.9	11.9	17.3	24.7	^{5}26.7	^{5}21.0	^{5}16.0	......

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[2] For t_s below 0° F. at all stations, use t_s (° F.), e_s (mb.) data: −70°, 0.013; −60°, 0.03; −50°, 0.05; −40°, 0.10; −30°, 0.19; −20°, 0.34; −10°, 0.60. See also reference notes on page 1 of this table.

TABLE 7.2.1 (CONTINUED)

Table of Mean Vapor Pressure, e_s, (in mb.) as a Function of Station Temperature Argument, t_s, in ° F. for Continental U.S. Stations[1] [2]

Station No.	State and station	Station elev. (H_p)	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
		feet	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
	MAINE														
606	Portland	63	[3]1.0	[3]1.7	[3]2.6	4.1	6.3	9.3	13.6	[4]18.5	[5]20.0	[5]18.6	[5]15.3	--------	--------
712	Caribou	628	[3]1.0	1.8	2.8	4.2	6.2	9.0	13.3	[5]17.6	[5]19.0	[5]17.6	[5]15.5	--------	--------
	MASSACHUSETTS														
509	Boston	29	[3]1.0	[3]1.7	[3]2.6	3.6	5.3	8.2	12.5	17.5	[5]19.8	[5]18.8	[5]15.5	--------	--------
	MICHIGAN														
537	Detroit	626	[3]1.0	[3]1.7	[3]2.8	4.2	6.0	8.4	12.1	17.0	[5]20.6	[5]20.6	[5]18.0	--------	--------
734	Sault Ste. Marie	724	[3]1.1	[3]1.8	2.9	4.3	6.4	9.3	13.6	[5]18.7	[5]20.2	[5]18.8	[5]17.2	--------	--------
	MINNESOTA														
658	Minneapolis	838	[3]1.0	[3]1.7	2.6	4.0	5.8	8.0	11.4	16.6	[5]20.9	[5]20.6	[5]19.2	[5]17.3	--------
745	Duluth	1417	[3]1.0	1.9	2.9	4.4	6.2	8.9	13.6	[5]18.4	[5]20.5	[5]19.9	[5]18.4	[5]15.9	--------
	MISSOURI														
445	Columbia	785	[3]1.0	[3]1.7	[3]2.8	4.1	5.7	8.2	11.9	17.5	[4]23.6	[5]24.5	[5]21.6	[5]18.3	--------
	MONTANA														
772	Helena	3898	[3]1.0	[3]1.7	2.5	3.6	5.1	7.0	9.2	[4]11.5	[5]13.2	[5]13.5	[5]12.0	[5]9.7	--------
777	Havre	2507	[3]1.0	[3]1.8	2.9	4.1	5.6	7.2	9.8	13.0	[5]15.8	[5]16.2	[6]14.5	[5]12.6	--------
	NEBRASKA														
553	Omaha	982	[3]1.0	[3]1.7	[3]2.7	4.1	5.8	7.8	11.2	16.7	[4]21.9	[5]22.7	[5]21.1	[5]18.5	--------
	NEVADA														
386	Las Vegas	2180	[3]1.0	[3]1.7	[3]2.7	[3]3.6	[3]4.3	5.0	5.6	6.3	6.7	11.0	[5]9.7	[5]7.0	[5]6.0
486	Ely	6262	[3]1.0	[3]1.7	[3]2.7	3.5	4.2	4.9	6.0	[4]9.4	[5]10.3	[5]9.8	[5]8.5	[5]7.0	--------
488	Reno	4400	[3]1.0	[3]1.7	[3]2.8	[3]3.9	5.1	6.4	7.9	[4]9.6	[5]11.6	[5]12.0	[5]10.2	[5]7.8	--------
583	Winnemucca	4339	[3]1.0	[3]1.8	[3]2.9	4.0	4.9	5.8	6.6	8.2	[5]10.0	[5]9.8	[6]8.1	[5]6.1	--------

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[2] For t_s below 0° F. at all stations, use t_s (° F.), e_s (mb.) data: −70°, 0.013; −60°, 0.03; −50°, 0.05; −40°, 0.10; −30°, 0.19; −20°, 0.34; −10°, 0.60. See also reference notes on page 1 of this table.

TABLE 7.2.1 (CONTINUED)

Table of Mean Vapor Pressure, e_s, (in mb.) as a Function of Station Temperature Argument, t_s, in ° F. for Continental U.S. Stations[1] [2]

Station No.	State and station	Station elev. (H_p)	Station temperature argument, t_s, in °F. 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
		feet	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
	NEW MEXICO														
365	Albuquerque	5314	[3]1.0	[3]1.7	[3]2.7	[3]3.5	4.1	5.1	6.9	9.9	[4]16.4	[5]18.9	[5]16.2	[5]11.6	....
	NEW YORK														
515	Binghamton	1638	[3]1.0	[3]1.8	[3]2.8	4.2	6.1	8.9	13.4	19.0	[5]21.2	[5]20.0	[5]16.4	....	....
528	Buffalo	706	[3]1.0	[3]1.7	[3]2.8	4.2	6.0	8.6	12.7	17.9	[5]20.5	[5]19.5	[5]16.8	....	....
	NORTH CAROLINA														
317	Greensboro	886	[3]1.0	[3]1.7	[3]2.8	[3]4.1	6.0	8.7	12.8	18.5	[4]27.0	[5]25.3	[5]19.2	[5]15.9	....
301	Wilmington	38	[3]1.0	[3]1.7	[3]2.8	[3]4.3	[3]6.2	8.8	12.9	19.0	28.0	[5]26.3	[5]20.0	....	....
	NORTH DAKOTA														
764	Bismarck	1660	[3]1.1	1.8	2.8	4.1	5.6	7.7	11.2	15.4	[5]18.6	[5]19.8	[5]18.5	[5]15.8	....
	OHIO														
429	Dayton	1003	[3]1.0	[3]1.7	[3]2.8	4.2	6.0	8.4	12.1	17.1	[5]21.6	[5]21.5	[5]19.1	[5]16.3	....
	OREGON														
597	Medford	1329	[3]1.0	[3]1.8	[3]3.1	[3]4.9	6.7	8.8	10.8	12.8	[5]14.4	[5]14.0	[5]11.8	[5]9.0	....
683	Burns	4162	[3]1.0	[3]1.8	[3]2.9	4.1	5.2	6.6	8.2	[4]10.2	[5]11.8	[5]11.8	[5]10.2	[5]7.6	....
388	Pendleton	1495	[3]1.0	[3]1.8	[3]2.9	[3]4.4	6.0	7.6	9.4	11.2	[5]12.9	[5]13.3	[5]11.0	[5]8.5	....
693	Eugene	373	[3]1.0	[3]1.8	[3]3.1	[3]5.0	7.4	9.9	12.4	[5]15.2	[5]16.5	[5]15.8	[5]13.4	....	....
791	Astoria	22	[3]1.0	[3]1.9	[3]3.2	[3]4.9	7.1	10.2	14.7	[5]17.8	[5]17.8	[5]16.2	[5]13.4	....	....
	PENNSYLVANIA														
408	Philadelphia	28	[3]1.0	[3]1.7	[3]2.7	[3]3.9	5.6	8.2	12.0	17.8	[5]22.4	[5]21.5	[5]17.4	....	....
520	Pittsburgh	1225	[3]1.0	[3]1.7	[3]2.8	4.1	5.7	8.0	11.6	16.9	[5]21.4	[5]21.0	[5]18.2	....	....
	SOUTH DAKOTA														
654	Huron	1289	[3]1.0	[3]1.7	2.8	4.2	5.8	8.0	11.6	16.7	[5]21.4	[5]21.7	[5]20.4	[5]17.5	....
662	Rapid City	3168	[3]1.0	[3]1.6	2.4	3.7	4.8	6.6	9.8	14.1	[5]16.8	[5]17.5	[5]16.1	[5]15.0	....

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[2] For t_s below 0° F. at all stations, use t_s (° F.), e_s (mb.) data: −70°, 0.013; −60°, 0.03; −50°, 0.05; −40°, 0.10; −30°, 0.19; −20°, 0.34; −10°, 0.60. See also reference notes on page 1 of this table.

TABLE 7.2.1 (CONTINUED)

Table of Mean Vapor Pressure, e_s, (in mb.) as a Function of Station Temperature Argument, t_s, in ° F. for Continental U.S. Stations[1] [2]

Station No.	State and station	Station elev. (H_p)	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
		feet	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
	TENNESSEE														
326	Knoxville	980	[3]1.0	[3]1.7	[3]2.8	[3]4.3	[3]6.1	8.4	12.1	17.7	[4]25.4	[5]25.5	[5]21.0	[5]16.2	......
334	Memphis	284	[3]1.0	[3]1.7	[3]2.8	[3]4.3	[3]6.2	8.5	11.9	17.1	25.3	[5]25.9	[5]21.3	[5]16.9	......
	TEXAS														
243	Houston	170	[3]1.0	[3]1.7	[3]2.8	[3]4.5	[3]6.5	[3]9.4	13.2	18.5	26.5	[5]27.8	[5]21.6	[5]15.5	......
250	Brownsville	20	......	[3]1.7	[3]2.8	[3]4.5	[3]7.0	[3]10.1	[3]14.1	19.1	27.4	[5]27.8	[5]21.7	[5]14.6	......
259	Fort Worth	576	[3]1.0	[3]1.7	[3]2.8	[3]4.4	[3]6.2	7.9	10.8	16.2	22.4	[5]24.9	[5]21.0	[5]16.0	......
261	Del Rio	1102	......	[3]1.7	[3]2.8	[3]4.4	[3]6.3	[3]8.4	10.8	14.7	21.9	[5]23.1	[5]19.6	[5]14.2	......
266	Abilene	1753	[3]1.0	[3]1.7	[3]2.8	[3]4.1	[3]5.6	7.1	10.0	15.1	20.6	[5]22.9	[5]19.8	[5]15.0	......
270	El Paso	3916	[3]1.0	[3]1.7	[3]2.7	[3]3.7	[3]4.4	4.9	6.2	8.9	15.3	[5]17.6	[5]13.9	[5]9.9	......
363	Amarillo	3604	[3]1.0	[3]1.7	[3]2.8	[3]4.0	5.1	6.8	9.9	14.2	[4]20.2	[5]22.3	[5]20.4	[5]16.0	......
	UTAH														
475	Milford	5033	[3]1.0	[3]1.7	[3]2.8	4.1	4.7	5.6	6.7	9.4	[5]12.4	[5]12.2	[5]10.0	[5]7.8	......
572	Salt Lake City	4227	[3]1.0	[3]1.7	[3]2.8	4.4	5.7	7.1	8.7	10.6	[4]12.6	[5]12.5	[5]10.7	[5]8.2	......
	VIRGINIA														
308	Norfolk	30	[3]1.0	[3]1.7	[3]2.8	[3]4.2	[3]6.0	8.3	13.3	19.4	[4]27.3	[5]24.4	[5]18.9	......	......
	WASHINGTON														
785	Spokane	2365	[3]1.0	[3]1.8	[3]2.9	4.5	6.0	7.6	9.4	10.7	[5]12.0	[5]12.5	[5]10.8	[5]8.8	......
793	Seattle	30	[3]1.0	[3]1.8	[3]2.9	[3]4.6	[3]6.6	9.4	12.8	[5]16.0	[5]16.5	[5]15.0	[5]13.0	......	......
798	Tatoosh Island	86	[3]1.0	[3]1.8	[3]3.0	[3]4.7	7.0	10.5	[5]15.8	[5]17.8	[5]17.8	[5]16.3	[5]13.8	......	......
	WISCONSIN														
645	Green Bay	699	[3]1.0	[3]1.7	2.6	4.1	6.0	8.4	12.1	17.8	[5]20.9	[5]20.5	[5]18.6	[5]15.7	......
	WYOMING														
569	Casper	5290	[3]1.0	[3]1.5	2.3	3.5	4.8	6.4	8.6	10.6	[5]12.5	[5]13.2	[5]12.5	[5]11.5	......
666	Sheridan	3968	[3]1.0	[3]1.7	2.6	3.8	5.2	7.2	10.0	13.2	[5]16.0	[5]17.0	[5]14.0	[5]13.0	......

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[2] For t_s below 0° F. at all stations, use t_s (° F.), e_s (mb.) data: −70°, 0.013; −60°, 0.03; −50°, 0.05; −40°, 0.10; −30°, 0.19; −20°, 0.34; −10°, 0.60. See also reference notes on page 1 of this table.

TABLE 7.2.2

Table of Mean Vapor Pressure, e_s, (in mb.) as a Function of Station Temperature Argument, t_s, in ° F. for Alaska Stations[1] [2]

Station No.	Station	Station elev. (H_p)	Station temperature argument, t_s, in °F. 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
		feet	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
70026	Barrow	13	1.2	2.0	3.2	5.1	[4]7.7	[5]10.3	[5]12.7	[5]12.8	[5]10.8	
70086	Barter Island	50	1.2	2.0	3.2	5.1	7.6	[5]10.2	[5]12.2	[5]12.5	[5]10.8	
70133	Kotzebue	16	1.1	1.9	3.0	4.7	7.1	10.4	[5]13.4	[5]13.3	[5]11.2	[5]9.0
70200	Nome	22	[3]1.2	1.9	3.0	4.6	6.8	[4]10.6	[5]13.6	[5]13.6	[5]11.5	[5]9.2
70219	Bethel	38	[3]1.2	1.9	3.1	4.8	7.1	10.3	[5]13.8	[5]14.3	[5]12.0	[5]9.5
70231	McGrath	338	1.1	1.8	2.8	4.1	6.1	9.0	[4]12.6	[5]13.6	[5]11.6	[5]9.0
70261	Fairbanks	454	1.1	1.7	2.7	4.0	5.8	8.3	12.2	[5]12.0	[5]10.8	[5]8.8
70273	Anchorage	132	[3]1.1	[3]1.8	2.8	4.1	6.2	9.0	[4]13.2	[5]14.0	[5]12.0	[5]9.7
70291	Northway	1721	1.1	1.8	2.7	4.0	5.9	8.3	[4]11.7	[5]12.8	[5]11.4	[5]9.4
70296	Cordova	48	[3]1.1	[3]1.8	[3]3.1	4.6	6.9	10.5	[5]13.8	[5]13.8	[5]11.9	[5]9.9
70308	St. Paul Island	20	[3]1.2	[3]1.9	[3]3.1	4.8	7.4	[4]11.6	[5]14.5	[5]15.0	[5]12.8	
70316	Cold Bay	103	[3]1.2	[3]1.9	[3]3.1	4.8	7.1	10.9	[5]14.5	[5]15.0	[5]12.8	
70326	King Salmon	49	[3]1.1	[3]1.8	2.9	4.5	6.5	9.5	[5]13.3	[5]14.5	[5]12.6	[5]9.8
70361	Yakutat	31	[3]1.1	[3]1.8	[3]3.0	4.6	7.2	10.8	[5]13.8	[5]13.6	[5]12.0	[5]9.9
70381	Juneau	24	[3]1.1	[3]1.8	[3]2.9	4.6	6.8	9.8	[5]13.2	[5]14.0	[5]12.6	[5]10.7
70398	Annette	110	[3]1.1	[3]1.8	[3]2.8	[3]4.4	6.6	9.9	[4]14.5	[5]15.6	[5]14.0	[5]12.0

TABLE 7.2.3

Table of Mean Vapor Pressure, e_s, (in mb.) as a Function of Station Temperature Argument, t_s, in ° F. for Canadian Stations[1] [2]

Station No.	Province and station	Station elev. (H_p)	Station temperature argument, t_s, in °F. 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
		feet	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
	ALBERTA												
877	Calgary	3540	[3]1.2	[3]1.7	[3]2.8	[3]4.2	5.9	8.3	11.9	[5]15.1	[5]14.9	[5]12.9	[5]10.4
879	Edmonton	2159	[3]1.2	[3]1.8	[3]2.9	[3]4.4	6.3	8.7	13.3	[5]16.4	[5]15.7	[5]12.3	....
	BRITISH COLUMBIA												
	Barkerville	4180	[3]1.2	[3]1.7	[3]2.8	[3]4.4	6.8	10.0	[5]13.1	[5]15.5	[5]15.5	[5]12.6	....
887	Kamloops	1263	[3]1.1	[3]1.7	[3]2.8	4.4	6.2	8.2	11.0	14.7	[5]16.0	[5]14.2	[5]12.5
898	Prince Rupert	171	[3]1.1	[3]1.8	[3]2.8	[3]4.3	[3]6.4	9.6	[4]14.3	[5]15.5	[5]14.6	[5]12.2	....
	MANITOBA												
852	Winnipeg	761	[3]1.2	[3]2.0	[3]3.1	[3]4.7	6.8	9.6	13.7	[4]18.5	[5]19.5	[5]17.8	[5]16.6
	NEW BRUNSWICK												
609	St. John	118	[3]1.0	[3]1.7	[3]2.6	4.1	6.2	9.4	13.9	[5]17.9	[5]19.1	[5]17.4	[5]15.5
	ONTARIO												
628	Ottawa	236	[3]1.1	[3]1.8	2.9	4.7	7.2	10.3	14.8	[4]20.1	[5]20.5	[5]18.4	[5]15.5
	Parry Sound	636	[3]1.2	[3]1.8	2.7	4.2	6.7	10.1	14.7	[4]19.6	[5]20.3	[5]18.2	....
738	White River	1243	1.2	2.0	3.2	5.0	7.4	10.5	14.5	[5]19.0	[5]19.8	[5]17.4	....
	QUEBEC												
714	Quebec	295	[3]1.0	1.7	2.8	4.5	6.7	9.7	14.1	[4]19.4	[5]19.8	[5]17.7	[5]15.3
	SASKATCHEWAN												
869	Prince Albert	1430	[3]1.2	[3]1.9	[3]3.1	[3]4.7	6.8	9.5	13.7	[5]18.2	[5]17.9	[5]15.1	....

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[2] For t_s below 0°F. at all stations, use t_s (°F.), e_s (mb.) data: −70°, 0.013; −60°, 0.03; −50°, 0.05; −40°, 0.10; −30°, 0.19; −20°, 0.34; −10°, 0.60.

See reference notes on page 1 of Table 7.2.1

TABLE 7.2.4

Table of Mean Vapor Pressure, e_s, (in mb.) as a Function of Station Temperature Argument, t_s, in ° F., for Atlantic Ocean Islands

Station No.	Station	Station elev. (H_p)	Station temperature argument, t_s, in °F. 50	60	70	80	90	100
		feet	mb.	mb.	mb.	mb.	mb.	mb.
	CARIBBEAN							
78525	San Juan	82	[3]10.0	[3]14.1	[3]19.3	28.3	[5]28.2	....

TABLE 7.2.5

Table of Mean Vapor Pressure, e_s, (in mb.) as a Function of Station Temperature Argument, t_s, in ° F. for Pacific Ocean Islands

Station No.	Station	Station elev. (H_p)	Station temperature argument, t_s, in °F. 50	60	70	80	90	100
		feet	mb.	mb.	mb.	mb.	mb.	mb.
91182	Honolulu	15	[3]9.3	[3]13.4	[3]18.2	[4]23.5	[5]26.7	[5]22.6
91245	Wake Island	12	[3]9.3	[3]13.5	[3]18.3	27.0	[5]30.1	[5]23.0
91334	Truk	8	[3]9.8	[3]14.5	[3]21.1	29.4	[5]31.3	[5]24.5
91348	Ponape	151	[3]10.2	[3]15.2	[3]22.1	30.7	[5]31.5	[5]24.6
91413	Yap	56	[3]9.4	[3]14.1	[3]20.7	[3]29.0	[5]33.5	[5]24.5
91700	Canton Island	11	[3]9.1	[3]13.2	[3]19.1	[3]26.9	[5]31.3	[5]24.2

See reference notes on page 1 of Table 7.2.1

TABLE 7.3

Tabular Values Represent Sum of Standard Lapse Rate Correction and Humidity Correction $= \left(\frac{aH_{pg}}{2} + e_sC_h\right)$, in ° F.

Station elevation H_{pg}, gpm.	e_s = station vapor pressure, in mb.													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
0	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.5	1.7	1.9	2.1	2.3	2.5
100	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
200	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8
300	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4
400	2.3	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.7	4.9	5.1
500	2.9	3.1	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.9	5.1	5.3	5.5	5.7
600	3.5	3.7	3.9	4.2	4.4	4.6	4.8	5.0	5.3	5.5	5.7	5.9	6.1	6.4
700	4.1	4.3	4.5	4.8	5.0	5.2	5.4	5.7	5.9	6.1	6.3	6.6	6.8	7.0
800	4.7	4.9	5.1	5.4	5.6	5.8	6.1	6.3	6.5	6.7	7.0	7.2	7.4	7.7
900	5.3	5.5	5.7	6.0	6.2	6.4	6.7	6.9	7.1	7.4	7.6	7.8	8.1	8.3
1000	5.9	6.1	6.3	6.6	6.8	7.0	7.3	7.5	7.8	8.0	8.2	8.5	8.7	9.0
1100	6.4	6.7	6.9	7.2	7.4	7.7	7.9	8.1	8.4	8.6	8.9	9.1	9.4	9.6
1200	7.0	7.3	7.5	7.8	8.0	8.3	8.5	8.8	9.0	9.3	9.5	9.8	10.0	10.3
1300	7.6	7.9	8.1	8.4	8.6	8.9	9.1	9.4	9.6	9.9	10.2	10.4	10.7	10.9
1400	8.2	8.5	8.7	9.0	9.2	9.5	9.8	10.0	10.3	10.5	10.8	11.1	11.3	11.6
1500	8.8	9.0	9.3	9.6	9.8	10.1	10.4	10.6	10.9	11.2	11.4	11.7	12.0	12.2
1600	9.4	9.6	9.9	10.2	10.4	10.7	11.0	11.3	11.5	11.8	12.1	12.3	12.6	12.9
1700	9.9	10.2	10.5	10.8	11.1	11.3	11.6	11.9	12.2	12.4	12.7	13.0	13.3	13.6
1800	10.5	10.8	11.1	11.4	11.7	11.9	12.2	12.5	12.8	13.1	13.4	13.6	13.9	14.2
1900	11.1	11.4	11.7	12.0	12.3	12.6	12.9	13.1	13.4	13.7	14.0	14.3	14.6	14.9
2000	11.7	12.0	12.3	12.6	12.9	13.2	13.5	13.8	14.1	14.4	14.7	15.0	15.3	15.6
2100	12.3	12.6	12.9	13.2	13.5	13.8	14.1	14.4	14.7	15.0	15.3	15.6	15.9	16.2
2200	12.9	13.2	13.5	13.8	14.1	14.4	14.7	15.0	15.3	15.7	16.0	16.3	16.6	16.9
2300	13.5	13.8	14.1	14.4	14.7	15.0	15.4	15.7	16.0	16.3	16.6	16.9	17.3	17.6
2400	14.0	14.4	14.7	15.0	15.3	15.7	16.0	16.3	16.6	17.0	17.3	17.6	17.9	18.2
2500	14.6	15.0	15.3	15.6	15.9	16.3	16.6	16.9	17.3	17.6	17.9	18.3	18.6	18.9
2600	15.2	15.5	15.9	16.2	16.6	16.9	17.2	17.6	17.9	18.3	18.6	18.9	19.3	19.6
2700	15.8	16.1	16.5	16.8	17.2	17.5	17.9	18.2	18.6	18.9	19.3	19.6	19.9	20.3
2800	16.4	16.7	17.1	17.4	17.8	18.1	18.5	18.9	19.2	19.6	19.9	20.3	20.6	21.0
2900	17.0	17.3	17.7	18.0	18.4	18.8	19.1	19.5	19.9	20.2	20.6	20.9	21.3	21.7
3000	17.6	17.9	18.3	18.7	19.0	19.4	19.8	20.1	20.5	20.9	21.2	21.6	22.0	22.4

TABLE 7.3 (CONTINUED)

Tabular Values Represent Sum of Standard Lapse Rate Correction and Humidity Correction $= \left(\frac{aH_{pg}}{2} + e_sC_h\right)$, in ° F.

Station elevation H_{pg} gpm.	e_s = station vapor pressure, in mb.													
	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
0	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.6	4.8	5.0
100	3.2	3.4	3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7
200	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0	6.2	6.4
300	4.4	4.6	4.8	5.1	5.3	5.5	5.7	5.9	6.1	6.3	6.5	6.7	6.9	7.1
400	5.1	5.3	5.5	5.7	5.9	6.1	6.3	6.5	6.8	7.0	7.2	7.4	7.6	7.8
500	5.7	5.9	6.1	6.4	6.6	6.8	7.0	7.2	7.4	7.7	7.9	8.1	8.3	8.5
600	6.4	6.6	6.8	7.0	7.2	7.5	7.7	7.9	8.1	8.3	8.6	8.8	9.0	9.2
700	7.0	7.2	7.5	7.7	7.9	8.1	8.4	8.6	8.8	9.0	9.2	9.5	9.7	9.9
800	7.7	7.9	8.1	8.3	8.6	8.8	9.0	9.3	9.5	9.7	9.9	10.2	10.4	10.6
900	8.3	8.5	8.8	9.0	9.2	9.5	9.7	9.9	10.2	10.4	10.6	10.9	11.1	11.3
1000	9.0	9.2	9.4	9.7	9.9	10.1	10.4	10.6	10.9	11.1	11.3	11.6	11.8	12.1
1100	9.6	9.8	10.1	10.3	10.6	10.8	11.1	11.3	11.6	11.8	12.0	12.3	12.5	12.8
1200	10.3	10.5	10.8	11.0	11.3	11.5	11.8	12.0	12.3	12.5	12.7	13.0	13.2	13.5
1300	10.9	11.2	11.4	11.7	11.9	12.2	12.4	12.7	12.9	13.2	13.5	13.7	14.0	14.2
1400	11.6	11.8	12.1	12.4	12.6	12.9	13.1	13.4	13.7	13.9	14.2	14.4	14.7	15.0
1500	12.2	12.5	12.8	13.0	13.3	13.6	13.8	14.1	14.4	14.6	14.9	15.2	15.4	15.7
1600	12.9	13.2	13.4	13.7	14.0	14.2	14.5	14.8	15.1	15.3	15.6	15.9	16.1	16.4
1700	13.6	13.8	14.1	14.4	14.7	14.9	15.2	15.5	15.8	16.1	16.3	16.6	16.9	17.2
1800	14.2	14.5	14.8	15.1	15.4	15.6	15.9	16.2	16.5	16.8	17.1	17.3	17.6	17.9
1900	14.9	15.2	15.5	15.8	16.0	16.3	16.6	16.9	17.2	17.5	17.8	18.1	18.4	18.6
2000	15.6	15.8	16.1	16.4	16.7	17.0	17.3	17.6	17.9	18.2	18.5	18.8	19.1	19.4
2100	16.2	16.5	16.8	17.1	17.4	17.7	18.0	18.3	18.6	18.9	19.2	19.6	19.9	20.2
2200	16.9	17.2	17.5	17.8	18.1	18.4	18.8	19.1	19.4	19.7	20.0	20.3	20.6	20.9
2300	17.6	17.9	18.2	18.5	18.8	19.2	19.5	19.8	20.1	20.4	20.7	21.0	21.4	21.7
2400	18.2	18.6	18.9	19.2	19.5	19.9	20.2	20.5	20.8	21.2	21.5	21.8	22.1	22.5
2500	18.9	19.3	19.6	19.9	20.2	20.6	20.9	21.2	21.6	21.9	22.2	22.6	22.9	23.2
2600	19.6	19.9	20.3	20.6	21.0	21.3	21.6	22.0	22.3	22.7	23.0	23.3	23.7	24.0
2700	20.3	20.6	21.0	21.3	21.7	22.0	22.4	22.7	23.1	23.4	23.7	24.1	24.4	24.8
2800	21.0	21.3	21.7	22.0	22.4	22.7	23.1	23.5	23.8	24.2	24.5	24.9	25.2	25.6
2900	21.7	22.0	22.4	22.8	23.1	23.5	23.8	24.2	24.6	24.9	25.3	25.6	26.0	26.4
3000	22.4	22.7	23.1	23.5	23.8	24.2	24.6	24.9	25.3	25.7	26.1	26.4	26.8	27.2

TABLE 7.3 (CONTINUED)

Tabular Values Represent Sum of Standard Lapse Rate Correction and Humidity Correction $= \left(\frac{aH_{pg}}{2} + e_s C_h\right)$, in ° F.

Station elevation H_{pg} gpm.	e_s = station vapor pressure, in mb.													
	26	27	28	29	30	31	32	33	34	35	36	37	38	39
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
0	5.0	5.2	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.5
100	5.7	5.9	6.1	6.3	6.5	6.7	6.9	7.1	7.3	7.5	7.7	7.9	8.1	8.3
200	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6	8.8	9.0
300	7.1	7.3	7.5	7.7	7.9	8.1	8.3	8.6	8.8	9.0	9.2	9.4	9.6	9.8
400	7.8	8.0	8.2	8.4	8.6	8.9	9.1	9.3	9.5	9.7	9.9	10.1	10.3	10.5
500	8.5	8.7	8.9	9.2	9.4	9.6	9.8	10.0	10.2	10.4	10.7	10.9	11.1	11.3
600	9.2	9.4	9.7	9.9	10.1	10.3	10.5	10.7	11.0	11.2	11.4	11.6	11.8	12.1
700	9.9	10.1	10.4	10.6	10.8	11.0	11.3	11.5	11.7	11.9	12.2	12.4	12.6	12.8
800	10.6	10.9	11.1	11.3	11.5	11.8	12.0	12.2	12.5	12.7	12.9	13.1	13.4	13.6
900	11.3	11.6	11.8	12.0	12.3	12.5	12.7	13.0	13.2	13.4	13.7	13.9	14.1	14.4
1000	12.1	12.3	12.5	12.8	13.0	13.2	13.5	13.7	14.0	14.2	14.4	14.7	14.9	15.2
1100	12.8	13.0	13.3	13.5	13.8	14.0	14.2	14.5	14.7	15.0	15.2	15.5	15.7	15.9
1200	13.5	13.7	14.0	14.2	14.5	14.7	15.0	15.2	15.5	15.7	16.0	16.2	16.5	16.7
1300	14.2	14.5	14.7	15.0	15.2	15.5	15.7	16.0	16.3	16.5	16.8	17.0	17.3	17.5
1400	15.0	15.2	15.5	15.7	16.0	16.3	16.5	16.8	17.0	17.3	17.6	17.8	18.1	18.3
1500	15.7	15.9	16.2	16.5	16.7	17.0	17.3	17.5	17.8	18.1	18.3	18.6	18.9	19.1
1600	16.4	16.7	17.0	17.2	17.5	17.8	18.0	18.3	18.6	18.9	19.1	19.4	19.7	19.9
1700	17.2	17.4	17.7	18.0	18.3	18.5	18.8	19.1	19.4	19.7	19.9	20.2	20.5	20.8
1800	17.9	18.2	18.5	18.8	19.0	19.3	19.6	19.9	20.2	20.5	20.7	21.0	21.3	21.6
1900	18.6	18.9	19.2	19.5	19.8	20.1	20.4	20.7	21.0	21.3	21.5	21.8	22.1	22.4
2000	19.4	19.7	20.0	20.3	20.6	20.9	21.2	21.5	21.8	22.1	22.4	22.7	23.0	23.3
2100	20.2	20.5	20.8	21.1	21.4	21.7	22.0	22.3	22.6	22.9	23.2	23.5	23.8	24.1
2200	20.9	21.2	21.5	21.8	22.2	22.5	22.8	23.1	23.4	23.7	24.0	24.3	24.6	24.9
2300	21.7	22.0	22.3	22.6	22.9	23.3	23.6	23.9	24.2	24.5	24.8	25.2	25.5	25.8
2400	22.5	22.8	23.1	23.4	23.7	24.1	24.4	24.7	25.0	25.4	25.7	26.0	26.3	26.7
2500	23.2	23.6	23.9	24.2	24.5	24.9	25.2	25.5	25.9	26.2	26.5	26.9	27.2	27.5
2600	24.0	24.3	24.7	25.0	25.4	25.7	26.0	26.4	26.7	27.0	27.4	27.7	28.1	28.4
2700	24.8	25.1	25.5	25.8	26.2	26.5	26.9	27.2	27.6	27.9	28.2	28.6	28.9	29.3
2800	25.6	25.9	26.3	26.6	27.0	27.3	27.7	28.0	28.4	28.8	29.1	29.5	29.8	30.2
2900	26.4	26.7	27.1	27.5	27.8	28.2	28.5	28.9	29.3	29.6	30.0	30.3	30.7	31.1
3000	27.2	27.5	27.9	28.3	28.6	29.0	29.4	29.8	30.1	30.5	30.9	31.2	31.6	32.0

TABLE 7.3 (CONTINUED)

Tabular Values Represent Sum of Standard Lapse Rate Correction and Humidity Correction $= \left(\frac{aH_{pg}}{2} + e_sC_h\right)$, in ° F.

Station elevation H_{pg} gpm.	e_s = station vapor pressure, in mb.													
	39	40	41	42	43	44	45	46	47	48	49	50	51	52
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
0	7.5	7.7	7.9	8.1	8.3	8.5	8.7	8.9	9.1	9.3	9.5	9.7	9.9	10.1
100	8.3	8.5	8.7	8.9	9.1	9.3	9.5	9.7	9.9	10.1	10.3	10.5	10.7	10.9
200	9.0	9.2	9.4	9.6	9.8	10.0	10.2	10.4	10.6	10.9	11.1	11.3	11.5	11.7
300	9.8	10.0	10.2	10.4	10.6	10.8	11.0	11.2	11.4	11.6	11.8	12.1	12.3	12.5
400	10.5	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.2	12.4	12.6	12.9	13.1	13.3
500	11.3	11.5	11.7	11.9	12.2	12.4	12.6	12.8	13.0	13.2	13.5	13.7	13.9	14.1
600	12.1	12.3	12.5	12.7	12.9	13.2	13.4	13.6	13.8	14.0	14.3	14.5	14.7	14.9
700	12.8	13.1	13.3	13.5	13.7	14.0	14.2	14.4	14.6	14.8	15.1	15.3	15.5	15.7
800	13.6	13.8	14.1	14.3	14.5	14.7	15.0	15.2	15.4	15.7	15.9	16.1	16.3	16.6
900	14.4	14.6	14.8	15.1	15.3	15.5	15.8	16.0	16.2	16.5	16.7	17.0	17.2	17.4
1000	15.2	15.4	15.6	15.9	16.1	16.4	16.6	16.8	17.1	17.3	17.5	17.8	18.0	18.3
1100	15.9	16.2	16.4	16.7	16.9	17.2	17.4	17.7	17.9	18.1	18.4	18.6	18.9	19.1
1200	16.7	17.0	17.2	17.5	17.7	18.0	18.2	18.5	18.7	19.0	19.2	19.5	19.7	20.0
1300	17.5	17.8	18.0	18.3	18.5	18.8	19.1	19.3	19.6	19.8	20.1	20.3	20.6	20.8
1400	18.3	18.6	18.9	19.1	19.4	19.6	19.9	20.2	20.4	20.7	20.9	21.2	21.5	21.7
1500	19.1	19.4	19.7	19.9	20.2	20.5	20.7	21.0	21.3	21.5	21.8	22.1	22.3	22.6
1600	19.9	20.2	20.5	20.8	21.0	21.3	21.6	21.8	22.1	22.4	22.7	22.9	23.2	23.5
1700	20.8	21.0	21.3	21.6	21.9	22.2	22.4	22.7	23.0	23.3	23.5	23.8	24.1	24.4
1800	21.6	21.9	22.2	22.4	22.7	23.0	23.3	23.6	23.9	24.1	24.4	24.7	25.0	25.3
1900	22.4	22.7	23.0	23.3	23.6	23.9	24.2	24.4	24.7	25.0	25.3	25.6	25.9	26.2
2000	23.3	23.5	23.8	24.1	24.4	24.7	25.0	25.3	25.6	25.9	26.2	26.5	26.8	27.1
2100	24.1	24.4	24.7	25.0	25.3	25.6	25.9	26.2	26.5	26.8	27.1	27.4	27.7	28.0
2200	24.9	25.3	25.6	25.9	26.2	26.5	26.8	27.1	27.4	27.7	28.0	28.3	28.7	29.0
2300	25.8	26.1	26.4	26.7	27.1	27.4	27.7	28.0	28.3	28.6	29.0	29.3	29.6	29.9
2400	26.7	27.0	27.3	27.6	28.0	28.3	28.6	28.9	29.2	29.6	29.9	30.2	30.5	30.9
2500	27.5	27.9	28.2	28.5	28.8	29.2	29.5	29.8	30.2	30.5	30.8	31.2	31.5	31.8
2600	28.4	28.7	29.1	29.4	29.8	30.1	30.4	30.8	31.1	31.4	31.8	32.1	32.5	32.8
2700	29.3	29.6	30.0	30.3	30.7	31.0	31.4	31.7	32.0	32.4	32.7	33.1	33.4	33.8
2800	30.2	30.5	30.9	31.2	31.6	31.9	32.3	32.6	33.0	33.4	33.7	34.1	34.4	34.8
2900	31.1	31.4	31.8	32.2	32.5	32.9	33.2	33.6	34.0	34.3	34.7	35.0	35.4	35.8
3000	32.0	32.3	32.7	33.1	33.5	33.8	34.2	34.6	34.9	35.3	35.7	36.0	36.4	36.8

TABLE 7.4.1

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Continental U.S. Stations Having Elevations of 305 gpm (1,000 Feet) or Lower

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s.]

Annual normal station temperature (t_{sn}) °F.	Station temperature argument, t_s, in ° F.									
	−70°	−60°	−50°	−40°	−30°	−20°	−10°	0°	+10°	+20°
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
35.0	32.3	30.6	28.6	26.3	23.7	20.9	17.7	14.3	10.6	6.6
40.0	34.0	32.3	30.4	28.2	25.7	22.9	19.8	16.4	12.8	8.8
45.0	......	34.1	32.2	30.1	27.6	24.9	21.9	18.6	15.0	11.1
50.0	......	35.9	34.1	32.0	29.6	26.9	24.0	20.7	17.2	13.4
55.0	......	......	35.9	33.9	31.6	29.0	26.1	22.9	19.4	15.7
60.0	......	......	......	35.8	33.6	31.0	28.2	25.1	21.7	18.0
65.0	......	......	......	......	35.6	33.1	30.4	27.3	23.9	20.3
70.0	......	......	......	......	37.7	35.2	32.6	29.6	26.3	22.7
75.0	......	......	......	......	39.7	37.4	34.8	31.8	28.6	25.0

Annual normal station temperature (t_{sn}) °F.	Station temperature argument, t_s, in ° F.									
	+30°	+40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°	+120°
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
35.0	2.3	−2.3	−7.3	−12.5	−18.1	−23.9	−29.9	−36.2	−42.8	......
40.0	4.5	0.0	−4.9	−10.1	−15.6	−21.3	−27.4	−33.7	−40.1	......
45.0	6.9	2.4	−2.4	− 7.6	−13.0	−18.8	−24.8	−31.1	−37.5	......
50.0	9.2	4.7	0.0	− 5.1	−10.5	−16.2	−22.2	−28.4	−34.8	......
55.0	11.6	7.2	2.5	− 2.5	− 7.9	−13.6	−19.5	−25.7	−32.0	......
60.0	13.9	9.6	5.0	0.0	− 5.3	−10.9	−16.9	−23.0	−29.3	−35.9
65.0	16.4	12.1	7.5	2.6	− 2.7	− 8.2	−14.1	−20.3	−26.5	−33.0
70.0	18.8	14.6	10.0	5.1	0.0	− 5.5	−11.4	−17.5	−23.6	−30.2
75.0	21.3	17.1	12.6	7.8	2.7	− 2.8	− 8.6	−14.7	−20.8	−27.3

TABLE 7.4.2

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Alaskan Stations Having Elevations of 305 gpm (1,000 Feet) or Lower

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s.]

Annual normal station temperature (t_{sn}) °F.	Station temperature argument, t_s, in ° F.								
	−70°	−60°	−50°	−40°	−30°	−20°	−10°	0°	+10°
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
10.0	24.4	22.3	19.9	17.3	14.4	11.3	7.8	4.0	0.0
15.0	26.0	24.0	21.7	19.1	16.3	13.2	9.8	6.1	2.1
20.0	27.6	25.7	23.5	21.0	18.2	15.1	11.8	8.1	4.2
25.0	29.3	27.4	25.2	22.8	20.1	17.1	13.8	10.2	6.4
30.0	30.9	29.1	27.0	24.7	22.0	19.1	15.8	12.3	8.5
35.0	32.6	30.9	28.8	26.5	24.0	21.1	17.9	14.5	10.7
40.0	34.3	32.6	30.7	28.4	25.9	23.1	20.0	16.6	12.9
45.0	36.0	34.4	32.5	30.3	27.9	25.1	22.1	18.8	15.1

Annual normal station temperature (t_{sn}) °F.	Station temperature argument, t_s, in ° F.							
	+20°	+30°	+40°	+50°	+60°	+70°	+80°	+90°
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
10.0	−4.3	−8.9	−13.9	−19.1	−24.6	−30.4	−36.4	−42.6
15.0	−2.2	−6.8	−11.6	−16.8	−22.3	−28.0	−34.0	−40.2
20.0	0.0	−4.5	− 9.3	−14.5	−19.9	−25.6	−31.5	−37.7
25.0	2.2	−2.3	− 7.0	−12.1	−17.5	−23.1	−29.0	−35.2
30.0	4.4	0.0	− 4.7	− 9.7	−15.0	−20.7	−26.5	−32.7
35.0	6.6	2.3	− 2.4	− 7.3	−12.6	−18.1	−24.0	−30.0
40.0	8.9	4.6	0.0	− 4.9	−10.1	−15.6	−21.4	−27.5
45.0	11.2	6.9	2.4	− 2.5	− 7.6	−13.1	−18.9	−24.9

TABLE 7.4.3 CONTINENTAL U.S. STATIONS

List of Stations, and Their Coordinates, for which the "Correction for Plateau Effect and Local Lapse Rate Anomaly (F)" is Tabulated in Table 7.4.6 as a Function of Station Temperature Argument (t_s)

Station No.	State and station	Latitude North	Longitude West	Station elevation	
				feet	gpm
	ARIZONA				
274	Tucson	32°08′	110°57′	2555	778.3
278*	Phoenix	33°27′	112°05′	1107	337.3
372*	Prescott	34°32′	112°29′	5393	1642.9
375*	Flagstaff	35°12′	111°40′	6907	2104.0
378	Grand Canyon	36°03′	112°08′	6912	2105.7
Ariz. A	Douglas	31°27′	109°36′	4107	1250.9
Ariz. B	Fort Apache	33°47′	109°58′	5004	1524.3
	ARKANSAS				
Ark. A	Fayetteville	36°00′	94°10′	1259	383.6
	CALIFORNIA				
480	Bishop	37°22′	118°22′	4145	1263.1
490	Mount Hamilton	37°20′	121°40′	4213	1283.7
584	Susanville	40°23′	120°33′	4199	1279.9
Calif. A	Independence	36°48′	118°12′	3910	1191.5
Calif. B	Keeler	36°35′	117°50′	3612	1100.6
Calif. C	Daggett	34°52′	116°48′	1929	587.7
Calif. D	Mt. Laguna	32°52′	116°25′	6208	1890.8
Calif. E	Palmdale	34°38′	118°05′	2538	773.3
	COLORADO				
462	Alamosa	37°27′	105°52′	7541	2297.5
464*	Pueblo	38°18′	104°36′	4690	1429.2
469	Denver	39°46′	104°53′	5332	1625.0
476*	Grand Junction	39°04′	108°34′	4602	1402.5
571	Craig	40°31′	107°33′	6199	1889.3
Col. A	Las Animas	38°04′	103°12′	3887	1184.5
Col. B	Montrose	38°30′	107°53′	5819	1773.2
Col. C	Akron	40°07′	103°10′	4621	1408.4
Col. D	Colorado Springs	38°51′	104°50′	6072	1850.4
	GEORGIA				
219*	Atlanta	33°45′	84°23′	1173	357.4
	IDAHO				
578*	Pocatello	42°52′	112°29′	4478	1365.2
681*	Boise	43°37′	116°12′	2739	835.2
686	Salmon	45°11′	113°53′	3947	1203.5
687	Grangeville	45°55′	116°08′	3304	1007.6
Ida. A	Idaho Falls	43°31′	112°04′	4744	1446.4
	IOWA				
557*	Sioux City	42°30′	96°24′	1138	347.0
Ia. A	Charles City	43°04′	92°40′	1015	309.5
Ia. B	Lamoni	40°39′	94°00′	1173	357.6
	KANSAS				
450*	Wichita	37°41′	97°20′	1358	413.9
451*	Dodge City	37°45′	100°01′	2509	764.6
458*	Concordia	39°34′	97°40′	1392	424.3
465	Goodland	39°22′	101°42′	3688	1124.0

* See note at end of table.

TABLE 7.4.3 (CONTINUED) **CONTINENTAL U.S. STATIONS**

List of Stations, and Their Coordinates, for which the "Correction for Plateau Effect and Local Lapse Rate Anomaly (F)" is Tabulated in Table 7.4.6 as a Function of Station Temperature Argument (t_s)

Station No.	State and station	Latitude North	Longitude West	Station elevation feet	gpm
	KENTUCKY				
329	Corbin	36°58′	84°08′	1175	358.1
	MAINE				
619	Greenville	45°27′	69°35′	1069	326.2
	MASSACHUSETTS				
Mass. A	Pittsfield	42°26′	73°17′	1169	356.4
	MICHIGAN				
744	Houghton	47°10′	88°30′	1079	329.1
Mich. A	Cadillac	44°17′	85°25′	1305	398.0
	MINNESOTA				
644	Rochester	44°00′	92°27′	1021	311.4
745	Duluth	46°50′	92°11′	1417	432.2
747	International Falls	48°34′	93°23′	1183	360.9
755	Bemidji	47°30′	94°56′	1377	420.0
Minn. A	Redwood Falls	44°33′	95°05′	1030	314.1
Minn. B	Alexandria	45°52′	95°23′	1431	436.5
	MISSOURI				
348	West Plains	36°44′	91°51′	1011	308.1
440*	Springfield	37°12′	93°18′	1324	403.5
Mo. A	Vichy	38°08′	91°46′	1137	346.5
	MONTANA				
677	Billings	45°48′	108°32′	3570	1088.7
768	Glasgow	48°13′	106°37′	2298	701.0
772*	Helena	46°35′	112°02′	4123	1257.4
773	Missoula	46°55′	114°05′	3189	972.6
775	Great Falls	47°29′	111°21′	3657	1115.5
777	Havre	48°34′	109°40′	2507	764.8
779*	Kalispell	48°12′	114°19′	2973	906.9
Mont. A	Miles City	46°25′	105°49′	2371	723.1
Mont. B	Virginia City	45°18′	112°03′	5822	1775.1
	NEBRASKA				
551*	Lincoln	40°49′	96°42′	1189	362.5
553*	Omaha	41°16′	95°56′	1105	336.9
562*	North Platte	41°08′	100°45′	2821	860.0
566	Scottsbluff	41°52′	103°36′	3958	1206.6
567	Valentine	42°50′	100°32′	2598	792.1
	NEVADA				
386	Las Vegas	36°05′	115°10′	2180	664.3
487	Austin	39°30′	117°05′	6547	1995.2
488	Reno	39°30′	119°47′	4400	1341.0
583*	Winnemucca	40°58′	117°43′	4339	1322.6
587	Owyhee	41°57′	116°06′	5401	1646.4
Nev. A	Pioche	37°55′	114°26′	5936	1808.7

* See note at end of table.

TABLE 7.4.3 (CONTINUED) **CONTINENTAL U.S. STATIONS**

List of Stations, and Their Coordinates, for which the "Correction for Plateau Effect and Local Lapse Rate Anomaly (F)" is Tabulated in Table 7.4.6 as a Function of Station Temperature Argument (t_s)

Station No.	State and station	Latitude North	Longitude West	Station elevation	
				feet	gpm
	NEW HAMPSHIRE				
613	Mount Washington	44°16′	71°16′	6279	1914.3
	NEW MEXICO				
268	Roswell	33°24′	104°32′	3619	1102.4
362	Socorro	34°04′	106°54′	4625	1408.8
3/6	Raton	36°45′	104°30′	6376	1942.6
N.M. A	Santa Fe	35°41′	105°57′	7013	2136.6
N.M. B	Zuni	35°06′	108°47′	6447	1963.8
N.M. C	Tucumcari	35°11′	103°36′	4039	1230.5
N.M. D	Farmington	36°45′	108°15′	5502	1676.4
	NEW YORK				
5/1	Oneonta	42°27′	75°00′	1163	354.6
N.Y. A	Bear Mountain	41°19′	74°00′	1302	396.9
	NORTH CAROLINA				
N.C. A	Hickory	35°44′	81°23′	1188	362.0
	NORTH DAKOTA				
757	Devil's Lake	48°07′	98°52′	1478	450.9
764*	Bismarck	46°48′	100°48′	1677	511.5
767	Williston	48°09′	103°37′	1878	572.9
	OHIO				
429	Dayton	39°54′	84°12′	1003	305.8
	OKLAHOMA				
353*	Oklahoma City	35°28′	97°30′	1214	369.9
Okla. A	Fort Sill	34°39′	98°23′	1200	365.7
	OREGON				
589	Lakeview	42°11′	120°21′	4764	1452.3
597	Medford	42°22′	122°52′	1329	405.2
683	Burns	43°35′	119°03′	4170	1271.4
Oreg. A	Baker	44°46′	117°50′	3471	1058.4
Oreg. B	Redmond	44°16′	121°08′	3084	940.4
	PENNSYLVANIA				
512	Phillipsburg	40°54′	78°05′	1914	583.5
520	Pittsburgh (Greater)	40°30′	80°13′	1225	373.4
Pa. A	Park Place	40°51′	76°07′	1944	592.5
	SOUTH CAROLINA				
312	Greenville	34°51′	82°21′	1040	316.9
	SOUTH DAKOTA				
654*	Huron	44°22′	98°13′	1301	396.7
662*	Rapid City	44°04′	103°12′	3259	993.7
S. Dak. A	Pierre	44°22′	100°21′	1572	479.4

* See note at end of table.

TABLE 7.4.3 (CONTINUED) **CONTINENTAL U.S. STATIONS**

List of Stations, and Their Coordinates, for which the "Correction for Plateau Effect and Local Lapse Rate Anomaly (F)" is Tabulated in Table 7.4.6 as a Function of Station Temperature Argument (t_s)

Station No.	State and station	Latitude North	Longitude West	Station elevation	
				feet	gpm
	TENNESSEE				
326*	Knoxville	35°58′	83°56′	995#	303.2
Tenn. A	Crossville	35°57′	85°05′	1870	569.8
Tenn. B	Bristol	36°29′	82°24′	1525	464.7
	TEXAS				
261	Del Rio	29°22′	100°49′	1102	335.6
266*	Abilene	32°27′	99°44′	1738	529.4
267	Lubbock	33°39′	101°50′	3241	987.3
270*	El Paso	31°47′	106°30′	3778	1150.7
271	Presidio	29°33′	104°24′	2612	795.4
351	Wichita Falls	33°59′	98°31′	1030	313.8
363*	Amarillo	35°13′	101°50′	3676	1120.0
Tex. A	Junction	30°30′	99°46′	1713	521.7
Tex. B	Fort Stockton	30°53′	102°53′	3052	929.5
Tex. C	Camp Hood	31°08′	97°43′	1027	312.8
Tex. D	Big Spring	32°14′	101°30′	2537	772.8
	UTAH				
477	Green River	39°00′	110°09′	4087	1245.6
479	Delta	39°23′	112°31′	4714	1436.7
572*	Salt Lake City	40°46′	111°54′	4357	1328.1
581	Wendover	40°43′	114°02′	4239	1292.1
Ut. A	Cedar City	37°42′	113°04′	5850	1782.6
Ut. B	Modena	37°48′	113°54′	5473	1667.7
Ut. C	Hanksville	38°25′	110°41′	4462	1359.8
	VIRGINIA				
411	Roanoke	37°19′	79°58′	1176	358.4
	WASHINGTON				
781	Yakima	46°34′	120°32′	1066	325.2
785	Spokane	47°37′	117°31′	2365	721.4
789	Omak	48°26′	119°32′	1232	375.8
Wash. A	Walla Walla	46°02′	118°20′	1000	305.0
Wash. B	Dayton	46°23′	117°50′	1621	494.4
Wash. C	Stampede Pass	47°17′	121°20′	3967	1209.9
	WEST VIRGINIA				
412	Flat Top	37°35′	81°06′	3270	996.4
417*	Elkins	38°56′	79°51′	1947	593.4
	WISCONSIN				
646	Wausau	44°55′	89°37′	1196	364.7
Wis. A	Land O'Lakes	46°09′	89°12′	1710	521.6

* See note at end of table.

\# The elevation of the Knoxville station was originally believed to be 1004 feet but this was subsequently corrected to 995 feet. It is sufficiently close to 1000 feet to permit use of data for that station in determining the plateau effect and local lapse rate anomaly correction for nearby stations at elevations of more than 1000 feet.

TABLE 7.4.3 (CONTINUED) CONTINENTAL U.S. STATIONS

List of Stations, and Their Coordinates, for which the "Correction for Plateau Effect and Local Lapse Rate Anomaly (F)" is Tabulated in Table 7.4.6 as a Function of Station Temperature Argument (t_s)

Station No.	State and station	Latitude North	Longitude West	Station elevation	
				feet	gpm
	WYOMING				
564*	Cheyenne	41°08′	104°48′	6088	1855.7
569	Casper	42°55′	106°28′	5290	1612.7
576*	Lander	42°50′	108°45′	5352	1631.6
666	Sheridan	44°46′	106°58′	3968	1210.0
674	Cody	44°30′	109°01′	5106	1556.8
Wyo. A	Fort Bridger	41°28′	110°30′	6643	2024.8

* Station coordinates, and data presented in Table 7.4.6, pertain to the city office location on January 1, 1900 or on the subsequent date of establishment of the station; but the station number refers to the airport station of the same name effective on January 1, 1959, in accordance with published lists of International Station Numbers.

TABLE 7.4.4 ALASKAN STATIONS

List of Stations, and Their Coordinates, for which the "Correction for Plateau Effect and Local Lapse Rate Anomaly (F)" is Tabulated in Table 7.4.7 as a Function of Station Temperature Argument (t_s)

Station No.	State and station	Latitude North	Longitude West	Station elevation	
				feet	gpm
	ALASKA				
248	Farewell	62°32′	153°54′	1503	459.1
264	Summit	63°20′	149°09′	2405	734.6
271	Gulkana	62°09′	145°27′	1579	482.3
291	Northway	62°58′	141°58′	1721	525.6
267	Big Delta	64°00′	145°44′	1274	389.2

TABLE 7.4.5 CANADIAN STATIONS

List of Stations, and Their Coordinates, for Which the "Correction for Plateau Effect and Local Lapse Rate Anomaly (F)" is Tabulated in Table 7.4.8 as a Function of Station Temperature Argument (t_s)

Station No.	Name of station	Latitude North	Longitude West	Station elevation	
				feet	gpm
Can. A	Dawson Creek, B.C.	55°45′	120°15′	2160	659.4
958	Dease Lake, B.C.	58°28′	130°03′	2678	817.7
932	McMurray, Alta.	56°45′	111°09′	1216	371.2
Can. B	210 Mile Post, B.C.	59°23′	126°02′	1386	423.1
Can. C	Fish Lake, Y.T.	60°38′	132°03′	2845	868.7
738	White River, Ont.	48°35′	85°16′	1252	381.9
887	Kamloops, B.C.	50°41′	120°29′	1193	364.0
869	Prince Albert, Sask.	53°10′	106°00′	1432	437.0
Can. D	Barkerville, B.C.	53°02′	121°35′	4180	1275.5
879	Edmonton, Alta.	53°33′	113°30′	2158	658.6
876	North Battleford, Sask.	52°41′	108°20′	1620	494.4
872	Medicine Hat, Alta.	50°01′	110°37′	2161	659.3
122	Banff, Alta.	51°10′	115°35′	4542	1385.8
Can. E	Qu'Appelle, Sask.	50°30′	103°47′	2115	645.3
877	Calgary, Alta.	51°02′	114°02′	3389	1034.0
853	Minnedosa, Man.	50°15′	99°50′	1690	515.7
870	Swift Current, Sask.	50°20′	107°45′	2440	743.6
Can. F	Stratford, Ont.	43°23′	81°00′	1191	363.2

TABLE 7.4.6

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Continental U.S. Stations Above 305 gpm (1,000 Feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations listed in Table 7.4.3.]

Station No. or letter	State and station	Station elevation	Station temperature argument, t_s, in °F. −50°	−40°	−30°	−20°	−10°	0°	+10°	+20°	+30°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
	ARIZONA										
274	Tucson	2555	......	36.5	34.4	32.0	29.3	26.2	22.5	18.8	14.6
278	Phoenix	1107	......	......	......	33.6	30.7	27.5	24.2	20.4	16.6
372	Prescott	5393	......	31.1	28.7	25.7	22.5	18.8	14.7	10.4	5.9
375	Flagstaff	6907	......	27.1	24.6	21.6	18.7	14.6	11.0	7.4	3.5
378	Grand Canyon	6912	......	27.1	24.5	21.4	18.1	14.5	11.0	7.4	3.7
Ariz. A	Douglas	4107	......	......	31.9	29.2	26.3	23.0	19.6	15.8	11.7
Ariz. B	Fort Apache	5004	......	......	29.0	26.2	23.2	20.0	16.6	12.8	9.0
	ARKANSAS										
Ark. A	Fayetteville	1259	......	35.4	32.7	29.8	26.7	23.3	19.8	16.1	12.1
	CALIFORNIA										
480	Bishop	4145	......	27.3	25.5	23.7	21.6	19.3	16.7	13.5	9.6
490	Mount Hamilton	4213	......	24.5	22.8	20.8	18.7	16.6	14.4	11.5	7.3
584	Susanville	4199	......	27.0	25.0	23.2	20.9	18.2	14.8	10.9	6.2
Calif. A	Independence	3910	......	......	26.6	24.8	22.7	20.2	17.7	14.6	10.7
Calif. B	Keeler	3612	......	......	27.0	25.8	24.0	21.6	18.3	14.5	9.8
Calif. C	Daggett	1929	......	......	......	30.1	27.8	25.1	22.0	18.4	14.3
Calif. D	Mt. Laguna	6208	......	22.6	21.4	19.9	18.0	16.2	14.2	11.5	7.6
Calif. E	Palmdale	2538	......	......	31.2	28.7	25.8	22.9	19.7	16.0	12.1
	COLORADO										
462	Alamosa	7541	24.1	22.3	20.0	17.6	14.5	11.1	7.5	3.7	− 0.5
464	Pueblo	4690	29.3	27.4	25.0	22.0	18.6	15.3	12.0	8.5	5.0
469	Denver	5332	30.9	28.7	26.2	23.2	19.8	15.9	12.1	8.4	4.7
476	Grand Junction	4602	30.1	28.3	25.9	23.0	19.7	16.3	13.0	9.6	6.0
571	Craig	6199	27.3	25.2	22.7	19.7	16.4	12.6	8.7	4.5	0.5
Col. A	Las Animas	3887	33.0	31.1	28.8	26.1	22.9	19.5	16.2	12.8	9.2
Col. B	Montrose	5819	27.3	25.8	24.0	21.9	19.4	16.6	13.2	9.6	5.2
Col. C	Akron	4621	29.8	27.6	24.9	21.7	18.2	14.7	11.0	7.2	3.7
Col. D	Colorado Springs	6072	26.7	24.3	21.6	18.4	14.5	10.4	6.3	2.2	− 1.6
	GEORGIA										
219	Atlanta	1173	......	......	......	30.5	27.6	24.5	21.0	17.5	13.3
	IDAHO										
578	Pocatello	4478	29.6	27.6	25.1	22.4	19.4	15.9	12.5	8.8	4.8
681	Boise	2739	31.5	29.8	27.8	25.4	22.7	19.7	16.2	12.3	8.1
686	Salmon	3947	28.9	27.0	24.9	22.3	19.2	15.8	12.0	7.8	3.5
687	Grangeville	3304	29.4	28.0	26.2	24.1	21.4	18.2	14.5	10.3	5.7
Ida. A	Idaho Falls	4744	28.6	26.8	24.4	21.6	18.4	15.0	11.3	7.7	3.6
	IOWA										
557	Sioux City	1138	34.5	32.1	29.4	26.3	23.1	19.4	15.7	11.7	7.6
Ia. A	Charles City	1015	......	31.3	28.7	25.7	22.3	18.7	15.1	11.2	7.2
Ia. B	Lamoni	1173	......	32.6	29.9	27.1	23.8	20.3	16.6	12.7	8.6

TABLE 7.4.6 (CONTINUED)

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Continental U.S. Stations Above 305 gpm (1,000 Feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations listed in Table 7.4.3.]

Station No. or letter	State and station	Station elevation	Station temperature argument, t_s, in °F.								
			+40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°	+120°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
	ARIZONA										
274	Tucson	2555	10.4	5.9	1.5	−3.3	−8.4	−14.1	−20.2	−26.4	−33.2
278	Phoenix	1107	12.4	7.8	2.9	−2.0	−7.8	−13.3	−19.7	−26.1	−32.4
372	Prescott	5393	1.4	−2.6	−6.3	−10.8	−16.3	−22.2	−28.8	−35.8	......
375	Flagstaff	6907	−0.4	−4.9	−9.9	−15.5	−21.4	−27.7	−34.4	−41.0	......
378	Grand Canyon	6912	−0.4	−4.8	−9.9	−15.3	−21.3	−27.6	−34.1	−41.0	......
Ariz. A	Douglas	4107	7.5	3.0	−1.6	−6.5	−11.9	−17.8	−24.0	−30.5	−37.3
Ariz. B	Fort Apache	5004	4.9	0.5	−4.5	−9.9	−15.6	−21.9	−28.4	−35.2	−42.1
	ARKANSAS										
Ark. A	Fayetteville	1259	7.9	3.4	−1.5	−6.7	−12.2	−18.2	−24.4	−30.9	......
	CALIFORNIA										
480	Bishop	4145	4.4	−1.2	−7.2	−13.2	−19.5	−25.7	−32.1	−38.4	−45.2
490	Mount Hamilton	4213	2.1	−3.6	−9.6	−15.9	−22.4	−28.9	−35.2	......	......
584	Susanville	4199	1.2	−4.0	−9.4	−14.9	−20.8	−26.9	−33.3	−40.0	
Calif. A	Independence	3910	5.7	0.0	−5.9	−11.9	−18.1	−24.2	−30.7	−37.2	−43.6
Calif. B	Keeler	3612	4.8	−0.7	−6.3	−12.1	−18.0	−24.0	−30.2	−36.5	−43.1
Calif. C	Daggett	1929	9.6	4.5	−0.8	−6.4	−12.1	−18.0	−24.3	−30.6	−36.9
Calif. D	Mt. Laguna	6208	2.2	−3.8	−10.0	−16.5	−23.0	−29.7	−36.2	......	......
Calif. E	Palmdale	2538	7.8	2.9	−2.3	−7.7	−13.5	−19.4	−25.6	−32.0	−38.7
	COLORADO										
462	Alamosa	7541	−4.7	−9.3	−14.7	−20.7	−27.1	−33.6	−40.4	−47.3	......
464	Pueblo	4690	1.1	−3.2	−8.3	−13.8	−19.8	−26.0	−32.7	−39.4	......
469	Denver	5332	0.8	−3.6	−8.5	−13.9	−19.9	−26.4	−33.0	−39.9	......
476	Grand Junction	4602	2.2	−2.1	−7.1	−12.6	−18.5	−24.8	−31.4	−38.3	......
571	Craig	6199	−3.1	−7.2	−12.2	−17.9	−24.0	−30.5	−37.3	......	......
Col. A	Las Animas	3887	5.0	0.4	−4.8	−10.5	−16.6	−23.0	−29.5	−36.2	......
Col. B	Montrose	5819	0.6	−4.6	−10.2	−16.1	−22.2	−28.6	−35.1	−41.7	......
Col. C	Akron	4621	0.0	−4.2	−9.2	−14.9	−21.1	−27.4	−34.1	−40.9	......
Col. D	Colorado Springs	6072	−4.7	−8.0	−11.5	−16.5	−22.5	−28.9	−35.5	......	......
	GEORGIA										
219	Atlanta	1173	9.4	4.8	−0.1	−5.3	−10.9	−16.9	−23.0	−29.6	
	IDAHO										
578	Pocatello	4478	0.5	−4.2	−9.2	−14.8	−20.6	−26.8	−33.3	−40.0	......
681	Boise	2739	3.3	−1.5	−6.6	−12.1	−17.8	−23.7	−30.0	−36.5	......
686	Salmon	3947	−1.2	−6.2	−11.4	−17.1	−23.0	−29.3	−36.0	......	......
687	Grangeville	3304	0.9	−4.1	−9.1	−14.5	−20.4	−26.5	−32.9	−39.5	......
Ida. A	Idaho Falls	4744	−1.0	−6.1	−11.5	−17.3	−23.4	−29.8	−36.4	......	......
	IOWA										
557	Sioux City	1138	3.1	−1.5	−6.6	−12.1	−17.8	−23.8	−30.1	−36.6	......
Ia. A	Charles City	1015	2.7	−2.0	−7.2	−12.7	−18.5	−24.6	−30.8	−37.3	......
Ia. B	Lamoni	1173	4.4	−0.3	−5.2	−10.7	−16.6	−22.7	−29.0	−35.6	......

TABLE 7.4.6 (CONTINUED)

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Continental U.S. Stations Above 305 gpm (1,000 Feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations listed in Table 7.4.3.]

Station No. or letter	State and station	Station elevation	Station temperature argument, t_s, in °F. −50°	−40°	−30°	−20°	−10°	0°	+10°	+20°	+30°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
	KANSAS										
450	Wichita	1358	......	......	30.8	28.0	24.9	21.5	17.9	14.1	10.4
451	Dodge City	2509	......	......	28.9	26.2	23.2	19.9	16.3	12.4	8.5
458	Concordia	1392	......	33.9	31.1	28.0	24.8	21.3	17.7	13.9	9.8
465	Goodland	3688	......	29.6	27.0	24.1	20.7	17.3	13.8	10.2	6.4
	KENTUCKY										
329	Corbin	1175	......	......	32.0	29.5	26.7	23.4	19.8	16.1	12.0
	MAINE										
619	Greenville	1069	31.3	28.9	26.2	23.3	20.1	16.6	12.7	8.5	4.2
	MASSACHUSETTS										
Mass. A	Pittsfield	1169	......	29.4	26.9	24.1	21.1	17.8	14.2	10.5	6.3
	MICHIGAN										
744	Houghton	1079	30.3	27.8	25.0	22.1	19.0	15.7	12.3	8.3	4.0
Mich. A	Cadillac	1305	33.0	30.8	28.0	25.0	21.8	18.2	14.4	10.3	5.9
	MINNESOTA										
644	Rochester	1021	33.0	30.5	27.7	24.7	21.4	17.9	14.1	10.2	6.0
745	Duluth	1417	30.4	28.0	25.1	21.9	18.5	14.9	11.1	7.1	2.7
747	International Falls	1183	30.4	27.7	24.8	21.7	18.4	15.0	11.3	7.3	3.0
755	Bemidji	1377	31.0	28.6	25.7	22.6	19.3	15.7	11.9	7.9	3.7
Minn. A	Redwood Falls	1030	33.5	31.1	28.5	25.5	22.3	18.8	15.0	10.9	6.6
Minn. B	Alexandria	1431	31.9	29.4	26.5	23.2	19.9	16.2	12.4	8.5	4.2
	MISSOURI										
348	West Plains	1011	......	34.7	32.3	29.4	26.2	22.9	19.4	15.7	11.7
440	Springfield	1324	......	34.0	31.1	28.1	24.9	21.5	17.9	14.3	10.3
Mo. A	Vichy	1137	......	34.2	31.5	28.6	25.5	22.1	18.5	14.8	10.9
	MONTANA										
677	Billings	3570	33.9	31.2	28.1	24.5	20.7	16.6	12.4	8.0	3.6
768	Glasgow	2298	34.5	31.6	28.2	24.5	20.6	16.6	12.5	7.9	3.5
772	Helena	4123	32.1	29.4	26.2	22.4	18.4	14.1	9.6	5.0	0.9
773	Missoula	3189	31.1	28.9	26.3	23.4	20.0	16.4	12.3	8.0	3.8
775	Great Falls	3657	24.0	21.6	18.8	15.8	12.5	9.0	5.3	1.3	2.3
777	Havre	2507	34.6	31.8	28.5	25.0	21.3	17.3	13.0	8.6	4.0
779	Kalispell	2973	28.3	26.8	24.8	22.5	19.7	16.6	13.0	9.0	4.5
Mont. A	Miles City	2371	34.3	31.6	28.5	25.3	21.7	17.9	13.9	9.5	5.0
Mont. B	Virginia City	5822	27.0	24.7	22.1	18.8	15.3	11.4	7.4	3.9	1.0
	NEBRASKA										
551	Lincoln	1189	......	33.2	30.7	27.9	24.7	21.3	17.5	13.6	9.5
553	Omaha	1105	......	32.4	29.6	26.6	23.2	19.5	15.7	12.2	8.1
562	North Platte	2821	......	29.8	27.1	24.0	20.7	17.1	13.4	9.8	5.9
566	Scottsbluff	3958	30.8	28.6	25.9	22.7	19.2	15.6	11.9	8.3	4.8
567	Valentine	2598	......	29.0	26.3	23.2	20.0	16.5	12.7	8.9	4.6

TABLE 7.4.6 (CONTINUED)

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Continental U.S. Stations Above 305 gpm (1,000 Feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations listed in Table 7.4.3.]

Station No. or letter	State and station	Station elevation	Station temperature argument, t_s, in °F. +40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°	+120°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
	KANSAS										
450	Wichita	1358	6.0	1.4	−3.4	−8.7	−14.2	−20.1	−26.6	−32.8	......
451	Dodge City	2509	4.3	−0.2	−5.1	−10.6	−16.4	−22.6	−28.8	−35.4	......
458	Concordia	1392	5.5	1.0	−3.8	−9.1	−14.8	−20.7	−26.9	−33.4	......
465	Goodland	3688	2.3	−2.2	−7.3	−12.9	−19.0	−25.4	−32.0	−38.8	......
	KENTUCKY										
329	Corbin	1175	7.8	3.2	−1.7	−7.0	−12.6	−18.6	−24.8	−31.3	......
	MAINE										
619	Greenville	1069	−0.4	−5.4	−10.7	−16.3	−22.1	−28.1	−34.4	......	......
	MASSACHUSETTS										
Mass. A	Pittsfield	1169	2.0	−2.7	−7.8	−13.2	−18.9	−25.1	−31.6	......	......
	MICHIGAN										
744	Houghton	1079	−0.8	−5.7	−10.9	−16.4	−22.2	−28.3	−34.8	......	......
Mich. A	Cadillac	1305	1.4	−3.6	−8.7	−14.3	−20.1	−26.1	−32.4	......	......
	MINNESOTA										
644	Rochester	1021	1.5	−3.2	−8.3	−13.8	−19.6	−25.7	−32.0	−38.5	......
745	Duluth	1417	−1.8	−6.7	−11.9	−17.5	−23.3	−29.4	−35.7	......	......
747	International Falls	1183	−1.6	−6.5	−11.7	−17.3	−23.1	−29.2	−35.5	......	......
755	Bemidji	1377	−0.9	−5.8	−11.0	−16.6	−22.5	−28.5	−34.8	......	......
Minn. A	Redwood Falls	1030	2.1	−2.7	−7.7	−13.1	−18.9	−24.9	−31.2	−37.8	......
Minn. B	Alexandria	1431	−0.4	−5.3	−10.4	−15.9	−21.8	−27.9	−34.2	......	......
	MISSOURI										
348	West Plains	1011	7.5	3.0	−1.9	−7.2	−12.8	−18.7	−24.9	−31.3	......
440	Springfield	1324	6.1	1.5	−3.1	−8.6	−14.3	−20.1	−26.2	−32.8	......
Mo. A	Vichy	1137	6.7	2.1	−2.8	−8.0	−13.7	−19.6	−26.2	−32.3	......
	MONTANA										
677	Billings	3570	−0.8	−5.2	−10.1	−15.7	−21.8	−28.2	−34.7	−41.5	......
768	Glasgow	2298	−0.9	−5.4	−10.6	−16.2	−22.1	−28.1	−34.6	−41.2	......
772	Helena	4123	−2.8	−7.0	−12.1	−17.8	−23.8	−30.3	−37.1	−43.9	......
773	Missoula	3189	−0.7	−5.4	−10.6	−16.2	−22.1	−28.3	−34.8	−41.5	......
775	Great Falls	3657	−5.8	−9.0	−12.3	−15.9	−19.6	−23.7	−27.9	......	......
777	Havre	2507	−0.5	−5.1	−10.1	−15.7	−21.6	−28.0	−34.4	−41.1	......
779	Kalispell	2973	−0.3	−5.3	−10.5	−16.0	−21.9	−28.0	−34.3	−40.9	......
Mont. A	Miles City	2371	0.4	−4.1	−9.3	−15.1	−21.1	−27.4	−34.2	−41.2	......
Mont. B	Virginia City	5822	−2.0	−6.4	−12.1	−18.3	−24.7	−31.3	−38.0	−44.9	......
	NEBRASKA										
551	Lincoln	1189	5.3	0.8	−4.2	−9.6	−15.4	−21.6	−27.9	−34.5	......
553	Omaha	1105	3.8	−1.0	−6.1	−11.3	−17.1	−23.3	−29.6	−36.2	......
562	North Platte	2821	1.9	−2.6	−7.5	−13.1	−19.3	−25.6	−32.0	−38.6	......
566	Scottsbluff	3958	1.1	−3.0	−7.8	−13.4	−19.4	−25.8	−32.4	−39.1	......
567	Valentine	2598	0.1	−4.7	−9.7	−15.2	−20.9	−27.0	−33.4	−39.8	......

TABLE 7.4.6 (CONTINUED)

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Continental U.S. Stations Above 305 gpm (1,000 Feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations listed in Table 7.4.3.]

Station No. or letter	State and station	Station elevation	Station temperature argument, t_s, in °F. −50°	−40°	−30°	−20°	−10°	0°	+10°	+20°	+30°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
	NEVADA										
386	Las Vegas	2180	......	......	33.6	31.0	28.2	25.1	21.7	18.0	14.0
487	Austin	6547	......	25.9	24.0	22.0	19.6	16.6	13.0	9.0	4.7
488	Reno	4400	29.3	27.6	25.7	24.0	21.8	19.0	15.6	11.7	7.3
583	Winnemucca	4339	28.1	27.1	25.7	23.9	21.7	18.9	15.5	11.5	7.0
587	Owyhee	5401	26.9	25.7	24.0	22.0	19.3	16.1	12.5	8.6	4.1
Nev. A	Pioche	5936	......	28.3	25.9	23.2	20.2	16.8	13.3	9.6	5.7
	NEW HAMPSHIRE										
613	Mount Washington	6279	20.6	17.4	14.2	10.7	7.2	3.5	− 0.2	− 3.9	− 7.6
	NEW MEXICO										
268	Roswell	3619	......	......	33.0	30.3	27.1	23.7	20.1	16.4	12.5
362	Socorro	4625	......	......	29.5	26.6	23.5	20.1	16.6	12.8	8.9
3/6	Raton	6376	28.1	25.9	23.4	20.4	17.0	13.4	10.0	6.5	2.9
N.M. A	Santa Fe	7013	28.5	26.5	23.8	20.6	17.4	13.7	9.8	6.1	1.9
N.M. B	Zuni	6447	......	......	24.8	21.7	18.4	14.8	11.1	7.2	3.3
N.M. C	Tucumcari	4039			28.2	25.4	22.5	19.3	16.0	12.4	8.4
N.M. D	Farmington	5502	29.5	27.7	25.3	22.5	19.1	15.5	11.9	8.2	4.5
	NEW YORK										
5/1	Oneonta	1163	......	30.9	28.4	25.6	22.5	19.2	15.6	11.6	7.3
N.Y. A	Bear Mountain	1302	......	29.9	27.6	24.8	21.7	18.4	15.1	11.3	7.1
	NORTH CAROLINA										
N.C. A	Hickory	1188	......	......	32.8	30.6	27.5	24.3	20.6	16.9	12.9
	NORTH DAKOTA										
757	Devil's Lake	1478	31.2	28.8	25.6	22.3	18.8	15.2	11.6	7.6	3.4
764	Bismarck	1677	32.7	30.0	26.9	23.5	20.0	16.4	12.8	8.9	4.7
767	Williston	1878	34.3	31.4	28.1	24.4	20.5	16.5	12.3	8.0	3.7
	OHIO										
429	Dayton	1003	......	33.4	30.9	27.8	24.5	20.9	17.3	13.6	9.7
	OKLAHOMA										
353	Oklahoma City	1214	......	......	32.5	29.5	26.3	23.0	19.5	15.9	11.7
Okla. A	Fort Sill	1200	......	......	33.5	30.8	28.2	24.8	21.5	17.2	13.1
	OREGON										
589	Lakeview	4764	27.9	26.2	24.5	22.7	20.5	17.5	14.0	9.8	5.1
597	Medford	1329	......	32.3	30.1	27.7	25.0	22.1	18.7	15.0	10.8
683	Burns	4170	27.8	26.4	24.6	22.9	20.7	17.8	14.3	10.2	5.4
Oreg. A	Baker	3471	28.9	27.2	25.2	23.2	20.9	18.1	14.6	10.4	5.8
Oreg. B	Redmond	3084	30.2	28.5	26.7	24.6	22.1	19.2	15.9	11.8	7.4

TABLE 7.4.6 (CONTINUED)

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Continental U.S. Stations Above 305 gpm (1,000 Feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations listed in Table 7.4.3.]

Station No. or letter	State and station	Station elevation	Station temperature argument, t_s, in °F. +40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°	+120°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
	NEVADA										
386	Las Vegas	2180	9.8	5.2	0.2	−5.0	−10.6	−16.5	−22.6	−29.0	−35.7
487	Austin	6547	0.0	−5.2	−10.6	−16.6	−22.7	−29.0	−35.6	−42.4	......
488	Reno	4400	2.4	−2.7	−8.1	−13.9	−19.9	−26.1	−32.7	−39.5	......
583	Winnemucca	4339	2.1	−3.0	−8.4	−14.1	−20.2	−26.5	−32.9	−39.5	......
587	Owyhee	5401	−0.7	−5.8	−11.2	−16.9	−23.0	−29.3	−35.8	−42.6	......
Nev. A	Pioche	5936	1.2	−3.6	−8.8	−14.4	−20.5	−26.9	−33.5	−40.2	......
	NEW HAMPSHIRE										
613	Mount Washington	6279	−11.5	−16.1	−21.5	−27.3	−33.6	−40.1	−46.9	......	......
	NEW MEXICO										
268	Roswell	3619	8.6	4.3	−0.4	−5.6	−11.3	−17.4	−23.8	−30.5	......
362	Socorro	4625	4.7	0.3	−4.2	−9.4	−15.2	−21.4	−27.8	−34.6	......
3/6	Raton	6376	−0.9	−5.2	−10.2	−16.0	−22.3	−28.8	−35.5	......	......
N.M. A	Santa Fe	7013	−1.8	−5.9	−10.2	−15.8	−22.0	−28.5	−35.1	......	......
N.M. B	Zuni	6447	−0.8	−4.9	−9.7	−15.1	−21.0	−27.3	−33.9	−40.8	......
N.M. C	Tucumcari	4039	+4.2	−0.3	−5.0	−10.4	−16.0	−22.0	−28.4	−35.0	......
N.M. D	Farmington	5502	+0.6	−3.4	−8.1	−13.6	−19.6	−26.0	−32.6	−39.5	......
	NEW YORK										
5/1	Oneonta	1163	2.9	−1.8	−7.0	−12.4	−18.2	−24.3	−30.5	......	......
N.Y. A	Bear Mountain	1302	2.7	−1.8	−7.1	−12.4	−17.8	−23.9	−30.4	......	......
	NORTH CAROLINA										
N.C. A	Hickory	1188	8.7	4.2	−0.8	−6.0	−11.7	−17.6	−23.9	−30.4	......
	NORTH DAKOTA										
757	Devil's Lake	1478	−1.1	−5.9	−11.3	−16.7	−22.8	−28.9	−35.0	−41.8	......
764	Bismarck	1677	0.2	−4.7	−9.9	−15.5	−21.4	−27.6	−33.9	−40.5	......
767	Williston	1878	−0.7	−5.4	−10.5	−16.1	−22.0	−28.2	−34.6	−41.3	......
	OHIO										
429	Dayton	1003	5.4	0.6	−4.4	−9.8	−15.5	−21.5	−27.8	−34.3	......
	OKLAHOMA										
353	Oklahoma City	1214	7.5	2.9	−2.0	−7.5	−12.5	−18.4	−24.6	−31.4	......
Okla. A	Fort Sill	1200	8.8	4.4	−0.6	−6.0	−11.4	−17.3	−23.4	−30.2	......
	OREGON										
589	Lakeview	4764	0.2	−4.9	−10.3	−15.8	−21.7	−27.8	−34.2	−40.9	......
597	Medford	1329	6.1	1.2	−3.9	−9.2	−14.8	−20.7	−26.8	−33.3	......
683	Burns	4170	0.4	−4.7	−10.0	−15.6	−21.5	−27.6	−34.0	−40.6	......
Oreg. A	Baker	3471	0.7	−4.3	−9.6	−14.9	−20.6	−26.5	−32.9	−39.4	......
Oreg. B	Redmond	3084	2.5	−2.5	−7.8	−13.4	−19.2	−25.2	−31.6	−38.1	......

TABLE 7.4.6 (CONTINUED)

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Continental U.S. Stations Above 305 gpm (1,000 Feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations listed in Table 7.4.3]

Station No. or letter	State and station	Station elevation	Station temperature argument, t_s, in °F. −50°	−40°	−30°	−20°	−10°	0°	+10°	+20°	+30°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
	PENNSYLVANIA										
512	Phillipsburg	1914	......	29.3	27.3	24.6	21.6	18.4	14.9	11.1	7.1
520	Pittsburgh (Greater)	1225	......	31.7	29.2	26.6	23.7	20.5	17.0	13.2	9.2
Pa. A	Park Place	1944	......	29.0	26.4	23.7	20.7	17.4	13.8	10.0	6.0
	SOUTH CAROLINA										
312	Greenville	1040	......	......	......	31.2	28.4	25.3	21.7	17.9	13.9
	SOUTH DAKOTA										
654	Huron	1301	33.8	31.4	28.7	25.8	22.5	18.9	15.0	11.0	6.6
662	Rapid City	3259	31.1	28.4	25.4	22.1	18.5	14.6	10.6	6.7	3.0
S. Dak. A	Pierre	1572	34.3	31.7	28.9	25.9	22.6	19.1	15.5	11.5	7.3
	TENNESSEE										
326	Knoxville	995#	......	......	32.9	30.4	27.6	24.4	20.9	17.1	13.1
Tenn. A	Crossville	1870	......	......	31.2	28.7	25.8	22.4	18.8	15.0	11.0
Tenn. B	Bristol	1525	......	......	31.6	29.1	26.2	22.8	19.2	15.5	11.5
	TEXAS										
261	Del Rio	1102	......	......	......	34.4	31.6	28.7	25.0	21.5	17.5
266	Abilene	1738	......	......	......	31.4	28.5	25.0	21.4	17.6	13.7
267	Lubbock	3241	......	......	31.4	28.6	25.7	22.5	19.1	15.5	11.5
270	El Paso	3778	......	......	......	29.6	26.5	23.3	19.9	16.3	12.4
271	Presidio	2612	......	......	......	33.2	30.6	27.7	24.8	22.0	18.8
351	Wichita Falls	1030	......	......	34.3	31.6	28.6	25.5	21.6	18.2	14.4
363	Amarillo	3676	......	......	29.5	26.6	23.7	20.5	17.2	13.5	9.4
Tex. A	Junction	1713	......	......	......	32.3	29.4	26.0	22.5	18.7	14.7
Tex. B	Fort Stockton	3052	......	......	......	30.6	27.9	25.0	22.3	19.7	16.4
Tex. C	Camp Hood	1027	......	......	35.1	32.5	29.6	26.4	23.0	19.3	15.2
Tex. D	Big Spring	2537	......	......	......	31.2	28.0	24.6	20.9	17.2	13.1
	UTAH										
477	Green River	4087	30.6	28.5	26.2	23.3	20.1	16.7	13.2	9.8	6.1
479	Delta	4714	30.7	28.5	26.0	23.4	20.5	17.5	14.0	10.4	6.3
572	Salt Lake City	4357	30.3	28.4	26.3	23.9	21.3	18.6	15.4	11.9	7.8
581	Wendover	4239	31.2	29.4	27.2	24.9	22.3	19.5	16.4	12.9	8.8
Utah A	Cedar City	5850	......	27.9	25.2	22.4	19.4	16.1	12.5	8.9	4.9
Utah B	Modena	5473	......	29.2	26.5	23.6	20.5	17.1	13.5	9.7	5.7
Utah C	Hanksville	4462	29.9	28.0	25.7	22.8	19.5	16.0	12.6	9.2	5.5
	VIRGINIA										
411	Roanoke	1176	......	......	31.5	29.0	26.0	22.9	19.3	15.6	11.6

The elevation of the Knoxville station was originally believed to be 1004 feet but this was subsequently corrected to 995 feet. It is sufficiently close to 1000 feet to permit use of data for that station in determining the plateau effect and local lapse rate anomaly correction for nearby stations at elevations of more than 1000 feet.

TABLE 7.4.6 (CONTINUED)

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Continental U.S. Stations Above 305 gpm (1,000 Feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations Listed in Table 7.4.3.]

Station No. or letter	State and station	Station elevation	Station temperature argument, t_s, in °F. +40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°	+120°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
	PENNSYLVANIA										
512	Phillipsburg	1914	2.8	−1.8	−6.8	−12.1	−18.5	−24.6	−31.0	−37.8	......
520	Pittsburgh (Greater)	1225	4.8	0.1	−4.9	−10.2	−15.9	−21.9	−28.1	−34.6	......
Pa. A	Park Place	1944	1.7	−2.9	−7.9	−13.2	−19.0	−25.1	−31.6	......	......
	SOUTH CAROLINA										
312	Greenville	1040	9.7	5.2	0.4	−4.9	−10.5	−16.5	−22.6	−29.0	......
	SOUTH DAKOTA										
654	Huron	1301	2.1	−2.6	−7.7	−13.1	−18.9	−24.9	−31.3	−37.9	......
662	Rapid City	3259	−0.9	−5.2	−10.2	−15.8	−21.8	−28.1	−34.7	−41.4	......
S. Dak. A	Pierre	1572	2.9	−1.8	−6.9	−12.3	−18.1	−24.2	−30.5	−37.2	......
	TENNESSEE										
326	Knoxville	995#	8.9	4.3	−0.6	−5.8	−11.5	−17.4	−23.5	−29.9	......
Tenn. A	Crossville	1870	6.8	2.3	−2.7	−8.0	−13.6	−19.6	−25.9	−32.4	......
Tenn. B	Bristol	1525	7.3	2.8	−2.2	−7.4	−13.2	−19.3	−25.6	−31.8	......
	TEXAS										
261	Del Rio	1102	13.3	8.9	4.0	−0.9	−6.6	−12.6	−18.2	−24.7	......
266	Abilene	1738	9.6	5.1	0.2	−4.7	−10.4	−16.3	−22.6	−29.0	......
267	Lubbock	3241	7.2	2.6	−2.1	−7.4	−13.1	−19.0	−25.3	−31.9	......
270	El Paso	3778	8.3	3.6	−1.0	−6.1	−11.6	−17.9	−24.1	−30.7	......
271	Presidio	2612	14.7	9.6	3.7	−2.6	−8.8	−15.1	−21.4	−27.7	......
351	Wichita Falls	1030	9.9	5.3	0.4	−4.6	−10.1	−15.7	−22.0	−28.3	......
363	Amarillo	3676	5.1	0.6	−4.3	−9.6	−15.3	−21.4	−27.8	−34.3	......
Tex. A	Junction	1713	10.4	6.0	1.1	−4.0	−9.4	−15.3	−21.5	−27.9	......
Tex. B	Fort Stockton	3052	11.9	6.4	0.2	−6.2	−12.6	−18.8	−25.0	−31.2	......
Tex. C	Camp Hood	1027	11.1	6.6	1.7	−3.7	−9.4	−15.4	−21.5	−27.9	......
Tex. D	Big Spring	2537	8.8	4.6	−0.3	−5.3	−10.8	−16.7	−23.0	−29.5	−36.3
	UTAH										
477	Green River	4087	2.2	−2.2	−7.0	−12.5	−18.4	−24.7	−31.2	−38.0	......
479	Delta	4714	1.8	−3.2	−8.6	−14.3	−20.3	−26.5	−33.0	−39.6	......
572	Salt Lake City	4357	3.1	−2.0	−7.5	−13.2	−19.1	−25.2	−31.6	−38.1	......
581	Wendover	4239	4.2	−0.9	−6.3	−12.0	−18.0	−24.0	−30.3	−36.9	
Utah A	Cedar City	5850	0.5	−4.3	−9.4	−14.9	−21.0	−27.2	−33.6	−40.3	
Utah B	Modena	5473	1.5	−3.4	−8.6	−14.2	−20.2	−26.5	−33.0	−39.7	......
Utah C	Hanksville	4462	1.7	−2.7	−7.6	−13.0	−18.8	−25.1	−31.7	−38.5	......
	VIRGINIA										
411	Roanoke	1176	7.3	2.7	−2.2	−7.4	−13.1	−19.0	−25.2	......	......

The elevation of the Knoxville station was originally believed to be 1004 feet but this was subsequently corrected to 995 feet. It is sufficiently close to 1000 feet to permit use of data for that station in determining the plateau effect and local lapse rate anomaly correction for nearby stations at elevations of more than 1000 feet.

TABLE 7.4.6 (CONTINUED)

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Continental U.S. Stations Above 305 gpm (1,000 Feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations Listed in Table 7.4.3.]

Station No. or Letter	State and station	Station elevation	Station temperature argument, t_s, in °F. −50°	−40°	−30°	−20°	−10°	0°	+10°	+20°	+30°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
	WASHINGTON										
781	Yakima	1066	......	30.8	28.9	26.5	23.8	20.7	17.2	13.3	8.9
785	Spokane	2365	32.2	30.5	28.3	25.6	22.7	19.0	15.1	10.7	6.4
789	Omak	1232	......	30.8	28.5	25.9	22.9	19.5	15.8	11.7	7.4
Wash. A	Walla Walla	1000	......	31.0	28.9	26.6	23.6	20.6	17.2	13.6	9.4
Wash. B	Dayton	1621	......	29.6	27.7	25.6	22.9	19.9	16.2	12.2	7.8
Wash. C	Stampede Pass	3967	......	28.0	26.0	23.7	20.9	17.5	13.6	9.1	4.5
	WEST VIRGINIA										
412	Flat Top	3270	......	14.7	13.3	11.8	10.1	8.5	6.6	4.6	2.7
417	Elkins	1947	......	......	28.3	25.8	22.6	19.5	15.9	12.1	8.3
	WISCONSIN										
646	Wausau	1196	33.3	30.9	28.1	25.0	21.7	18.1	14.4	10.4	6.3
Wis. A	Land O'Lakes	1710	31.5	28.8	25.5	22.2	18.7	15.2	11.6	7.6	3.5
	WYOMING										
564	Cheyenne	6088	27.1	24.9	22.1	18.8	15.0	11.0	7.0	3.3	0.2
569	Casper	5290	28.6	26.9	24.3	21.4	18.1	14.6	10.8	7.0	3.2
576	Lander	5352	28.3	26.1	23.6	20.6	17.3	13.7	10.0	6.1	2.2
666	Sheridan	3968	30.8	28.3	25.4	22.0	18.4	14.6	10.4	6.4	2.4
674	Cody	5106	31.9	29.1	26.2	22.6	18.8	14.9	10.7	6.3	2.1
Wyo. A	Fort Bridger	6643	26.9	24.9	22.4	19.5	16.0	12.0	7.9	3.6	−0.5

TABLE 7.4.7

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Alaskan Stations Above 305 gpm (1000 feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations Listed in Table 7.4.4.]

Station No. or Letter	State and station	Station elevation	Station temperature argument, t_s, in °F. −60°	−50°	−40°	−30°	−20°	−10°	0°	+10°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
248	Farewell, Alaska	1503	5.9	5.6	5.1	4.6	4.0	3.2	2.4	1.5
264	Summit, Alaska	2405	− 9.3	− 8.3	− 7.3	− 6.2	− 5.0	− 3.8	− 2.4	− 1.1
267	Big Delta, Alaska	1274	2.9	2.8	2.6	2.3	1.9	1.5	1.0	0.3
271	Gulkana, Alaska	1579	10.5	9.6	8.6	7.5	6.3	4.9	3.5	1.9
291	Northway, Alaska	1721	11.5	10.9	10.2	9.2	8.0	6.6	4.8	2.9

TABLE 7.4.6 (CONTINUED)

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Continental U.S. Stations Above 305 gpm (1,000 Feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations Listed in Table 7.4.3.]

Station No. or Letter	State and station	Station elevation	Station temperature argument, t_s, in °F. +40°	+50°	+60°	+70°	+80°	+90°	+100°	+110°	+120°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
	WASHINGTON										
781	Yakima	1066	4.3	− 0.5	− 5.5	−10.8	−16.4	−22.3	−28.6	−35.2	......
785	Spokane	2365	1.9	− 2.9	− 8.1	−13.5	−19.4	−25.6	−32.1	−38.6	......
789	Omak	1232	2.9	− 1.9	− 7.0	−12.4	−18.1	−24.2	−30.5	−36.9	......
Wash. A	Walla Walla	1000	5.0	0.2	− 5.0	−10.3	−16.0	−22.0	−28.1	−34.9	......
Wash. B	Dayton	1621	3.0	− 1.8	− 6.9	−11.9	−17.6	−23.5	−30.0	−36.6	......
Wash. C	Stampede Pass	3967	− 0.3	− 5.2	−10.4	−15.9	−21.9	−28.1	−34.7	......	......
	WEST VIRGINIA										
412	Flat Top	3270	0.7	− 1.3	− 3.5	− 6.2	− 9.2	−12.6	−16.2	......	......
417	Elkins	1947	3.8	− 0.5	− 5.9	−10.8	−16.5	−22.6	−28.8	......	......
	WISCONSIN										
646	Wausau	1196	1.8	− 3.0	− 8.2	−13.6	−19.4	−25.4	−31.7	−38.2	......
Wis. A	Land O'Lakes	1710	− 1.1	− 6.0	−11.3	−17.0	−22.9	−29.0	−35.3	−41.9	......
	WYOMING										
564	Cheyenne	6088	− 2.0	− 5.0	− 9.9	−15.6	−21.9	−28.6	−35.6	−42.6	......
569	Casper	5290	− 0.7	− 4.8	− 9.7	−15.1	−21.2	−27.7	−34.4	−41.4	......
576	Lander	5352	− 1.7	− 5.9	−10.7	−16.3	−22.7	−28.8	−35.6	−42.6	......
666	Sheridan	3968	− 1.7	− 6.0	−10.9	−16.5	−22.7	−29.1	−35.7	−42.6	......
674	Cody	5106	− 1.6	− 5.6	−10.4	−16.0	−22.1	−28.0	−35.2	−42.1	......
Wyo. A	Fort Bridger	6643	− 3.6	− 7.9	−13.3	−19.2	−25.6	−32.2	−39.0	−45.9	......

TABLE 7.4.7 (CONTINUED)

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Alaskan Stations Above 305 gpm (1000 feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations Listed in Table 7.4.4.]

Station No. or Letter	State and station	Station elevation	Station temperature argument, t_s, in °F. +20°	+30°	+40°	+50°	+60°	+70°	+80°	+90°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
248	Farewell, Alaska	1503	0.6	− 0.4	− 1.4	− 2.4	− 3.5	− 4.6	− 5.7	− 6.8
264	Summit, Alaska	2405	− 0.1	− 0.4	− 1.4	− 2.4	− 3.3	− 4.1	− 4.8	− 5.5
267	Big Delta, Alaska	1274	− 0.6	− 2.1	− 4.3	− 6.6	− 8.8	−11.0	−13.1	−15.2
271	Gulkana, Alaska	1579	0.3	− 1.5	− 3.3	− 5.2	− 7.2	− 9.2	−11.3	−13.4
291	Northway, Alaska	1721	0.8	− 1.4	− 3.8	− 6.1	− 8.4	−10.8	−13.0	−15.2

TABLE 7.4.8

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Canadian Stations Above 305 gpm (1000 feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations Listed in Table 7.4.5.]

Station No. or Letter	Name of station	Station elevation	Station temperature argument, t_s, in °F. −60°	−50°	−40°	−30°	−20°	−10°	0°	+10°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Can. A	Dawson Creek, B.C.	2160	31.8	29.8	27.2	24.2	21.0	17.4	13.5	9.4
958	Dease Lake, B.C.	2678	27.8	25.8	23.5	20.9	18.1	14.8	11.3	7.5
932	McMurray, Alta.	1216	31.7	29.2	26.2	23.0	19.5	15.8	11.7	7.6
Can. B	210 Mile Post, B.C.	1386	29.4	27.4	25.1	22.5	19.7	16.5	13.1	9.3
Can. C	Fish Lake, Y.T.	2845	39.9	37.4	34.3	30.9	27.0	22.6	17.1	10.6
738	White River, Ont.	1252	......	26.4	23.8	21.2	18.4	15.4	12.2	8.9
887	Kamloops, B.C.	1193	......	......	29.6	27.2	24.6	21.8	18.5	15.0
869	Prince Albert, Sask.	1432	34.3	31.3	27.9	24.5	20.9	16.9	12.8	8.5
Can. D	Barkerville, B.C.	4180	......	31.1	28.1	24.7	21.1	17.1	12.8	8.5
879	Edmondton, Alta.	2158	......	33.4	30.0	26.4	22.6	18.6	14.4	9.9
876	North Battleford, Sask.	1620	36.9	33.9	30.8	27.2	23.4	19.3	15.0	10.5
872	Medicine Hat, Alta.	2161	......	......	32.4	28.9	25.1	21.1	16.9	12.5
122	Banff, Alta.	4542	......	......	24.1	20.9	17.4	13.6	9.5	5.2
Can. E	Qu'Appelle, Sask.	2115	......	31.6	28.7	25.4	21.7	17.7	13.6	9.4
877	Calgary, Alta.	3389	......	......	28.2	24.8	20.9	16.7	12.3	7.8
853	Minnedosa, Man.	1690	......	28.4	25.9	23.1	20.0	16.6	12.9	9.1
870	Swift Current, Sask.	2440	......	31.2	28.3	25.0	21.4	17.7	13.7	9.3
Can. F	Stratford, Ont.	1191	......	......	30.6	27.9	24.9	21.7	18.3	14.5

TABLE 7.4.8 (CONTINUED)

Correction for Plateau Effect and Local Lapse Rate Anomaly, $F(t_s)$, for Canadian Stations Above 305 gpm (1000 feet)

[$F(t_s)$ Data Are Tabulated as a Function of Station Temperature Argument, t_s, for Stations Listed in Table 7.4.5.]

Station No. or Letter	Name of station	Station elevation	Station temperature argument, t_s, in °F. +20°	+30°	+40°	+50°	+60°	+70°	+80°	+90°	+100°
		ft.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Can. A	Dawson Creek, B.C.	2160	5.0	0.4	− 4.5	− 9.7	−15.1	−20.7	−26.5	−32.7	. .
958	Dease Lake, B.C.	2678	3.4	− 1.0	− 5.7	−10.6	−16.1	−21.8	−27.8	−34.1	.
932	McMurray, Alta.	1216	3.2	− 1.5	− 6.2	−11.1	−16.4	−22.0	−27.9	−33.9	
Can. B	210 Mile Post, B.C.	1386	5.3	1.0	− 3.7	− 8.6	−13.9	−19.5	−25.4	−31.6	......
Can. C	Fish Lake, Y.T.	2845	5.1	− 0.4	− 5.9	−11.6	−17.4	−23.2	−29.2	−35.4	.
738	White River, Ont.	1252	4.7	− 0.1	− 5.0	−10.0	−15.3	−20.8	−26.6	−32.7	. .
887	Kamloops, B.C.	1193	11.2	7.1	2.6	− 2.3	− 7.5	−13.0	−18.8	−24.8	−31.0
869	Prince Albert, Sask.	1432	4.3	− 0.1	− 5.0	− 9.9	−15.3	−20.9	−26.8	−32.8	......
Can. D	Barkerville, B.C.	4180	3.8	− 1.1	− 6.2	−11.6	−17.2	−23.0	−28.9	−35.0	......
879	Edmonton, Alta.	2158	5.3	0.5	− 4.4	− 9.5	−14.8	−20.3	−26.1	−32.2	......
876	North Battleford, Sask.	1620	5.7	0.8	− 4.3	− 9.4	−14.7	−20.3	−26.1	−32.2	......
872	Medicine Hat, Alta.	2161	7.9	3.1	− 1.8	− 6.9	−12.3	−17.8	−23.7	−29.8	−36.2
122	Banff, Alta.	4542	1.1	− 2.2	− 5.6	− 9.7	−14.7	−20.3	−26.3	−32.7	−39.3
Can. E	Qu'Appelle, Sask.	2115	5.2	0.7	− 4.0	− 8.9	−14.3	−19.9	−25.8	−32.0	......
877	Calgary, Alta.	3389	3.3	− 1.3	− 5.8	−10.1	−14.6	−19.7	−25.4	−31.7	−38.2
853	Minnedosa, Man.	1690	5.0	0.6	− 4.0	− 9.1	−14.4	−20.1	−26.0	−32.1	......
870	Swift Current, Sask.	2440	5.1	0.8	− 3.5	− 8.0	−12.9	−18.4	−24.2	−30.4	......
Can. F	Stratford, Ont.	1191	10.3	6.0	1.3	− 3.6	− 8.9	−14.5	−20.3	−26.4	−32.7

TABLE 7.5

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean Virtual temperature of air column (T_{mv}, in ° Rankine)*									
	400	405	410	415	420	425	430	435	440	445
0	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
10	1.00154	1.00152	1.00150	1.00147	1.00147	1.00145	1.00143	1.00141	1.00141	1.00138
20	1.00306	1.00304	1.00300	1.00297	1.00293	1.00290	1.00285	1.00284	1.00279	1.00277
30	1.00461	1.00457	1.00450	1.00445	1.00441	1.00434	1.00429	1.00425	1.00420	1.00415
40	1.00617	1.00610	1.00600	1.00594	1.00587	1.00580	1.00573	1.00566	1.00561	1.00554
50	1.00772	1.00763	1.00751	1.00744	1.00733	1.00726	1.00716	1.00709	1.00700	1.00693
60	1.00925	1.00914	1.00904	1.00893	1.00881	1.00872	1.00860	1.00851	1.00842	1.00832
70	1.01081	1.01067	1.01056	1.01042	1.01030	1.01018	1.01004	1.00993	1.00983	1.00972
80	1.01237	1.01221	1.01207	1.01191	1.01177	1.01163	1.01151	1.01137	1.01123	1.01111
90	1.01393	1.01375	1.01358	1.01342	1.01326	1.01309	1.01295	1.01279	1.01265	1.01251
100	1.01548	1.01529	1.01510	1.01492	1.01473	1.01457	1.01440	1.01424	1.01407	1.01391
110	1.01704	1.01683	1.01662	1.01641	1.01623	1.01604	1.01585	1.01566	1.01548	1.01531
120	1.01861	1.01838	1.01815	1.01793	1.01772	1.01751	1.01730	1.01709	1.01690	1.01672
130	1.02016	1.01993	1.01967	1.01944	1.01920	1.01897	1.01876	1.01854	1.01833	1.01812
140	1.02173	1.02148	1.02120	1.02094	1.02068	1.02045	1.02021	1.01998	1.01974	1.01952
150	1.02331	1.02303	1.02275	1.02247	1.02219	1.02193	1.02167	1.02141	1.02117	1.02094
160	1.02489	1.02457	1.02428	1.02398	1.02369	1.02341	1.02313	1.02287	1.02261	1.02235
170	1.02646	1.02612	1.02582	1.02549	1.02520	1.02490	1.02459	1.02431	1.02402	1.02376
180	1.02803	1.02768	1.02736	1.02702	1.02669	1.02636	1.02605	1.02575	1.02546	1.02518
190	1.02962	1.02925	1.02889	1.02854	1.02818	1.02785	1.02752	1.02721	1.02690	1.02660
200	1.03119	1.03081	1.03043	1.03005	1.02970	1.02934	1.02899	1.02866	1.02832	1.02802
210	1.03279	1.03238	1.03198	1.03160	1.03119	1.03084	1.03046	1.03010	1.02977	1.02944
220	1.03438	1.03395	1.03352	1.03312	1.03271	1.03233	1.03195	1.03157	1.03119	1.03084
230	1.03598	1.03552	1.03507	1.03464	1.03424	1.03381	1.03343	1.03302	1.03264	1.03226
240	1.03755	1.03710	1.03662	1.03617	1.03574	1.03531	1.03490	1.03450	1.03409	1.03369
250	1.03915	1.03868	1.03817	1.03772	1.03726	1.03681	1.03638	1.03596	1.03552	1.03511
260	1.04076	1.04023	1.03973	1.03925	1.03877	1.03832	1.03786	1.03741	1.03698	1.03655
270	1.04237	1.04181	1.04131	1.04078	1.04030	1.03982	1.03935	1.03889	1.03844	1.03798
280	1.04395	1.04340	1.04287	1.04234	1.04181	1.04131	1.04083	1.04035	1.03987	1.03942
290	1.04556	1.04498	1.04443	1.04388	1.04335	1.04282	1.04232	1.04181	1.04133	1.04085
300	1.04718	1.04657	1.04600	1.04542	1.04486	1.04434	1.04381	1.04330	1.04280	1.04229
310	1.04877	1.04817	1.04756	1.04698	1.01641	1.04585	1.04530	1.04477	1.04424	1.04373
320	1.05039	1.04976	1.04913	1.04853	1.04792	1.04737	1.04679	1.04624	1.04571	1.04518
330	1.05201	1.05136	1.05070	1.05007	1.04947	1.04887	1.04829	1.04773	1.04717	1.04662
340	1.05363	1.05296	1.05228	1.05165	1.05102	1.05039	1.04978	1.04920	1.04862	1.04807
350	1.05524	1.05456	1.05385	1.05320	1.05254	1.05191	1.05128	1.05068	1.05010	1.04952
360	1.05687	1.05614	1.05543	1.05475	1.05410	1.05344	1.05279	1.05218	1.05157	1.05097
370	1.05850	1.05774	1.05704	1.05633	1.05563	1.05497	1.05431	1.05366	1.05303	1.05242
380	1.06013	1.05935	1.05862	1.05789	1.05718	1.05648	1.05582	1.05514	1.05451	1.05388
390	1.06174	1.06096	1.06021	1.05945	1.05872	1.05801	1.05733	1.05665	1.05599	1.05533
400	1.06338	1.06258	1.06179	1.06101	1.06028	1.05955	1.05884	1.05813	1.05745	1.05679
410	1.06503	1.06419	1.06338	1.06260	1.06182	1.06108	1.06035	1.05964	1.05894	1.05825
420	1.06665	1.06581	1.06498	1.06417	1.06338	1.06262	1.06187	1.06113	1.06043	1.05972
430	1.06829	1.06743	1.06657	1.06574	1.06493	1.06414	1.06338	1.06262	1.06189	1.06118
440	1.06994	1.06905	1.06817	1.06733	1.06650	1.06569	1.06490	1.06414	1.06338	1.06265
450	1.07159	1.07068	1.06977	1.06890	1.06807	1.06723	1.06642	1.06564	1.06488	1.06412
460	1.07322	1.07228	1.07137	1.07048	1.06962	1.06878	1.06795	1.06714	1.06635	1.06559
470	1.07488	1.07392	1.07300	1.07206	1.07120	1.07034	1.06947	1.06866	1.06785	1.06706
480	1.07654	1.07555	1.07461	1.07367	1.07275	1.07186	1.07100	1.07016	1.06935	1.06854
490	1.07818	1.07718	1.07622	1.07525	1.07434	1.07342	1.07253	1.07167	1.07083	1.07002
500	1.07984	1.07882	1.07783	1.07686	1.07590	1.07498	1.07406	1.07320	1.07233	1.07149

* T in ° Rankine = (459.67 + t °F.)

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	400	405	410	415	420	425	430	435	440	445
500	1.07984	1.07882	1.07783	1.07686	1.07590	1.07498	1.07406	1.07320	1.07233	1.07149
510	1.08151	1.08046	1.07944	1.07845	1.07748	1.07654	1.07562	1.07471	1.07384	1.07289
520	1.08318	1.08211	1.08107	1.08004	1.07906	1.07810	1.07716	1.07622	1.07533	1.07446
530	1.08483	1.08375	1.08268	1.08166	1.08064	1.07964	1.07870	1.07775	1.07684	1.08594
540	1.08650	1.08540	1.08430	1.08325	1.08223	1.08121	1.08024	1.07927	1.07835	1.07743
550	1.08818	1.08705	1.08593	1.08485	1.08380	1.08278	1.08178	1.08081	1.07984	1.07892
560	1.08986	1.08868	1.08755	1.08645	1.08540	1.08435	1.08333	1.08233	1.08136	1.08041
570	1.09152	1.09034	1.08918	1.08808	1.08698	1.08593	1.08488	1.08385	1.08288	1.08191
580	1.09320	1.09199	1.09084	1.08968	1.08858	1.08748	1.08643	1.08540	1.08438	1.08340
590	1.09489	1.09365	1.09247	1.09129	1.09016	1.08906	1.08798	1.08693	1.08590	1.08490
600	1.09655	1.09532	1.09411	1.09292	1.09177	1.09064	1.08953	1.08845	1.08740	1.08640
610	1.09825	1.09698	1.09575	1.09454	1.09335	1.09222	1.09109	1.09001	1.08893	1.08790
620	1.09994	1.09865	1.09739	1.09615	1.09496	1.09381	1.09265	1.09154	1.09046	1.08941
630	1.10164	1.10032	1.09903	1.09779	1.09655	1.09537	1.09421	1.09308	1.09197	1.09091
640	1.10332	1.10200	1.10068	1.09941	1.09817	1.09696	1.09577	1.09464	1.09350	1.09240
650	1.10502	1.10367	1.10233	1.10103	1.09979	1.09855	1.09734	1.09618	1.09504	1.09391
660	1.10673	1.10533	1.10398	1.10268	1.10139	1.10015	1.09893	1.09772	1.09655	1.09542
670	1.10841	1.10701	1.10563	1.10431	1.10301	1.10174	1.10050	1.09928	1.09809	1.09693
680	1.11012	1.10869	1.10731	1.10594	1.10461	1.10332	1.10207	1.10083	1.09964	1.09845
690	1.11183	1.11038	1.10897	1.10759	1.10624	1.10492	1.10365	1.10240	1.10116	1.09997
700	1.11355	1.11206	1.11063	1.10923	1.10785	1.10652	1.10522	1.10395	1.10271	1.10149
710	1.11524	1.11376	1.11230	1.11086	1.10948	1.10813	1.10680	1.10550	1.10426	1.10301
720	1.11697	1.11545	1.11396	1.11250	1.11109	1.10974	1.10838	1.10706	1.10578	1.10454
730	1.11869	1.11715	1.11563	1.11417	1.11273	1.11132	1.10997	1.10864	1.10734	1.10606
740	1.12042	1.11885	1.11730	1.11581	1.11435	1.11294	1.11155	1.11020	1.10889	1.10759
750	1.12212	1.12055	1.11897	1.11745	1.11599	1.11455	1.11314	1.11178	1.11043	1.10912
760	1.12385	1.12223	1.12065	1.11913	1.11764	1.11617	1.11473	1.11335	1.11199	1.11066
770	1.12559	1.12393	1.12233	1.12078	1.11926	1.11779	1.11632	1.11491	1.11355	1.11219
780	1.12730	1.12564	1.12404	1.12243	1.12091	1.11939	1.11792	1.11650	1.11509	1.11373
790	1.12904	1.12735	1.12572	1.12411	1.12254	1.12101	1.11954	1.11807	1.11666	1.11527
800	1.13078	1.12907	1.12741	1.12577	1.12419	1.12264	1.12114	1.11964	1.11823	1.11681
810	1.13253	1.13078	1.12909	1.12743	1.12582	1.12427	1.12274	1.12124	1.11977	1.11836
820	1.13425	1.13250	1.13078	1.12912	1.12748	1.12590	1.12435	1.12282	1.12135	1.11990
830	1.13600	1.13423	1.13248	1.13078	1.12912	1.12751	1.12595	1.12440	1.12292	1.12145
840	1.13776	1.13595	1.13418	1.13245	1.13078	1.12915	1.12756	1.12600	1.12448	1.12300
850	1.13951	1.13768	1.13587	1.13415	1.13243	1.13078	1.12917	1.12759	1.12606	1.12455
860	1.14125	1.13938	1.13757	1.13582	1.13410	1.13243	1.13078	1.12920	1.12764	1.12611
870	1.14301	1.14112	1.13928	1.13750	1.13577	1.13407	1.13240	1.13078	1.12920	1.12766
880	1.14477	1.14285	1.14099	1.13917	1.13742	1.13569	1.13402	1.13237	1.13078	1.12922
890	1.14652	1.14459	1.14272	1.14088	1.13910	1.13734	1.13564	1.13399	1.13237	1.13078
900	1.14829	1.14633	1.14443	1.14256	1.14075	1.13899	1.13726	1.13559	1.13394	1.13235
910	1.15006	1.14807	1.14615	1.14425	1.14243	1.14064	1.13889	1.13718	1.13553	1.13391
920	1.15183	1.14982	1.14786	1.14596	1.14409	1.14227	1.14051	1.13881	1.13713	1.13548
930	1.15359	1.15157	1.14958	1.14765	1.14578	1.14393	1.14214	1.14041	1.13870	1.13705
940	1.15537	1.15332	1.15130	1.14934	1.14744	1.14559	1.14377	1.14201	1.14030	1.13862
950	1.15715	1.15507	1.15303	1.15107	1.14913	1.14726	1.14543	1.14364	1.14191	1.14020
960	1.15891	1.15680	1.15476	1.15276	1.15080	1.14892	1.14707	1.14525	1.14348	1.14177
970	1.16070	1.15856	1.15648	1.15446	1.15250	1.15056	1.14871	1.14686	1.14509	1.14335
980	1.16249	1.16033	1.15822	1.15619	1.15420	1.15223	1.15035	1.14850	1.14667	1.14493
990	1.16429	1.16209	1.15998	1.15790	1.15587	1.15390	1.15199	1.15011	1.14829	1.14652
1000	1.16606	1.16386	1.16172	1.15960	1.15758	1.15558	1.15364	1.15175	1.14990	1.14810

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$r = 10^{(KH_{pg})/T_{mv}}$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	400	405	410	415	420	425	430	435	440	445
1000	1.16606	1.16386	1.16172	1.15960	1.15758	1.15558	1.15364	1.15175	1.14990	1.14810
1010	1.16785	1.16563	1.16346	1.16134	1.15926	1.15723	1.15529	1.15337	1.15149	1.14969
1020	1.16966	1.16740	1.16520	1.16305	1.16097	1.15891	1.15694	1.15499	1.15311	1.15128
1030	1.17147	1.16918	1.16694	1.16477	1.16265	1.16059	1.15859	1.15664	1.15473	1.15287
1040	1.17325	1.17095	1.16869	1.16649	1.16437	1.16228	1.16025	1.15827	1.15633	1.15446
1050	1.17506	1.17274	1.17044	1.16823	1.16608	1.16397	1.16190	1.15990	1.15795	1.15606
1060	1.17687	1.17449	1.17220	1.16996	1.16778	1.16565	1.16356	1.16156	1.15958	1.15766
1070	1.17866	1.17628	1.17395	1.17168	1.16950	1.16732	1.16523	1.16319	1.16118	1.15926
1080	1.18048	1.17807	1.17571	1.17344	1.17120	1.16901	1.16692	1.16485	1.16281	1.16086
1090	1.18231	1.17986	1.17750	1.17517	1.17292	1.17071	1.16858	1.16649	1.16445	1.16247
1100	1.18413	1.18165	1.17926	1.17690	1.17463	1.17241	1.17025	1.16813	1.16606	1.16405
1110	1.18593	1.18345	1.18103	1.17864	1.17636	1.17409	1.17193	1.16977	1.16770	1.16565
1120	1.18776	1.18525	1.18280	1.18040	1.17807	1.17579	1.17360	1.17144	1.16934	1.16728
1130	1.18960	1.18705	1.18457	1.18214	1.17980	1.17750	1.17528	1.17309	1.17095	1.16888
1140	1.19143	1.18886	1.18634	1.18389	1.18152	1.17921	1.17696	1.17476	1.17260	1.17050
1150	1.19325	1.19067	1.18812	1.18566	1.18326	1.18092	1.17864	1.17641	1.17425	1.17211
1160	1.19509	1.19245	1.18990	1.18741	1.18500	1.18261	1.18032	1.17807	1.17588	1.17373
1170	1.19693	1.19426	1.19168	1.18916	1.18672	1.18432	1.18201	1.17975	1.17752	1.17536
1180	1.19875	1.19608	1.19347	1.19094	1.18847	1.18604	1.18370	1.18141	1.17918	1.17698
1190	1.20060	1.19790	1.19528	1.19270	1.19020	1.18776	1.18539	1.18310	1.18084	1.17861
1200	1.20246	1.19972	1.19707	1.19446	1.19196	1.18949	1.18708	1.18476	1.18247	1.18024
1210	1.20431	1.20154	1.19886	1.19624	1.19369	1.19119	1.18878	1.18642	1.18413	1.18187
1220	1.20615	1.20337	1.20066	1.19801	1.19545	1.19292	1.19047	1.18809	1.18577	1.18350
1230	1.20801	1.20520	1.20246	1.19978	1.19718	1.19465	1.19217	1.18979	1.18744	1.18514
1240	1.20987	1.20701	1.20426	1.20157	1.19895	1.19638	1.19391	1.19146	1.18910	1.18678
1250	1.21171	1.20884	1.20606	1.20334	1.20069	1.19812	1.19561	1.19314	1.19075	1.18842
1260	1.21358	1.21068	1.20787	1.20512	1.20246	1.19985	1.19732	1.19484	1.19242	1.19006
1270	1.21546	1.21252	1.20968	1.20692	1.20423	1.20157	1.19903	1.19652	1.19410	1.19171
1280	1.21733	1.21437	1.21149	1.20870	1.20598	1.20332	1.20074	1.19820	1.19575	1.19336
1290	1.21919	1.21621	1.21331	1.21049	1.20776	1.20506	1.20246	1.19991	1.19743	1.19501
1300	1.22107	1.21806	1.21512	1.21230	1.20951	1.20681	1.20418	1.20160	1.19909	1.19666
1310	1.22295	1.21992	1.21694	1.21409	1.21130	1.20854	1.20590	1.20332	1.20077	1.19831
1320	1.22484	1.22177	1.21879	1.21588	1.21305	1.21029	1.20762	1.20501	1.20246	1.19997
1330	1.22671	1.22363	1.22062	1.21767	1.21484	1.21205	1.20934	1.20670	1.20412	1.20163
1340	1.22860	1.22549	1.22245	1.21949	1.21661	1.21381	1.21107	1.20843	1.20581	1.20329
1350	1.23050	1.22735	1.22428	1.22129	1.21840	1.21557	1.21280	1.21012	1.20751	1.20495
1360	1.23237	1.22919	1.22611	1.22309	1.22017	1.21733	1.21453	1.21185	1.20918	1.20662
1370	1.23427	1.23106	1.22795	1.22493	1.22197	1.21910	1.21630	1.21356	1.21088	1.20829
1380	1.23618	1.23293	1.22979	1.22673	1.22374	1.22084	1.21804	1.21526	1.21258	1.20996
1390	1.23808	1.23481	1.23163	1.22854	1.22555	1.22262	1.21978	1.21697	1.21426	1.21163
1400	1.23997	1.23669	1.23347	1.23038	1.22733	1.22439	1.22152	1.21871	1.21596	1.21331
1410	1.24188	1.23857	1.23532	1.23220	1.22914	1.22614	1.22326	1.22042	1.21767	1.21498
1420	1.24380	1.24045	1.23720	1.23401	1.23095	1.22792	1.22501	1.22214	1.21935	1.21666
1430	1.24569	1.24234	1.23905	1.23583	1.23276	1.22970	1.22676	1.22388	1.22107	1.21834
1440	1.24761	1.24423	1.24091	1.23768	1.23455	1.23149	1.22851	1.22560	1.22278	1.22003
1450	1.24954	1.24612	1.24277	1.23951	1.23635	1.23328	1.23027	1.22735	1.22448	1.22172
1460	1.25147	1.24799	1.24463	1.24134	1.23817	1.23507	1.23203	1.22908	1.22620	1.22338
1470	1.25337	1.24988	1.24649	1.24320	1.24000	1.23683	1.23379	1.23084	1.22792	1.22507
1480	1.25531	1.25179	1.24836	1.24503	1.24180	1.23863	1.23555	1.23257	1.22962	1.22676
1490	1.25725	1.25369	1.25023	1.24687	1.24363	1.24042	1.23731	1.23430	1.23135	1.22846
1500	1.25919	1.25560	1.25210	1.24873	1.24543	1.24222	1.23908	1.23603	1.23308	1.23016

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	400	405	410	415	420	425	430	435	440	445
1500	1.25919	1.25560	1.25210	1.24873	1.24543	1.24222	1.23908	1.23603	1.23308	1.23016
1510	1.26110	1.25751	1.25398	1.25058	1.24724	1.24400	1.24085	1.23780	1.23478	1.23186
1520	1.26305	1.25942	1.25589	1.25242	1.24908	1.24580	1.24262	1.23954	1.23652	1.23356
1530	1.26500	1.26133	1.25777	1.25430	1.25092	1.24761	1.24443	1.24131	1.23825	1.23526
1540	1.26692	1.26325	1.25965	1.25615	1.25274	1.24942	1.24621	1.24305	1.23997	1.23697
1550	1.26888	1.26517	1.26154	1.25800	1.25458	1.25124	1.24799	1.24480	1.24171	1.23868
1560	1.27084	1.26707	1.26343	1.25988	1.25643	1.25305	1.24977	1.24658	1.24345	1.24040
1570	1.27280	1.26900	1.26532	1.26174	1.25826	1.25484	1.25156	1.24833	1.24517	1.24211
1580	1.27474	1.27093	1.26721	1.26360	1.26011	1.25667	1.25334	1.25009	1.24692	1.24383
1590	1.27670	1.27286	1.26911	1.26549	1.26194	1.25849	1.25513	1.25187	1.24865	1.24555
1600	1.27867	1.27479	1.27101	1.26736	1.26378	1.26032	1.25693	1.25363	1.25040	1.24727
1610	1.28065	1.27673	1.27292	1.26923	1.26564	1.26212	1.25872	1.25542	1.25216	1.24899
1620	1.28260	1.27867	1.27485	1.27113	1.26751	1.26395	1.26052	1.25719	1.25389	1.25072
1630	1.28458	1.28062	1.27676	1.27300	1.26935	1.26579	1.26232	1.25895	1.25565	1.25245
1640	1.28656	1.28257	1.27867	1.27488	1.27122	1.26762	1.26412	1.26072	1.25742	1.25418
1650	1.28852	1.28452	1.28059	1.27676	1.27306	1.26946	1.26593	1.26253	1.25919	1.25591
1660	1.29051	1.28644	1.28251	1.27867	1.27494	1.27131	1.26774	1.26430	1.26093	1.25765
1670	1.29250	1.28840	1.28443	1.28056	1.27679	1.27312	1.26958	1.26608	1.26270	1.25939
1680	1.29449	1.29036	1.28635	1.28245	1.27867	1.27497	1.27139	1.26789	1.26445	1.26113
1690	1.29646	1.29232	1.28828	1.28437	1.28056	1.27682	1.27321	1.26967	1.26622	1.26287
1700	1.29846	1.29429	1.29021	1.28626	1.28242	1.27867	1.27503	1.27145	1.26800	1.26462
1710	1.30047	1.29625	1.29214	1.28816	1.28431	1.28050	1.27685	1.27327	1.26976	1.26637
1720	1.30245	1.29823	1.29408	1.29009	1.28617	1.28236	1.27867	1.27506	1.27155	1.26812
1730	1.30446	1.30020	1.29604	1.29199	1.28804	1.28422	1.28050	1.27688	1.27333	1.26987
1740	1.30647	1.30218	1.29799	1.29390	1.28994	1.28609	1.28233	1.27867	1.27509	1.27163
1750	1.30849	1.30416	1.29993	1.29584	1.29184	1.28795	1.28416	1.28047	1.27688	1.27339
1760	1.31048	1.30611	1.30188	1.29775	1.29375	1.28982	1.28600	1.28230	1.27867	1.27515
1770	1.31250	1.30810	1.30383	1.29966	1.29563	1.29167	1.28783	1.28410	1.28044	1.27691
1780	1.31453	1.31009	1.30578	1.30158	1.29751	1.29354	1.28967	1.28591	1.28224	1.27867
1790	1.31656	1.31208	1.30774	1.30353	1.29942	1.29542	1.29152	1.28775	1.28404	1.28044
1800	1.31856	1.31407	1.30969	1.30545	1.30131	1.29730	1.29336	1.28956	1.28582	1.28221
1810	1.32060	1.31607	1.31166	1.30737	1.30323	1.29918	1.29521	1.29140	1.28763	1.28399
1820	1.32263	1.31807	1.31362	1.30933	1.30515	1.30104	1.29709	1.29321	1.28944	1.28576
1830	1.32465	1.32008	1.31562	1.31126	1.30704	1.30293	1.29894	1.29503	1.29122	1.28754
1840	1.32669	1.32209	1.31759	1.31320	1.30894	1.30482	1.30080	1.29688	1.29303	1.28932
1850	1.32874	1.32410	1.31956	1.31516	1.31087	1.30671	1.30266	1.29870	1.29485	1.29110
1860	1.33079	1.32608	1.32154	1.31710	1.31280	1.30858	1.30452	1.30053	1.29664	1.29289
1870	1.33282	1.32810	1.32352	1.31905	1.31474	1.31048	1.30638	1.30239	1.29846	1.29467
1880	1.33487	1.33012	1.32550	1.32102	1.31665	1.31238	1.30825	1.30422	1.30026	1.29643
1890	1.33693	1.33214	1.32749	1.32297	1.31856	1.31429	1.31012	1.30605	1.30209	1.29823
1900	1.33900	1.33417	1.32947	1.32492	1.32050	1.31619	1.31199	1.30789	1.30392	1.30002
1910	1.34103	1.33620	1.33147	1.32691	1.32245	1.31810	1.31386	1.30975	1.30575	1.30182
1920	1.34311	1.33823	1.33346	1.32886	1.32437	1.31999	1.31574	1.31160	1.30756	1.30362
1930	1.34518	1.34026	1.33549	1.33082	1.32629	1.32190	1.31762	1.31347	1.30939	1.30542
1940	1.34722	1.34230	1.33749	1.33282	1.32825	1.32382	1.31950	1.31532	1.31123	1.30722
1950	1.34930	1.34434	1.33949	1.33478	1.33021	1.32575	1.32139	1.31716	1.31305	1.30903
1960	1.35139	1.34636	1.34150	1.33675	1.33214	1.32767	1.32331	1.31905	1.31489	1.31084
1970	1.35347	1.34840	1.34351	1.33872	1.33410	1.32957	1.32520	1.32090	1.31671	1.31265
1980	1.35553	1.35045	1.34552	1.34073	1.33607	1.33150	1.32709	1.32276	1.31856	1.31447
1990	1.35763	1.35251	1.34753	1.34270	1.33801	1.33343	1.32898	1.32465	1.32041	1.31629
2000	1.35972	1.35457	1.34955	1.34468	1.33995	1.33537	1.33088	1.32651	1.32227	1.31810

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$r = 10^{(KH_{pg})/T_{mv}}$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	400	405	410	415	420	425	430	435	440	445
2000	1.35972	1.35457	1.34955	1.34468	1.33995	1.33537	1.33088	1.32651	1.32227	1.31810
2010	1.36182	1.35663	1.35157	1.34670	1.34193	1.33730	1.33278	1.32840	1.32410	1.31993
2020	1.36389	1.35869	1.35360	1.34868	1.34388	1.33921	1.33469	1.33027	1.32596	1.32175
2030	1.36600	1.36076	1.35566	1.35067	1.34586	1.34116	1.33660	1.33214	1.32782	1.32358
2040	1.36811	1.36282	1.35769	1.35270	1.34781	1.34311	1.33851	1.33404	1.32966	1.32541
2050	1.37019	1.36490	1.35972	1.35469	1.34980	1.34504	1.34042	1.33592	1.33153	1.32724
2060	1.37230	1.36694	1.36176	1.35669	1.35176	1.34698	1.34233	1.33780	1.33337	1.32908
2070	1.37442	1.36902	1.36380	1.35872	1.35375	1.34893	1.34425	1.33971	1.33524	1.33091
2080	1.37654	1.37110	1.36584	1.36072	1.35575	1.35089	1.34617	1.34159	1.33712	1.33275
2090	1.37864	1.37319	1.36789	1.36273	1.35772	1.35285	1.34809	1.34348	1.33897	1.33460
2100	1.38077	1.37528	1.36994	1.36477	1.35972	1.35482	1.35002	1.34540	1.34085	1.33644
2110	1.38290	1.37737	1.37199	1.36678	1.36170	1.35678	1.35198	1.34729	1.34273	1.33829
2120	1.38500	1.37946	1.37404	1.36880	1.36370	1.35872	1.35391	1.34921	1.34459	1.34014
2130	1.38714	1.38156	1.37610	1.37082	1.36568	1.36069	1.35584	1.35111	1.34648	1.34199
2140	1.38928	1.38366	1.37819	1.37287	1.36770	1.36267	1.35778	1.35301	1.34837	1.34385
2150	1.39143	1.38577	1.38026	1.37490	1.36968	1.36465	1.35972	1.35494	1.35024	1.34571
2160	1.39354	1.38784	1.38232	1.37692	1.37170	1.36663	1.36166	1.35684	1.35213	1.34757
2170	1.39569	1.38995	1.38440	1.37899	1.37369	1.36858	1.36361	1.35875	1.35404	1.34943
2180	1.39785	1.39207	1.38647	1.38102	1.37572	1.37057	1.36556	1.36069	1.35591	1.35129
2190	1.40001	1.39418	1.38855	1.38306	1.37775	1.37256	1.36751	1.36261	1.35781	1.35316
2200	1.40214	1.39630	1.39062	1.38513	1.37975	1.37455	1.36946	1.36452	1.35972	1.35503
2210	1.40430	1.39843	1.39271	1.38717	1.38178	1.37651	1.37142	1.36644	1.36160	1.35691
2220	1.40647	1.40055	1.39479	1.38922	1.38382	1.37851	1.37338	1.36839	1.36352	1.35878
2230	1.40861	1.40268	1.39688	1.39130	1.38583	1.38051	1.37534	1.37031	1.36543	1.36066
2240	1.41078	1.40479	1.39901	1.39335	1.38787	1.38252	1.37730	1.37227	1.36732	1.36254
2250	1.41296	1.40692	1.40110	1.39540	1.38989	1.38452	1.37930	1.37420	1.36924	1.36443
2260	1.41514	1.40906	1.40320	1.39749	1.39194	1.38650	1.38127	1.37616	1.37113	1.36631
2270	1.41729	1.41120	1.40530	1.39956	1.39396	1.38851	1.38325	1.37810	1.37306	1.36820
2280	1.41948	1.41335	1.40741	1.40162	1.39601	1.39053	1.38522	1.38003	1.37499	1.37009
2290	1.42167	1.41550	1.40952	1.40369	1.39804	1.39255	1.38720	1.38197	1.37692	1.37199
2300	1.42384	1.41765	1.41163	1.40579	1.40010	1.39457	1.38918	1.38395	1.37883	1.37385
2310	1.42603	1.41981	1.41374	1.40786	1.40214	1.39659	1.39117	1.38589	1.38077	1.37575
2320	1.42824	1.42197	1.41586	1.41994	1.40420	1.39859	1.39316	1.38787	1.38271	1.37765
2330	1.43044	1.42413	1.41798	1.41205	1.40624	1.40062	1.39515	1.38982	1.38462	1.37956
2340	1.43262	1.42630	1.42010	1.41413	1.40832	1.40265	1.39714	1.39178	1.38656	1.38147
2350	1.43483	1.42847	1.42223	1.41622	1.41039	1.40466	1.39914	1.39377	1.38848	1.38338
2360	1.43704	1.43061	1.42439	1.41831	1.41244	1.40670	1.40114	1.39573	1.39043	1.38529
2370	1.43926	1.43278	1.42653	1.42043	1.41452	1.40874	1.40314	1.39769	1.39239	1.38720
2380	1.44145	1.43496	1.42866	1.42253	1.41658	1.41078	1.40514	1.39968	1.39434	1.38912
2390	1.44368	1.43714	1.43080	1.42466	1.41863	1.41283	1.40715	1.40165	1.39627	1.39104
2400	1.44591	1.43933	1.43295	1.42676	1.42072	1.41488	1.40919	1.40362	1.39823	1.39296
2410	1.44810	1.44152	1.43509	1.42886	1.42282	1.41694	1.41120	1.40563	1.40017	1.39489
2420	1.45034	1.44371	1.43724	1.43100	1.42489	1.41896	1.41322	1.40760	1.40214	1.39682
2430	1.45258	1.44591	1.43940	1.43311	1.42699	1.42102	1.41524	1.40958	1.40411	1.39875
2440	1.45482	1.44810	1.44155	1.43523	1.42909	1.42308	1.41726	1.41159	1.40605	1.40068
2450	1.45704	1.45031	1.44374	1.43734	1.43117	1.42512	1.41929	1.41358	1.40802	1.40262
2460	1.45928	1.45248	1.44591	1.43949	1.43328	1.42718	1.42131	1.41560	1.41000	1.40456
2470	1.46154	1.45469	1.44807	1.44162	1.43536	1.42926	1.42334	1.41759	1.41198	1.40650
2480	1.46376	1.45690	1.45024	1.44374	1.43747	1.43133	1.42538	1.41958	1.41394	1.40845
2490	1.46602	1.45912	1.45241	1.44591	1.43956	1.43341	1.42741	1.42158	1.41592	1.41039
2500	1.46828	1.46134	1.45459	1.44804	1.44168	1.43549	1.42945	1.42361	1.41791	1.41234

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	400	405	410	415	420	425	430	435	440	445
2500	1.46828	1.46134	1.45459	1.44804	1.44168	1.43549	1.42945	1.42361	1.41791	1.41234
2510	1.47055	1.46356	1.45677	1.45017	1.44381	1.43754	1.43150	1.42561	1.41987	1.41429
2520	1.47279	1.46578	1.45895	1.45235	1.44591	1.43963	1.43354	1.42761	1.42187	1.41625
2530	1.47506	1.46801	1.46113	1.45449	1.44800	1.44172	1.43559	1.42965	1.42384	1.41821
2540	1.47734	1.47025	1.46332	1.45663	1.45014	1.44381	1.43764	1.43166	1.42584	1.42017
2550	1.47962	1.47245	1.46551	1.45881	1.45228	1.44587	1.43973	1.43367	1.42784	1.42213
2560	1.48187	1.47469	1.46771	1.46097	1.45439	1.44795	1.44178	1.43572	1.42982	1.42410
2570	1.48416	1.47693	1.46994	1.46312	1.45653	1.45007	1.44384	1.43777	1.43183	1.42607
2580	1.48645	1.47918	1.47214	1.46528	1.45865	1.45218	1.44591	1.43979	1.43384	1.42804
2590	1.48871	1.48143	1.47435	1.46747	1.46080	1.45429	1.44797	1.44182	1.43582	1.43001
2600	1.49101	1.48368	1.47656	1.46964	1.46292	1.45640	1.45004	1.44384	1.43784	1.43199
2610	1.49331	1.48594	1.47877	1.47180	1.46508	1.45851	1.45212	1.44591	1.43986	1.43397
2620	1.49558	1.48820	1.48098	1.47401	1.46720	1.46060	1.45419	1.44794	1.44185	1.43595
2630	1.49789	1.49046	1.48320	1.47618	1.46937	1.46272	1.45626	1.44997	1.44388	1.43794
2640	1.50020	1.49273	1.48542	1.47836	1.47153	1.46484	1.45834	1.45204	1.44591	1.43993
2650	1.50248	1.49500	1.48765	1.48057	1.47367	1.46697	1.46043	1.45409	1.44790	1.44192
2660	1.50480	1.49724	1.48988	1.48276	1.47584	1.46910	1.46251	1.45616	1.44994	1.44391
2670	1.50713	1.49951	1.49214	1.48494	1.47798	1.47119	1.46460	1.45821	1.45198	1.44591
2680	1.50945	1.50179	1.49438	1.48717	1.48013	1.47333	1.46670	1.46026	1.45399	1.44790
2690	1.51175	1.50408	1.49661	1.48936	1.48231	1.47547	1.46879	1.46231	1.45603	1.44991
2700	1.51408	1.50636	1.49886	1.49156	1.48447	1.47761	1.47092	1.46440	1.45808	1.45191
2710	1.51642	1.50866	1.50110	1.49376	1.48665	1.47976	1.47302	1.46649	1.46009	1.45392
2720	1.51876	1.51095	1.50335	1.49599	1.48885	1.48187	1.47513	1.46855	1.46214	1.45593
2730	1.52107	1.51325	1.50560	1.49820	1.49101	1.48402	1.47724	1.47062	1.46420	1.45794
2740	1.52342	1.51555	1.50786	1.50041	1.49321	1.48618	1.47935	1.47272	1.46622	1.45996
2750	1.52577	1.51785	1.51011	1.50266	1.49541	1.48830	1.48146	1.47479	1.46828	1.46198
2760	1.52809	1.52013	1.51238	1.50487	1.49758	1.49046	1.48358	1.47686	1.47031	1.46400
2770	1.53045	1.52244	1.51468	1.50709	1.49975	1.49262	1.48570	1.47894	1.47238	1.46602
2780	1.53282	1.52475	1.51695	1.50935	1.50197	1.49479	1.48782	1.48105	1.47445	1.46805
2790	1.53518	1.52707	1.51922	1.51158	1.50418	1.49696	1.48994	1.48313	1.47649	1.47004
2800	1.53752	1.52940	1.52149	1.51381	1.50636	1.49913	1.49207	1.48522	1.47856	1.47208
2810	1.53989	1.53172	1.52377	1.51607	1.50855	1.50127	1.49420	1.48734	1.48064	1.47411
2820	1.54227	1.53402	1.52605	1.51831	1.51078	1.50345	1.49634	1.48943	1.48269	1.47615
2830	1.54465	1.53635	1.52834	1.52055	1.51300	1.50564	1.49848	1.49156	1.48477	1.47819
2840	1.54700	1.53869	1.53063	1.52279	1.51524	1.50782	1.50065	1.49365	1.48686	1.48023
2850	1.54939	1.54103	1.53292	1.52507	1.51743	1.50998	1.50280	1.49579	1.48892	1.48228
2860	1.55178	1.54337	1.53522	1.52732	1.51964	1.51217	1.50494	1.49789	1.49101	1.48433
2870	1.55414	1.54572	1.53752	1.52957	1.52188	1.51436	1.50709	1.50000	1.49310	1.48638
2880	1.55654	1.54807	1.53986	1.53186	1.52412	1.51656	1.50925	1.50214	1.49517	1.48844
2890	1.55894	1.55042	1.54216	1.53412	1.52634	1.51876	1.51140	1.50425	1.49727	1.49049
2900	1.56135	1.55278	1.54447	1.53638	1.52855	1.52097	1.51356	1.50636	1.49937	1.49255
2910	1.56372	1.55514	1.54679	1.53865	1.53081	1.52314	1.51572	1.50848	1.50145	1.49462
2920	1.56614	1.55747	1.54910	1.54096	1.53306	1.52535	1.51789	1.51064	1.50356	1.49668
2930	1.56856	1.55984	1.55142	1.54323	1.53529	1.52757	1.52006	1.51276	1.50567	1.49875
2940	1.57094	1.56221	1.55375	1.54550	1.53755	1.52978	1.52223	1.51492	1.50775	1.50082
2950	1.57337	1.56459	1.55607	1.54782	1.53982	1.53197	1.52440	1.51705	1.50987	1.50290
2960	1.57580	1.56697	1.55840	1.55010	1.54206	1.53419	1.52658	1.51918	1.51199	1.50498
2970	1.57823	1.56935	1.56074	1.55239	1.54433	1.53642	1.52880	1.52132	1.51408	1.50706
2980	1.58063	1.57174	1.56308	1.55471	1.54657	1.53865	1.53098	1.52349	1.51621	1.50914
2990	1.58307	1.57413	1.56545	1.55700	1.54885	1.54088	1.53313	1.52563	1.51834	1.51123
3000	1.58551	1.57652	1.56780	1.55934	1.55110	1.54312	1.53536	1.52781	1.52044	1.51332

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$r = 10^{(KH_{pg})/T_{mv}}$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	450	455	460	465	470	475	480	485	490	495
0	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
10	1.00136	1.00136	1.00134	1.00131	1.00131	1.00129	1.00129	1.00127	1.00124	1.00124
20	1.00274	1.00270	1.00267	1.00265	1.00263	1.00258	1.00256	1.00254	1.00251	1.00249
30	1.00410	1.00406	1.00401	1.00397	1.00392	1.00390	1.00385	1.00381	1.00376	1.00374
40	1.00547	1.00543	1.00536	1.00531	1.00524	1.00519	1.00512	1.00508	1.00503	1.00499
50	1.00686	1.00677	1.00670	1.00663	1.00656	1.00647	1.00642	1.00635	1.00628	1.00624
60	1.00823	1.00814	1.00805	1.00795	1.00788	1.00779	1.00772	1.00763	1.00756	1.00749
70	1.00960	1.00951	1.00939	1.00930	1.00921	1.00909	1.00900	1.00890	1.00881	1.00872
80	1.01097	1.01086	1.01074	1.01062	1.01051	1.01042	1.01030	1.01018	1.01009	1.00997
90	1.01237	1.01223	1.01209	1.01198	1.01184	1.01172	1.01158	1.01146	1.01135	1.01123
100	1.01375	1.01361	1.01344	1.01330	1.01316	1.01302	1.01288	1.01274	1.01263	1.01249
110	1.01513	1.01496	1.01480	1.01464	1.01450	1.01433	1.01419	1.01403	1.01389	1.01375
120	1.01653	1.01634	1.01616	1.01599	1.01580	1.01564	1.01548	1.01531	1.01517	1.01501
130	1.01791	1.01772	1.01751	1.01733	1.01714	1.01697	1.01679	1.01660	1.01644	1.01627
140	1.01930	1.01908	1.01887	1.01869	1.01847	1.01829	1.01810	1.01789	1.01772	1.01754
150	1.02070	1.02047	1.02023	1.02002	1.01981	1.01960	1.01939	1.01918	1.01899	1.01880
160	1.02209	1.02186	1.02160	1.02136	1.02115	1.02092	1.02070	1.02047	1.02026	1.02007
170	1.02348	1.02322	1.02296	1.02273	1.02247	1.02223	1.02200	1.02179	1.02155	1.02134
180	1.02490	1.02461	1.02433	1.02407	1.02381	1.02355	1.02332	1.02308	1.02282	1.02261
190	1.02629	1.02601	1.02570	1.02544	1.02516	1.02490	1.02461	1.02438	1.02412	1.02386
200	1.02768	1.02738	1.02707	1.02679	1.02650	1.02622	1.02594	1.02568	1.02539	1.02513
210	1.02911	1.02877	1.02844	1.02813	1.02785	1.02754	1.02726	1.02698	1.02669	1.02641
220	1.03050	1.03015	1.02982	1.02951	1.02918	1.02887	1.02856	1.02828	1.02797	1.02768
230	1.03191	1.03155	1.03119	1.03087	1.03053	1.03020	1.02989	1.02958	1.02927	1.02896
240	1.03331	1.03295	1.03257	1.03224	1.03188	1.03155	1.03119	1.03088	1.03055	1.03024
250	1.03474	1.03433	1.03397	1.03359	1.03324	1.03288	1.03252	1.03219	1.03186	1.03153
260	1.03614	1.03574	1.03536	1.03495	1.03457	1.03421	1.03386	1.03350	1.03314	1.03281
270	1.03755	1.03715	1.03674	1.03633	1.03593	1.03555	1.03517	1.03481	1.03445	1.03409
280	1.03899	1.03853	1.03813	1.03770	1.03729	1.03688	1.03650	1.03612	1.03574	1.03538
290	1.04040	1.03994	1.03951	1.03908	1.03865	1.03822	1.03782	1.03743	1.03705	1.03667
300	1.04181	1.04136	1.04090	1.04045	1.04002	1.03958	1.03915	1.03875	1.03834	1.03796
310	1.04325	1.04275	1.04229	1.04181	1.04136	1.04093	1.04050	1.04006	1.03966	1.03923
320	1.04467	1.04417	1.04369	1.04321	1.04273	1.04227	1.04181	1.04138	1.04095	1.04052
330	1.04609	1.04559	1.04508	1.04458	1.04409	1.04361	1.04316	1.04270	1.04225	1.04181
340	1.04754	1.04698	1.04648	1.04595	1.04547	1.04496	1.04450	1.04402	1.04357	1.04311
350	1.04896	1.04841	1.04788	1.04735	1.04684	1.04633	1.04583	1.04535	1.04486	1.04441
360	1.05039	1.04983	1.04928	1.04872	1.04819	1.04768	1.04718	1.04667	1.04619	1.04571
370	1.05182	1.05124	1.05068	1.05010	1.04957	1.04904	1.04850	1.04800	1.04749	1.04701
380	1.05327	1.05266	1.05208	1.05150	1.05095	1.05039	1.04986	1.04932	1.04882	1.04831
390	1.05470	1.05410	1.05349	1.05291	1.05233	1.05174	1.05121	1.05065	1.05012	1.04961
400	1.05614	1.05550	1.05490	1.05429	1.05368	1.05313	1.05254	1.05199	1.05145	1.05092
410	1.05760	1.05694	1.05631	1.05567	1.05507	1.05448	1.05390	1.05332	1.05276	1.05223
420	1.05903	1.05838	1.05772	1.05709	1.05645	1.05584	1.05524	1.05465	1.05410	1.05354
430	1.06047	1.05979	1.05913	1.05847	1.05784	1.05721	1.05660	1.05599	1.05541	1.05483
440	1.06194	1.06123	1.06055	1.05986	1.05923	1.05857	1.05796	1.05733	1.05674	1.05614
450	1.06338	1.06267	1.06196	1.06128	1.06060	1.05994	1.05930	1.05867	1.05806	1.05745
460	1.06483	1.06409	1.06339	1.06267	1.06199	1.06133	1.06067	1.06001	1.05940	1.05877
470	1.06630	1.06554	1.06480	1.06409	1.06338	1.06270	1.06201	1.06135	1.06072	1.06008
480	1.06775	1.06699	1.06623	1.06549	1.06478	1.06407	1.06338	1.06270	1.06204	1.06140
490	1.06920	1.06842	1.06765	1.06689	1.06618	1.06544	1.06476	1.06405	1.06338	1.06272
500	1.07068	1.06987	1.06908	1.06832	1.06755	1.06682	1.06611	1.06542	1.06471	1.06405

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	450	455	460	465	470	475	480	485	490	495
500	1.07068	1.06987	1.06908	1.06832	1.06755	1.06682	1.06611	1.06542	1.06471	1.06405
510	1.07214	1.07130	1.07051	1.06972	1.06896	1.06822	1.06748	1.06677	1.06606	1.06537
520	1.07359	1.07275	1.07194	1.07115	1.07036	1.06960	1.06883	1.06812	1.06738	1.06669
530	1.07505	1.07421	1.07337	1.07256	1.07177	1.07098	1.07021	1.06947	1.06873	1.06802
540	1.07654	1.07567	1.07481	1.07396	1.07315	1.07236	1.07159	1.07083	1.07006	1.06935
550	1.07800	1.07711	1.07624	1.07540	1.07456	1.07374	1.07295	1.07219	1.07142	1.07068
560	1.07947	1.07857	1.07768	1.07681	1.07597	1.07515	1.07434	1.07354	1.07275	1.07199
570	1.08096	1.08004	1.07912	1.07825	1.07738	1.07654	1.07570	1.07490	1.07411	1.07332
580	1.08243	1.08148	1.08056	1.07967	1.07880	1.07793	1.07709	1.07627	1.07545	1.07466
590	1.08390	1.08295	1.08201	1.08109	1.08019	1.07932	1.07847	1.07763	1.07681	1.07599
600	1.08540	1.08440	1.08345	1.08253	1.08161	1.08071	1.07984	1.07900	1.07815	1.07733
610	1.08688	1.08588	1.08490	1.08395	1.08303	1.08211	1.08123	1.08036	1.07952	1.07867
620	1.08835	1.08735	1.08635	1.08540	1.08445	1.08353	1.08260	1.08173	1.08086	1.08002
630	1.08986	1.08880	1.08780	1.08683	1.08588	1.08493	1.08400	1.08310	1.08223	1.08136
640	1.09134	1.09028	1.08926	1.08825	1.08728	1.08633	1.08540	1.08448	1.08358	1.08270
650	1.09282	1.09177	1.09071	1.08971	1.08870	1.08773	1.08678	1.08585	1.08493	1.08405
660	1.09433	1.09323	1.09217	1.09114	1.09013	1.08913	1.08818	1.08723	1.08630	1.08540
670	1.09582	1.09471	1.09363	1.09260	1.09157	1.09056	1.08956	1.08860	1.08763	1.08675
680	1.09731	1.09620	1.09509	1.09403	1.09300	1.09197	1.09096	1.08998	1.08903	1.08808
690	1.09880	1.09767	1.09655	1.09547	1.09441	1.09338	1.09237	1.09136	1.09039	1.08943
700	1.10032	1.09916	1.09802	1.09693	1.09585	1.09479	1.09375	1.09275	1.09177	1.09079
710	1.10182	1.10065	1.09949	1.09837	1.09729	1.09620	1.09517	1.09413	1.09313	1.09214
720	1.10332	1.10212	1.10096	1.09984	1.09873	1.09764	1.09655	1.09552	1.09451	1.09350
730	1.10484	1.10362	1.10245	1.10129	1.10015	1.09906	1.09797	1.09691	1.09587	1.09487
740	1.10634	1.10512	1.10393	1.10273	1.10159	1.10047	1.09939	1.09830	1.09726	1.09623
750	1.10785	1.10660	1.10540	1.10421	1.10304	1.10189	1.10078	1.09969	1.09863	1.09759
760	1.10938	1.10810	1.10688	1.10566	1.10449	1.10332	1.10220	1.10108	1.10002	1.09896
770	1.11089	1.10961	1.10836	1.10713	1.10594	1.10477	1.10360	1.10248	1.10139	1.10032
780	1.11240	1.11109	1.10984	1.10859	1.10736	1.10619	1.10502	1.10388	1.10278	1.10169
790	1.11391	1.11260	1.11132	1.11004	1.10882	1.10762	1.10645	1.10527	1.10415	1.10306
800	1.11545	1.11411	1.11281	1.11153	1.11027	1.10905	1.10785	1.10667	1.10553	1.10441
810	1.11697	1.11560	1.11429	1.11299	1.11173	1.11048	1.10928	1.10808	1.10693	1.10578
820	1.11848	1.11712	1.11578	1.11447	1.11317	1.11191	1.11068	1.10948	1.10831	1.10716
830	1.12003	1.11864	1.11727	1.11594	1.11463	1.11337	1.11212	1.11089	1.10971	1.10854
840	1.12155	1.12013	1.11877	1.11740	1.11609	1.11481	1.11355	1.11232	1.11109	1.10992
850	1.12308	1.12166	1.12026	1.11890	1.11756	1.11625	1.11496	1.11373	1.11250	1.11130
860	1.12463	1.12318	1.12176	1.12037	1.11903	1.11769	1.11640	1.11514	1.11388	1.11268
870	1.12616	1.12468	1.12326	1.12186	1.12047	1.11913	1.11782	1.11655	1.11530	1.11406
880	1.12769	1.12621	1.12476	1.12334	1.12194	1.12060	1.11926	1.11797	1.11668	1.11545
890	1.12925	1.12774	1.12626	1.12481	1.12341	1.12204	1.12070	1.11939	1.11810	1.11684
900	1.13078	1.12925	1.12777	1.12632	1.12489	1.12349	1.12212	1.12080	1.11949	1.11823
910	1.13232	1.13078	1.12928	1.12779	1.12637	1.12494	1.12357	1.12223	1.12091	1.11962
920	1.13389	1.13232	1.13078	1.12930	1.12782	1.12639	1.12499	1.12365	1.12230	1.12099
930	1.13543	1.13384	1.13230	1.13078	1.12930	1.12787	1.12645	1.12507	1.12372	1.12238
940	1.13697	1.13538	1.13381	1.13227	1.13078	1.12933	1.12790	1.12650	1.12513	1.12378
950	1.13854	1.13692	1.13532	1.13378	1.13227	1.13078	1.12933	1.12792	1.12652	1.12517
960	1.14009	1.13844	1.13684	1.13527	1.13373	1.13224	1.13078	1.12935	1.12795	1.12657
970	1.14164	1.13999	1.13836	1.13676	1.13522	1.13370	1.13224	1.13078	1.12935	1.12798
980	1.14319	1.14154	1.13988	1.13828	1.13671	1.13517	1.13368	1.13222	1.13078	1.12938
990	1.14477	1.14306	1.14141	1.13978	1.13820	1.13666	1.13514	1.13365	1.13219	1.13078
1000	1.14633	1.14462	1.14293	1.14130	1.13970	1.13813	1.13658	1.13509	1.13363	1.13219

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$r = 10^{(KH_{pg})/T_{mv}}$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	450	455	460	465	470	475	480	485	490	495
1000	1.14633	1.14462	1.14293	1.14130	1.13970	1.13813	1.13658	1.13509	1.13363	1.13219
1010	1.14789	1.14615	1.14446	1.14280	1.14117	1.13959	1.13805	1.13653	1.13504	1.13360
1020	1.14945	1.14770	1.14599	1.14430	1.14267	1.14106	1.13949	1.13797	1.13648	1.13501
1030	1.15104	1.14926	1.14752	1.14583	1.14417	1.14254	1.14096	1.13941	1.13789	1.13642
1040	1.15260	1.15080	1.14905	1.14733	1.14567	1.14404	1.14243	1.14085	1.13933	1.13781
1050	1.15420	1.15236	1.15059	1.14887	1.14718	1.14551	1.14388	1.14230	1.14075	1.13923
1060	1.15577	1.15393	1.15213	1.15038	1.14866	1.14699	1.14535	1.14375	1.14219	1.14064
1070	1.15733	1.15547	1.15367	1.15189	1.15016	1.14847	1.14681	1.14520	1.14362	1.14206
1080	1.15891	1.15704	1.15521	1.15343	1.15168	1.14998	1.14829	1.14665	1.14506	1.14348
1090	1.16051	1.15862	1.15675	1.15494	1.15319	1.15146	1.14977	1.14810	1.14649	1.14491
1100	1.16209	1.16017	1.15830	1.15648	1.15468	1.15295	1.15122	1.14956	1.14792	1.14633
1110	1.16367	1.16174	1.15985	1.15800	1.15619	1.15444	1.15271	1.15101	1.14937	1.14776
1120	1.16528	1.16332	1.16140	1.15952	1.15771	1.15593	1.15420	1.15247	1.15080	1.14919
1130	1.16686	1.16488	1.16295	1.16107	1.15923	1.15742	1.15566	1.15393	1.15226	1.15061
1140	1.16845	1.16646	1.16450	1.16260	1.16075	1.15894	1.15715	1.15539	1.15369	1.15205
1150	1.17007	1.16805	1.16606	1.16415	1.16228	1.16043	1.15862	1.15686	1.15515	1.15348
1160	1.17166	1.16961	1.16762	1.16568	1.16378	1.16193	1.16011	1.15832	1.15659	1.15489
1170	1.17325	1.17120	1.16918	1.16721	1.16531	1.16343	1.16161	1.15982	1.15806	1.15633
1180	1.17487	1.17279	1.17074	1.16877	1.16684	1.16493	1.16308	1.16129	1.15950	1.15776
1190	1.17647	1.17436	1.17230	1.17031	1.16837	1.16646	1.16458	1.16276	1.16097	1.15920
1200	1.17807	1.17595	1.17390	1.17187	1.16988	1.16797	1.16606	1.16423	1.16241	1.16065
1210	1.17967	1.17755	1.17547	1.17341	1.17141	1.16947	1.16756	1.16571	1.16388	1.16209
1220	1.18130	1.17913	1.17704	1.17495	1.17295	1.17098	1.16904	1.16719	1.16533	1.16354
1230	1.18291	1.18073	1.17861	1.17652	1.17449	1.17249	1.17055	1.16866	1.16681	1.16498
1240	1.18451	1.18233	1.18018	1.17807	1.17603	1.17401	1.17206	1.17015	1.16826	1.16643
1250	1.18615	1.18391	1.18176	1.17964	1.17755	1.17555	1.17355	1.17163	1.16974	1.16788
1260	1.18776	1.18552	1.18334	1.18119	1.17910	1.17706	1.17506	1.17311	1.17120	1.16934
1270	1.18938	1.18713	1.18492	1.18274	1.18065	1.17858	1.17658	1.17460	1.17265	1.17079
1280	1.19102	1.18872	1.18651	1.18432	1.18220	1.18010	1.17807	1.17609	1.17414	1.17225
1290	1.19264	1.19034	1.18809	1.18588	1.18372	1.18163	1.17959	1.17758	1.17560	1.17368
1300	1.19426	1.19196	1.18968	1.18746	1.18528	1.18315	1.18108	1.17907	1.17709	1.17514
1310	1.19589	1.19355	1.19127	1.18902	1.18683	1.18470	1.18261	1.18057	1.17856	1.17660
1320	1.19754	1.19517	1.19286	1.19058	1.18839	1.18623	1.18410	1.18206	1.18005	1.17807
1330	1.19917	1.19680	1.19446	1.19217	1.18995	1.18776	1.18563	1.18356	1.18152	1.17953
1340	1.20080	1.19840	1.19605	1.19374	1.19149	1.18930	1.18716	1.18506	1.18301	1.18100
1350	1.20246	1.20002	1.19765	1.19531	1.19305	1.19086	1.18867	1.18656	1.18449	1.18247
1360	1.20409	1.20163	1.19925	1.19691	1.19462	1.19239	1.19020	1.18806	1.18599	1.18394
1370	1.20573	1.20326	1.20085	1.19848	1.19619	1.19393	1.19174	1.18957	1.18746	1.18541
1380	1.20740	1.20490	1.20246	1.20008	1.19776	1.19547	1.19325	1.19108	1.18897	1.18689
1390	1.20904	1.20651	1.20407	1.20166	1.19931	1.19702	1.19479	1.19259	1.19045	1.18837
1400	1.21068	1.20815	1.20567	1.20326	1.20088	1.19856	1.19630	1.19410	1.19196	1.18984
1410	1.21236	1.20979	1.20729	1.20484	1.20246	1.20011	1.19784	1.19561	1.19344	1.19130
1420	1.21400	1.21141	1.20890	1.20642	1.20404	1.20168	1.19939	1.19713	1.19492	1.19278
1430	1.21565	1.21305	1.21051	1.20804	1.20559	1.20323	1.20091	1.19864	1.19644	1.19426
1440	1.21733	1.21470	1.21213	1.20962	1.20717	1.20479	1.20246	1.20016	1.19793	1.19575
1450	1.21899	1.21633	1.21375	1.21121	1.20876	1.20634	1.20398	1.20168	1.19944	1.19724
1460	1.22065	1.21798	1.21537	1.21283	1.21035	1.20790	1.20553	1.20321	1.20094	1.19873
1470	1.22233	1.21964	1.21700	1.21442	1.21194	1.20948	1.20709	1.20473	1.20246	1.20022
1480	1.22400	1.22127	1.21862	1.21602	1.21350	1.21104	1.20862	1.20626	1.20395	1.20171
1490	1.22566	1.22293	1.22025	1.21764	1.21509	1.21261	1.21018	1.20779	1.20548	1.20321
1500	1.22735	1.22459	1.22188	1.21927	1.21669	1.21417	1.21171	1.20934	1.20698	1.20470

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	450	455	460	465	470	475	480	485	490	495
1500	1.22735	1.22459	1.22188	1.21927	1.21669	1.21417	1.21171	1.20934	1.20698	1.20470
1510	1.22902	1.22622	1.22352	1.22087	1.21829	1.21574	1.21328	1.21088	1.20851	1.20620
1520	1.23069	1.22789	1.22515	1.22248	1.21989	1.21733	1.21484	1.21241	1.21001	1.20770
1530	1.23237	1.22956	1.22679	1.22411	1.22146	1.21891	1.21638	1.21395	1.21155	1.20918
1540	1.23407	1.23120	1.22843	1.22572	1.22307	1.22048	1.21795	1.21549	1.21305	1.21068
1550	1.23575	1.23288	1.23007	1.22733	1.22467	1.22205	1.21949	1.21703	1.21459	1.21219
1560	1.23743	1.23455	1.23171	1.22897	1.22628	1.22363	1.22107	1.21857	1.21610	1.21370
1570	1.23914	1.23620	1.23336	1.23058	1.22789	1.22524	1.22264	1.22011	1.21762	1.21521
1580	1.24082	1.23788	1.23501	1.23220	1.22948	1.22682	1.22419	1.22166	1.21916	1.21672
1590	1.24251	1.23957	1.23666	1.23384	1.23109	1.22840	1.22577	1.22321	1.22067	1.21823
1600	1.24423	1.24122	1.23831	1.23549	1.23271	1.22999	1.22733	1.22476	1.22222	1.21975
1610	1.24592	1.24291	1.23997	1.23711	1.23433	1.23157	1.22891	1.22631	1.22374	1.22127
1620	1.24761	1.24460	1.24162	1.23874	1.23592	1.23316	1.23050	1.22786	1.22529	1.22278
1630	1.24931	1.24626	1.24328	1.24039	1.23754	1.23478	1.23205	1.22942	1.22682	1.22431
1640	1.25104	1.24796	1.24494	1.24202	1.23917	1.23637	1.23364	1.23098	1.22837	1.22583
1650	1.25274	1.24965	1.24661	1.24368	1.24079	1.23797	1.23521	1.23254	1.22990	1.22735
1660	1.25444	1.25132	1.24827	1.24532	1.24242	1.23957	1.23680	1.23410	1.23146	1.22885
1670	1.25617	1.25303	1.24994	1.24695	1.24403	1.24119	1.23837	1.23566	1.23299	1.23038
1680	1.25788	1.25470	1.25161	1.24859	1.24566	1.24280	1.23997	1.23723	1.23455	1.23191
1690	1.25959	1.25641	1.25329	1.25026	1.24730	1.24440	1.24157	1.23880	1.23609	1.23345
1700	1.26133	1.25811	1.25499	1.25190	1.24894	1.24601	1.24314	1.24037	1.23766	1.23498
1710	1.26305	1.25982	1.25667	1.25357	1.25058	1.24761	1.24474	1.24194	1.23920	1.23652
1720	1.26477	1.26151	1.25835	1.25522	1.25219	1.24922	1.24635	1.24351	1.24074	1.23806
1730	1.26651	1.26322	1.26003	1.25690	1.25383	1.25086	1.24793	1.24509	1.24231	1.23960
1740	1.26824	1.26491	1.26168	1.25855	1.25548	1.25248	1.24954	1.24667	1.24386	1.24114
1750	1.26996	1.26663	1.26340	1.26020	1.25713	1.25409	1.25115	1.24825	1.24543	1.24268
1760	1.27172	1.26835	1.26509	1.26189	1.25875	1.25571	1.25274	1.24983	1.24698	1.24423
1770	1.27344	1.27005	1.26678	1.26354	1.26040	1.25733	1.25435	1.25141	1.24856	1.24575
1780	1.27518	1.27177	1.26847	1.26520	1.26206	1.25898	1.25594	1.25300	1.25012	1.24730
1790	1.27691	1.27350	1.27016	1.26689	1.26372	1.26061	1.25756	1.25458	1.25170	1.24885
1800	1.27867	1.27520	1.27186	1.26856	1.26535	1.26223	1.25919	1.25617	1.25326	1.25040
1810	1.28041	1.27694	1.27356	1.27025	1.26701	1.26386	1.26078	1.25777	1.25484	1.25196
1820	1.28215	1.27867	1.27526	1.27192	1.26867	1.26549	1.26241	1.25939	1.25641	1.25352
1830	1.28393	1.28038	1.27697	1.27359	1.27034	1.26713	1.26401	1.26099	1.25800	1.25508
1840	1.28567	1.28212	1.27867	1.27529	1.27201	1.26879	1.26564	1.26258	1.25956	1.25664
1850	1.28742	1.28387	1.28038	1.27697	1.27368	1.27043	1.26727	1.26418	1.26116	1.25820
1860	1.28920	1.28558	1.28209	1.27867	1.27532	1.27207	1.26888	1.26579	1.26273	1.25977
1870	1.29095	1.28733	1.28381	1.28035	1.27700	1.27371	1.27052	1.26739	1.26430	1.26133
1880	1.29271	1.28908	1.28552	1.28204	1.27867	1.27538	1.27213	1.26900	1.26590	1.26290
1890	1.29446	1.29080	1.28724	1.28375	1.28035	1.27703	1.27377	1.27060	1.26748	1.26445
1900	1.29625	1.29256	1.28896	1.28543	1.28201	1.27867	1.27541	1.27221	1.26908	1.26602
1910	1.29802	1.29432	1.29068	1.28715	1.28369	1.28032	1.27703	1.27383	1.27066	1.26759
1920	1.29978	1.29604	1.29241	1.28884	1.28538	1.28198	1.27867	1.27544	1.27227	1.26917
1930	1.30158	1.29781	1.29414	1.29057	1.28706	1.28366	1.28029	1.27706	1.27386	1.27075
1940	1.30335	1.29957	1.29587	1.29226	1.28875	1.28532	1.28195	1.27867	1.27547	1.27233
1950	1.30512	1.30131	1.29760	1.29396	1.29042	1.28697	1.28360	1.28029	1.27706	1.27391
1960	1.30692	1.30308	1.29933	1.29566	1.29211	1.28864	1.28523	1.28192	1.27867	1.27550
1970	1.30870	1.30485	1.30107	1.29739	1.29381	1.29030	1.28689	1.28354	1.28027	1.27709
1980	1.31048	1.30659	1.30281	1.29909	1.29551	1.29196	1.28852	1.28517	1.28189	1.27867
1990	1.31229	1.30837	1.30455	1.30083	1.29721	1.29366	1.29018	1.28680	1.28348	1.28027
2000	1.31407	1.31015	1.30629	1.30254	1.29888	1.29533	1.29184	1.28843	1.28511	1.28186

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	450	455	460	465	470	475	480	485	490	495
2000	1.31407	1.31015	1.30629	1.30254	1.29888	1.29533	1.29184	1.28843	1.28511	1.28186
2010	1.31586	1.31190	1.30804	1.30428	1.30059	1.29700	1.29348	1.29006	1.28671	1.28345
2020	1.31768	1.31368	1.30978	1.30599	1.30230	1.29867	1.29515	1.29170	1.28834	1.28505
2030	1.31947	1.31547	1.31154	1.30774	1.30401	1.30035	1.29679	1.29333	1.28994	1.28662
2040	1.32127	1.31723	1.31329	1.30945	1.30572	1.30206	1.29846	1.29497	1.29155	1.28822
2050	1.32306	1.31902	1.31504	1.31117	1.30740	1.30374	1.30011	1.29661	1.29318	1.28982
2060	1.32489	1.32081	1.31680	1.31290	1.30912	1.30542	1.30179	1.29825	1.29479	1.29143
2070	1.32669	1.32257	1.31856	1.31465	1.31084	1.30710	1.30347	1.29990	1.29643	1.29303
2080	1.32850	1.32437	1.32032	1.31638	1.31253	1.30879	1.30512	1.30155	1.29805	1.29464
2090	1.33033	1.32617	1.32209	1.31814	1.31426	1.31048	1.30680	1.30320	1.29969	1.29625
2100	1.33214	1.32794	1.32385	1.31987	1.31598	1.31217	1.30849	1.30485	1.30131	1.29787
2110	1.33395	1.32975	1.32562	1.32163	1.31771	1.31389	1.31015	1.30653	1.30296	1.29948
2120	1.33580	1.33156	1.32739	1.32337	1.31944	1.31559	1.31184	1.30819	1.30458	1.30110
2130	1.33761	1.33334	1.32917	1.32510	1.32117	1.31729	1.31350	1.30985	1.30623	1.30272
2140	1.33943	1.33515	1.33094	1.32687	1.32291	1.31902	1.31519	1.31151	1.30786	1.30431
2150	1.34128	1.33693	1.33272	1.32862	1.32462	1.32072	1.31686	1.31317	1.30951	1.30593
2160	1.34311	1.33875	1.33454	1.33039	1.32636	1.32242	1.31856	1.31483	1.31114	1.30756
2170	1.34493	1.34057	1.33629	1.33214	1.32810	1.32413	1.32026	1.31650	1.31280	1.30918
2180	1.34676	1.34236	1.33807	1.33389	1.32984	1.32584	1.32193	1.31817	1.31444	1.31081
2190	1.34862	1.34419	1.33989	1.33567	1.33156	1.32755	1.32364	1.31984	1.31607	1.31244
2200	1.35045	1.34602	1.34168	1.33743	1.33331	1.32926	1.32535	1.32151	1.31774	1.31407
2210	1.35229	1.34785	1.34348	1.33921	1.33506	1.33101	1.32703	1.32318	1.31938	1.31571
2220	1.35416	1.34965	1.34527	1.34097	1.33678	1.33272	1.32874	1.32486	1.32105	1.31735
2230	1.35600	1.35148	1.34707	1.34276	1.33854	1.33444	1.33042	1.32654	1.32270	1.31899
2240	1.35784	1.35329	1.34887	1.34453	1.34029	1.33616	1.33214	1.32822	1.32437	1.32063
2250	1.35972	1.35513	1.35067	1.34629	1.34205	1.33789	1.33386	1.32990	1.32602	1.32227
2260	1.36157	1.35697	1.35248	1.34806	1.34382	1.33961	1.33555	1.33159	1.32770	1.32388
2270	1.36342	1.35878	1.35428	1.34986	1.34558	1.34137	1.33727	1.33328	1.32935	1.32553
2280	1.36531	1.36063	1.35609	1.35164	1.34732	1.34311	1.33897	1.33497	1.33104	1.32718
2290	1.36716	1.36248	1.35791	1.35344	1.34909	1.34484	1.34070	1.33666	1.33269	1.32883
2300	1.36902	1.36430	1.35972	1.35522	1.35086	1.34657	1.34242	1.33835	1.33438	1.33049
2310	1.37091	1.36616	1.36154	1.35700	1.35263	1.34831	1.34413	1.34005	1.33604	1.33214
2320	1.37278	1.36801	1.36336	1.35881	1.35441	1.35008	1.34586	1.34175	1.33773	1.33380
2330	1.37464	1.36984	1.36518	1.36060	1.35619	1.35182	1.34757	1.34345	1.33940	1.33546
2340	1.37654	1.37170	1.36700	1.36242	1.35794	1.35357	1.34930	1.34515	1.34107	1.33712
2350	1.37842	1.37357	1.36883	1.36421	1.35972	1.35531	1.35105	1.34685	1.34276	1.33878
2360	1.38029	1.37540	1.37066	1.36600	1.36148	1.35709	1.35276	1.34856	1.34444	1.34045
2370	1.38217	1.37727	1.37249	1.36782	1.36326	1.35885	1.35450	1.35027	1.34614	1.34212
2380	1.38408	1.37915	1.37433	1.36962	1.36505	1.36060	1.35625	1.35198	1.34781	1.34379
2390	1.38596	1.38099	1.37616	1.37142	1.36685	1.36235	1.35797	1.35369	1.34952	1.34543
2400	1.38784	1.38287	1.37800	1.37325	1.36864	1.36411	1.35972	1.35541	1.35120	1.34710
2410	1.38976	1.38475	1.37984	1.37509	1.37041	1.36590	1.36144	1.35713	1.35291	1.34878
2420	1.39165	1.38660	1.38169	1.37689	1.37221	1.36767	1.36320	1.35885	1.35460	1.35045
2430	1.39354	1.38848	1.38353	1.37870	1.37401	1.36943	1.36496	1.36057	1.35631	1.35213
2440	1.39544	1.39037	1.38538	1.38054	1.37581	1.37120	1.36669	1.36229	1.35800	1.35382
2450	1.39737	1.39223	1.38723	1.38236	1.37762	1.37297	1.36845	1.36402	1.35972	1.35550
2460	1.39927	1.39412	1.38909	1.38420	1.37943	1.37477	1.37019	1.36575	1.36141	1.35719
2470	1.40117	1.39601	1.39095	1.38602	1.38121	1.37654	1.37196	1.36748	1.36314	1.35888
2480	1.40310	1.39788	1.39280	1.38784	1.38302	1.37832	1.37373	1.36921	1.36483	1.36057
2490	1.40501	1.39978	1.39467	1.38970	1.38484	1.38010	1.37547	1.37094	1.36656	1.36226
2500	1.40695	1.40168	1.39653	1.39152	1.38666	1.38188	1.37724	1.37271	1.36826	1.36395

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$r = 10^{(KH_{pg})/T_{mv}}$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	450	455	460	465	470	475	480	485	490	495
2500	1.40695	1.40168	1.39653	1.39152	1.38666	1.38188	1.37724	1.37271	1.36826	1.36395
2510	1.40887	1.40356	1.39840	1.39335	1.38848	1.38369	1.37899	1.37445	1.37000	1.36562
2520	1.41078	1.40546	1.40026	1.39521	1.39028	1.38548	1.38077	1.37620	1.37170	1.36732
2530	1.41270	1.40734	1.40214	1.39704	1.39210	1.38727	1.38252	1.37794	1.37341	1.36902
2540	1.41465	1.40926	1.40401	1.39891	1.39393	1.38906	1.38430	1.37969	1.37515	1.37072
2550	1.41658	1.41117	1.40589	1.40075	1.39573	1.39085	1.38609	1.38143	1.37686	1.37243
2560	1.41850	1.41306	1.40776	1.40259	1.39756	1.39264	1.38784	1.38318	1.37861	1.37414
2570	1.42046	1.41498	1.40965	1.40446	1.39939	1.39444	1.38963	1.38494	1.38032	1.37585
2580	1.42239	1.41690	1.41153	1.40631	1.40123	1.39627	1.39143	1.38669	1.38207	1.37756
2590	1.42433	1.41880	1.41342	1.40819	1.40307	1.39807	1.39319	1.38845	1.38379	1.37927
2600	1.42630	1.42072	1.41530	1.41004	1.40488	1.39988	1.39499	1.39021	1.38554	1.38099
2610	1.42824	1.42266	1.41720	1.41189	1.40673	1.40168	1.39675	1.39197	1.38727	1.38271
2620	1.43018	1.42456	1.41912	1.41377	1.40858	1.40352	1.39856	1.39373	1.38902	1.38443
2630	1.43212	1.42650	1.42102	1.41563	1.41043	1.40534	1.40036	1.39550	1.39075	1.38612
2640	1.43410	1.42843	1.42292	1.41749	1.41228	1.40715	1.40214	1.39727	1.39248	1.38784
2650	1.43605	1.43034	1.42482	1.41938	1.41413	1.40896	1.40394	1.39904	1.39425	1.38957
2660	1.43800	1.43229	1.42672	1.42125	1.41596	1.41078	1.40572	1.40081	1.39598	1.39130
2670	1.43999	1.43423	1.42863	1.42315	1.41782	1.41260	1.40754	1.40259	1.39775	1.39303
2680	1.44195	1.43615	1.43054	1.42502	1.41968	1.41443	1.40935	1.40437	1.39952	1.39476
2690	1.44391	1.43810	1.43245	1.42692	1.42154	1.41628	1.41114	1.40614	1.40126	1.39650
2700	1.44591	1.44006	1.43437	1.42880	1.42338	1.41811	1.41296	1.40793	1.40301	1.39823
2710	1.44787	1.44198	1.43628	1.43070	1.42525	1.41994	1.41475	1.40974	1.40479	1.39997
2720	1.44984	1.44394	1.43820	1.43258	1.42712	1.42177	1.41658	1.41150	1.40653	1.40172
2730	1.45181	1.44591	1.44012	1.43447	1.42899	1.42361	1.41837	1.41329	1.40832	1.40346
2740	1.45382	1.44784	1.44205	1.43638	1.43087	1.42548	1.42020	1.41508	1.41007	1.40521
2750	1.45579	1.44981	1.44398	1.43827	1.43272	1.42732	1.42203	1.41687	1.41185	1.40692
2760	1.45777	1.45178	1.44591	1.44019	1.43460	1.42916	1.42384	1.41867	1.41361	1.40867
2770	1.45979	1.45372	1.44784	1.44208	1.43648	1.43100	1.42567	1.42046	1.41540	1.41043
2780	1.46177	1.45569	1.44977	1.44398	1.43837	1.43285	1.42751	1.42226	1.41716	1.41218
2790	1.46376	1.45767	1.45171	1.44591	1.44026	1.43473	1.42932	1.42407	1.41896	1.41394
2800	1.46578	1.45962	1.45365	1.44780	1.44212	1.43658	1.43117	1.42587	1.42072	1.41570
2810	1.46778	1.46160	1.45559	1.44971	1.44401	1.43843	1.43298	1.42771	1.42253	1.41746
2820	1.46977	1.46359	1.45754	1.45164	1.44591	1.44029	1.43483	1.42949	1.42430	1.41922
2830	1.47177	1.46555	1.45949	1.45355	1.44780	1.44218	1.43665	1.43133	1.42607	1.42099
2840	1.47380	1.46754	1.46144	1.45546	1.44971	1.44404	1.43850	1.43314	1.42787	1.42275
2850	1.47581	1.46954	1.46339	1.45740	1.45158	1.44591	1.44036	1.43496	1.42965	1.42452
2860	1.47785	1.47150	1.46535	1.45932	1.45348	1.44777	1.44218	1.43678	1.43146	1.42630
2870	1.47986	1.47350	1.46730	1.46127	1.45539	1.44964	1.44404	1.43860	1.43324	1.42807
2880	1.48187	1.47550	1.46926	1.46319	1.45730	1.45154	1.44587	1.44042	1.43506	1.42982
2890	1.48392	1.47747	1.47123	1.46511	1.45922	1.45342	1.44774	1.44225	1.43685	1.43159
2900	1.48594	1.47948	1.47319	1.46707	1.46110	1.45529	1.44961	1.44408	1.43867	1.43338
2910	1.48796	1.48146	1.47516	1.46899	1.46302	1.45717	1.45144	1.44591	1.44046	1.43516
2920	1.48998	1.48347	1.47713	1.47092	1.46494	1.45905	1.45332	1.44774	1.44228	1.43694
2930	1.49204	1.48549	1.47911	1.47289	1.46686	1.46093	1.45519	1.44957	1.44408	1.43873
2940	1.49407	1.48748	1.48109	1.47482	1.46876	1.46285	1.45704	1.45141	1.44591	1.44052
2950	1.49610	1.48950	1.48306	1.47679	1.47069	1.46474	1.45892	1.45325	1.44770	1.44231
2960	1.49817	1.49152	1.48505	1.47873	1.47262	1.46663	1.46076	1.45509	1.44954	1.44411
2970	1.50020	1.49355	1.48703	1.48071	1.47455	1.46852	1.46265	1.45693	1.45134	1.44591
2980	1.50224	1.49555	1.48902	1.48265	1.47649	1.47045	1.46454	1.45878	1.45318	1.44770
2990	1.50432	1.49758	1.49101	1.48460	1.47839	1.47235	1.46639	1.46063	1.45499	1.44951
3000	1.50636	1.49958	1.49300	1.48659	1.48033	1.47421	1.46828	1.46248	1.45680	1.45128

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	500	505	510	515	520	525	530	535	540	545
0	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
10	1.00122	1.00122	1.00120	1.00120	1.00118	1.00118	1.00115	1.00115	1.00113	1.00113
20	1.00246	1.00244	1.00242	1.00240	1.00237	1.00235	1.00233	1.00231	1.00228	1.00226
30	1.00369	1.00367	1.00362	1.00358	1.00355	1.00353	1.00348	1.00346	1.00341	1.00339
40	1.00494	1.00487	1.00482	1.00478	1.00473	1.00469	1.00464	1.00462	1.00457	1.00452
50	1.00617	1.00610	1.00605	1.00598	1.00594	1.00587	1.00582	1.00575	1.00570	1.00566
60	1.00740	1.00733	1.00726	1.00719	1.00712	1.00705	1.00698	1.00691	1.00686	1.00679
70	1.00865	1.00856	1.00846	1.00839	1.00830	1.00823	1.00816	1.00807	1.00800	1.00793
80	1.00988	1.00979	1.00969	1.00958	1.00951	1.00942	1.00932	1.00923	1.00914	1.00907
90	1.01111	1.01102	1.01090	1.01079	1.01069	1.01058	1.01049	1.01039	1.01030	1.01021
100	1.01237	1.01226	1.01212	1.01200	1.01188	1.01177	1.01167	1.01156	1.01144	1.01135
110	1.01361	1.01347	1.01335	1.01321	1.01309	1.01295	1.01284	1.01272	1.01260	1.01249
120	1.01487	1.01471	1.01457	1.01443	1.01428	1.01414	1.01400	1.01389	1.01375	1.01363
130	1.01611	1.01594	1.01578	1.01564	1.01548	1.01534	1.01520	1.01506	1.01492	1.01478
140	1.01735	1.01719	1.01702	1.01686	1.01669	1.01653	1.01637	1.01620	1.01606	1.01592
150	1.01861	1.01843	1.01824	1.01805	1.01789	1.01772	1.01754	1.01737	1.01721	1.01707
160	1.01986	1.01967	1.01946	1.01927	1.01908	1.01890	1.01873	1.01854	1.01838	1.01822
170	1.02110	1.02089	1.02070	1.02049	1.02028	1.02009	1.01991	1.01972	1.01953	1.01937
180	1.02237	1.02214	1.02193	1.02172	1.02150	1.02129	1.02108	1.02089	1.02070	1.02049
190	1.02362	1.02339	1.02315	1.02294	1.02270	1.02249	1.02228	1.02207	1.02186	1.02164
200	1.02490	1.02464	1.02440	1.02414	1.02393	1.02369	1.02346	1.02325	1.02303	1.02280
210	1.02615	1.02589	1.02563	1.02537	1.02513	1.02490	1.02466	1.02442	1.02419	1.02395
220	1.02740	1.02714	1.02686	1.02660	1.02634	1.02608	1.02584	1.02560	1.02534	1.02511
230	1.02868	1.02840	1.02811	1.02783	1.02754	1.02728	1.02702	1.02676	1.02653	1.02627
240	1.02994	1.02963	1.02934	1.02906	1.02877	1.02849	1.02823	1.02795	1.02768	1.02742
250	1.03119	1.03088	1.03058	1.03029	1.02998	1.02970	1.02941	1.02913	1.02887	1.02858
260	1.03248	1.03214	1.03183	1.03150	1.03119	1.03091	1.03060	1.03031	1.03003	1.02975
270	1.03374	1.03341	1.03307	1.03274	1.03243	1.03212	1.03181	1.03150	1.03119	1.03090
280	1.03502	1.03467	1.03431	1.03397	1.03364	1.03331	1.03300	1.03269	1.03238	1.03207
290	1.03629	1.03593	1.03557	1.03521	1.03486	1.03452	1.03419	1.03388	1.03355	1.03324
300	1.03755	1.03719	1.03681	1.03645	1.03610	1.03574	1.03540	1.03507	1.03474	1.03440
310	1.03884	1.03844	1.03805	1.03770	1.03731	1.03696	1.03660	1.03624	1.03591	1.03557
320	1.04011	1.03970	1.03932	1.03891	1.03853	1.03817	1.03779	1.03743	1.03710	1.03674
330	1.04141	1.04097	1.04057	1.04016	1.03978	1.03939	1.03901	1.03863	1.03827	1.03791
340	1.04268	1.04225	1.04181	1.04141	1.04100	1.04059	1.04021	1.03982	1.03944	1.03908
350	1.04395	1.04352	1.04309	1.04265	1.04222	1.04181	1.04143	1.04102	1.04064	1.04026
360	1.04525	1.04479	1.04434	1.04390	1.04347	1.04304	1.04263	1.04222	1.04181	1.04143
370	1.04653	1.04604	1.04559	1.04513	1.04470	1.04426	1.04383	1.04342	1.04301	1.04261
380	1.04780	1.04732	1.04686	1.04638	1.04592	1.04549	1.04506	1.04462	1.04419	1.04378
390	1.04911	1.04860	1.04812	1.04764	1.04718	1.04672	1.04626	1.04583	1.04539	1.04496
400	1.05039	1.04988	1.04937	1.04889	1.04841	1.04792	1.04747	1.04701	1.04657	1.04614
410	1.05170	1.05116	1.05063	1.05015	1.04964	1.04916	1.04870	1.04821	1.04776	1.04732
420	1.05298	1.05245	1.05191	1.05141	1.05090	1.05039	1.04990	1.04942	1.04896	1.04850
430	1.05427	1.05373	1.05317	1.05264	1.05213	1.05162	1.05111	1.05063	1.05015	1.04969
440	1.05558	1.05499	1.05446	1.05390	1.05339	1.05286	1.05235	1.05184	1.05136	1.05087
450	1.05687	1.05628	1.05572	1.05516	1.05463	1.05410	1.05356	1.05305	1.05254	1.05206
460	1.05816	1.05757	1.05699	1.05643	1.05587	1.05533	1.05478	1.05427	1.05376	1.05325
470	1.05947	1.05886	1.05828	1.05769	1.05711	1.05655	1.05601	1.05548	1.05495	1.05444
480	1.06077	1.06016	1.05955	1.05896	1.05838	1.05779	1.05723	1.05670	1.05614	1.05563
490	1.06209	1.06145	1.06082	1.06021	1.05962	1.05903	1.05847	1.05789	1.05735	1.05682
500	1.06338	1.06275	1.06211	1.06148	1.06086	1.06028	1.05969	1.05911	1.05855	1.05801

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$r = 10^{(KH_{pg})/T_{mv}}$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	500	505	510	515	520	525	530	535	540	545
500	1.06338	1.06275	1.06211	1.06148	1.06086	1.06028	1.05969	1.05911	1.05855	1.05801
510	1.06468	1.06402	1.06338	1.06275	1.06214	1.06152	1.06091	1.06033	1.05977	1.05920
520	1.06601	1.06532	1.06466	1.06402	1.06338	1.06277	1.06216	1.06155	1.06096	1.06040
530	1.06731	1.06662	1.06596	1.06530	1.06463	1.06400	1.06338	1.06277	1.06218	1.06157
540	1.06861	1.06792	1.06723	1.06657	1.06591	1.06525	1.06461	1.06400	1.06338	1.06277
550	1.06994	1.06923	1.06851	1.06782	1.06714	1.06650	1.06586	1.06522	1.06458	1.06397
560	1.07125	1.07053	1.06982	1.06910	1.06842	1.06775	1.06709	1.06645	1.06581	1.06517
570	1.07258	1.07182	1.07110	1.07038	1.06970	1.06901	1.06832	1.06768	1.06701	1.06638
580	1.07389	1.07312	1.07238	1.07167	1.07095	1.07026	1.06957	1.06888	1.06824	1.06758
590	1.07520	1.07443	1.07369	1.07295	1.07221	1.07149	1.07080	1.07011	1.06945	1.06878
600	1.07654	1.07575	1.07498	1.07421	1.07349	1.07275	1.07204	1.07135	1.07068	1.06999
610	1.07785	1.07706	1.07627	1.07550	1.07476	1.07401	1.07330	1.07258	1.07189	1.07120
620	1.07917	1.07838	1.07758	1.07679	1.07602	1.07528	1.07453	1.07382	1.07310	1.07241
630	1.08051	1.07969	1.07887	1.07808	1.07731	1.07654	1.07580	1.07505	1.07434	1.07362
640	1.08183	1.08099	1.08016	1.07937	1.07857	1.07780	1.07704	1.07629	1.07555	1.07483
650	1.08318	1.08231	1.08148	1.08066	1.07984	1.07905	1.07828	1.07753	1.07679	1.07604
660	1.08450	1.08363	1.08278	1.08193	1.08114	1.08031	1.07954	1.07877	1.07800	1.07726
670	1.08583	1.08495	1.08408	1.08323	1.08241	1.08158	1.08079	1.07999	1.07922	1.07847
680	1.08718	1.08628	1.08540	1.08453	1.08368	1.08285	1.08203	1.08123	1.08046	1.07969
690	1.08850	1.08760	1.08670	1.08583	1.08498	1.08413	1.08330	1.08248	1.08168	1.08090
700	1.08986	1.08893	1.08800	1.08713	1.08625	1.08540	1.08455	1.08373	1.08293	1.08213
710	1.09119	1.09023	1.08933	1.08843	1.08753	1.08665	1.08580	1.08498	1.08415	1.08335
720	1.09252	1.09157	1.09063	1.08971	1.08880	1.08793	1.08708	1.08623	1.08540	1.08458
730	1.09388	1.09290	1.09194	1.09101	1.09011	1.08921	1.08833	1.08748	1.08663	1.08580
740	1.09522	1.09423	1.09328	1.09232	1.09139	1.09049	1.08958	1.08873	1.08785	1.08703
750	1.09655	1.09557	1.09459	1.09363	1.09267	1.09177	1.09086	1.08998	1.08911	1.08825
760	1.09792	1.09691	1.09590	1.09494	1.09398	1.09305	1.09212	1.09121	1.09034	1.08948
770	1.09926	1.09822	1.09724	1.09623	1.09527	1.09431	1.09340	1.09247	1.09159	1.09071
780	1.10063	1.09956	1.09855	1.09754	1.09655	1.09559	1.09466	1.09373	1.09282	1.09194
790	1.10197	1.10091	1.09987	1.09885	1.09787	1.09688	1.09592	1.09499	1.09408	1.09318
800	1.10332	1.10225	1.10121	1.10017	1.09916	1.09817	1.09721	1.09625	1.09532	1.09441
810	1.10469	1.10360	1.10253	1.10149	1.10045	1.09946	1.09847	1.09751	1.09655	1.09565
820	1.10604	1.10494	1.10385	1.10281	1.10177	1.10075	1.09974	1.09878	1.09782	1.09688
830	1.10739	1.10629	1.10517	1.10410	1.10306	1.10202	1.10103	1.10004	1.09906	1.09812
840	1.10877	1.10762	1.10652	1.10543	1.10436	1.10332	1.10230	1.10131	1.10032	1.09936
850	1.11012	1.10897	1.10785	1.10675	1.10568	1.10461	1.10357	1.10255	1.10156	1.10060
860	1.11150	1.11032	1.10920	1.10808	1.10698	1.10591	1.10487	1.10382	1.10283	1.10184
870	1.11286	1.11168	1.11053	1.10940	1.10828	1.10721	1.10614	1.10510	1.10408	1.10309
880	1.11422	1.11304	1.11186	1.11073	1.10961	1.10851	1.10744	1.10637	1.10533	1.10431
890	1.11560	1.11440	1.11322	1.11204	1.11091	1.10981	1.10872	1.10764	1.10660	1.10555
900	1.11697	1.11576	1.11455	1.11337	1.11222	1.11109	1.10999	1.10892	1.10785	1.10680
910	1.11833	1.11709	1.11589	1.11471	1.11355	1.11240	1.11130	1.11020	1.10912	1.10805
920	1.11972	1.11846	1.11725	1.11604	1.11486	1.11370	1.11258	1.11148	1.11038	1.10930
930	1.12109	1.11982	1.11859	1.11738	1.11617	1.11501	1.11386	1.11273	1.11165	1.11055
940	1.12248	1.12119	1.11993	1.11869	1.11751	1.11632	1.11517	1.11401	1.11291	1.11181
950	1.12385	1.12256	1.12130	1.12003	1.11882	1.11764	1.11645	1.11530	1.11417	1.11306
960	1.12523	1.12393	1.12264	1.12137	1.12013	1.11892	1.11774	1.11658	1.11545	1.11432
970	1.12663	1.12528	1.12398	1.12272	1.12148	1.12024	1.11905	1.11787	1.11671	1.11558
980	1.12800	1.12665	1.12536	1.12406	1.12279	1.12155	1.12034	1.11915	1.11800	1.11684
990	1.12941	1.12803	1.12670	1.12541	1.12411	1.12287	1.12163	1.12044	1.11926	1.11810
1000	1.13078	1.12941	1.12805	1.12673	1.12546	1.12419	1.12295	1.12173	1.12055	1.11936

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$r = 10^{(KH_{pg})/T_{mv}}$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	500	505	510	515	520	525	530	535	540	545
1000	1.13078	1.12941	1.12805	1.12673	1.12546	1.12419	1.12295	1.12173	1.12055	1.11936
1010	1.13217	1.13078	1.12943	1.12808	1.12678	1.12551	1.12424	1.12303	1.12181	1.12062
1020	1.13357	1.13217	1.13078	1.12943	1.12811	1.12681	1.12554	1.12432	1.12308	1.12189
1030	1.13496	1.13355	1.13214	1.13078	1.12946	1.12813	1.12686	1.12559	1.12437	1.12316
1040	1.13634	1.13491	1.13352	1.13214	1.13078	1.12946	1.12816	1.12689	1.12567	1.12442
1050	1.13776	1.13629	1.13488	1.13347	1.13211	1.13078	1.12948	1.12818	1.12694	1.12569
1060	1.13915	1.13768	1.13624	1.13483	1.13347	1.13211	1.13078	1.12948	1.12821	1.12696
1070	1.14056	1.13907	1.13763	1.13619	1.13480	1.13344	1.13209	1.13078	1.12951	1.12824
1080	1.14196	1.14046	1.13899	1.13755	1.13614	1.13475	1.13342	1.13209	1.13078	1.12951
1090	1.14335	1.14185	1.14035	1.13891	1.13750	1.13608	1.13472	1.13339	1.13209	1.13078
1100	1.14477	1.14325	1.14175	1.14028	1.13883	1.13742	1.13603	1.13470	1.13337	1.13206
1110	1.14617	1.14462	1.14312	1.14162	1.14017	1.13875	1.13737	1.13600	1.13467	1.13334
1120	1.14757	1.14601	1.14448	1.14298	1.14154	1.14009	1.13868	1.13729	1.13595	1.13462
1130	1.14900	1.14741	1.14588	1.14435	1.14288	1.14143	1.13999	1.13860	1.13723	1.13590
1140	1.15040	1.14881	1.14726	1.14572	1.14422	1.14277	1.14133	1.13991	1.13854	1.13718
1150	1.15183	1.15022	1.14863	1.14710	1.14559	1.14409	1.14264	1.14122	1.13983	1.13847
1160	1.15324	1.15162	1.15003	1.14844	1.14694	1.14543	1.14396	1.14254	1.14112	1.13975
1170	1.15465	1.15300	1.15141	1.14982	1.14829	1.14678	1.14530	1.14385	1.14243	1.14104
1180	1.15609	1.15441	1.15279	1.15120	1.14966	1.14813	1.14662	1.14517	1.14372	1.14233
1190	1.15750	1.15582	1.15420	1.15258	1.15101	1.14948	1.14797	1.14649	1.14504	1.14362
1200	1.15891	1.15723	1.15558	1.15396	1.15236	1.15080	1.14929	1.14778	1.14633	1.14491
1210	1.16035	1.15864	1.15696	1.15534	1.15372	1.15215	1.15061	1.14911	1.14762	1.14620
1220	1.16177	1.16006	1.15838	1.15672	1.15510	1.15351	1.15197	1.15043	1.14895	1.14749
1230	1.16322	1.16148	1.15977	1.15808	1.15646	1.15486	1.15329	1.15175	1.15024	1.14879
1240	1.16464	1.16287	1.16115	1.15947	1.15782	1.15622	1.15462	1.15308	1.15157	1.15009
1250	1.16606	1.16429	1.16257	1.16086	1.15920	1.15758	1.15598	1.15441	1.15287	1.15138
1260	1.16751	1.16571	1.16397	1.16225	1.16057	1.15894	1.15731	1.15574	1.15420	1.15266
1270	1.16893	1.16713	1.16536	1.16364	1.16196	1.16030	1.15864	1.15707	1.15550	1.15396
1280	1.17039	1.16856	1.16678	1.16501	1.16332	1.16166	1.16001	1.15840	1.15683	1.15526
1290	1.17182	1.16998	1.16818	1.16641	1.16469	1.16300	1.16134	1.15971	1.15814	1.15656
1300	1.17325	1.17141	1.16958	1.16780	1.16606	1.16437	1.16271	1.16105	1.15944	1.15787
1310	1.17471	1.17282	1.17098	1.16920	1.16745	1.16574	1.16405	1.16239	1.16075	1.15918
1320	1.17614	1.17425	1.17241	1.17060	1.16883	1.16711	1.16539	1.16372	1.16209	1.16049
1330	1.17758	1.17568	1.17382	1.17198	1.17020	1.16845	1.16676	1.16506	1.16343	1.16180
1340	1.17904	1.17712	1.17525	1.17338	1.17160	1.16982	1.16810	1.16641	1.16474	1.16311
1350	1.18048	1.17856	1.17666	1.17479	1.17298	1.17120	1.16945	1.16775	1.16608	1.16442
1360	1.18195	1.17999	1.17807	1.17620	1.17436	1.17257	1.17082	1.16910	1.16740	1.16574
1370	1.18340	1.18141	1.17951	1.17761	1.17576	1.17395	1.17217	1.17044	1.16872	1.16705
1380	1.18484	1.18285	1.18092	1.17902	1.17715	1.17533	1.17352	1.17179	1.17007	1.16837
1390	1.18631	1.18430	1.18233	1.18043	1.17853	1.17668	1.17490	1.17311	1.17139	1.16969
1400	1.18776	1.18574	1.18375	1.18182	1.17994	1.17807	1.17625	1.17446	1.17274	1.17101
1410	1.18921	1.18719	1.18520	1.18323	1.18133	1.17945	1.17761	1.17582	1.17406	1.17233
1420	1.19069	1.18864	1.18662	1.18465	1.18271	1.18084	1.17899	1.17717	1.17541	1.17365
1430	1.19215	1.19009	1.18806	1.18607	1.18413	1.18222	1.18035	1.17853	1.17674	1.17498
1440	1.19363	1.19154	1.18949	1.18749	1.18552	1.18361	1.18173	1.17989	1.17807	1.17631
1450	1.19509	1.19297	1.19091	1.18889	1.18692	1.18498	1.18310	1.18125	1.17942	1.17763
1460	1.19655	1.19443	1.19234	1.19031	1.18834	1.18637	1.18446	1.18261	1.18076	1.17896
1470	1.19804	1.19589	1.19380	1.19174	1.18973	1.18776	1.18585	1.18394	1.18212	1.18029
1480	1.19950	1.19735	1.19523	1.19316	1.19113	1.18916	1.18722	1.18530	1.18345	1.18163
1490	1.20096	1.19881	1.19666	1.19459	1.19256	1.19056	1.18858	1.18667	1.18479	1.18296
1500	1.20246	1.20027	1.19812	1.19602	1.19396	1.19196	1.18998	1.18804	1.18615	1.18430

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	500	505	510	515	520	525	530	535	540	545
1500	1.20246	1.20027	1.19812	1.19602	1.19396	1.19196	1.18998	1.18804	1.18615	1.18430
1510	1.20393	1.20171	1.19955	1.19743	1.19536	1.19333	1.19135	1.18941	1.18749	1.18563
1520	1.20542	1.20318	1.20099	1.19886	1.19680	1.19473	1.19272	1.19078	1.18886	1.18697
1530	1.20690	1.20465	1.20246	1.20030	1.19820	1.19613	1.19413	1.19215	1.19020	1.18831
1540	1.20837	1.20612	1.20390	1.20174	1.19961	1.19754	1.19550	1.19352	1.19154	1.18965
1550	1.20987	1.20759	1.20537	1.20318	1.20105	1.19895	1.19688	1.19487	1.19292	1.19100
1560	1.21135	1.20907	1.20681	1.20462	1.20246	1.20036	1.19828	1.19624	1.19426	1.19234
1570	1.21286	1.21051	1.20826	1.20604	1.20387	1.20174	1.19967	1.19762	1.19564	1.19369
1580	1.21434	1.21199	1.20971	1.20748	1.20531	1.20315	1.20107	1.19900	1.19699	1.19503
1590	1.21582	1.21347	1.21118	1.20893	1.20673	1.20456	1.20246	1.20038	1.19837	1.19638
1600	1.21733	1.21495	1.21263	1.21038	1.20815	1.20598	1.20384	1.20177	1.19972	1.19773
1610	1.21882	1.21644	1.21409	1.21183	1.20957	1.20740	1.20526	1.20315	1.20107	1.19906
1620	1.22031	1.21792	1.21557	1.21325	1.21102	1.20882	1.20665	1.20454	1.20246	1.20041
1630	1.22183	1.21941	1.21703	1.21470	1.21244	1.21021	1.20804	1.20592	1.20382	1.20177
1640	1.22332	1.22087	1.21848	1.21616	1.21386	1.21163	1.20946	1.20729	1.20520	1.20312
1650	1.22484	1.22236	1.21997	1.21762	1.21532	1.21305	1.21085	1.20868	1.20656	1.20448
1660	1.22634	1.22386	1.22143	1.21907	1.21675	1.21448	1.21224	1.21007	1.20795	1.20584
1670	1.22783	1.22535	1.22290	1.22053	1.21818	1.21591	1.21367	1.21146	1.20932	1.20720
1680	1.22936	1.22685	1.22439	1.22197	1.21964	1.21733	1.21507	1.21286	1.21068	1.20856
1690	1.23086	1.22834	1.22586	1.22343	1.22107	1.21874	1.21649	1.21426	1.21208	1.20993
1700	1.23237	1.22984	1.22733	1.22490	1.22250	1.22017	1.21790	1.21565	1.21344	1.21130
1710	1.23390	1.23132	1.22882	1.22637	1.22397	1.22160	1.21930	1.21705	1.21484	1.21266
1720	1.23541	1.23282	1.23030	1.22784	1.22541	1.22304	1.22073	1.21846	1.21621	1.21403
1730	1.23694	1.23433	1.23177	1.22931	1.22685	1.22448	1.22214	1.21983	1.21762	1.21540
1740	1.23845	1.23583	1.23328	1.23075	1.22832	1.22591	1.22355	1.22124	1.21899	1.21677
1750	1.23997	1.23734	1.23475	1.23222	1.22976	1.22733	1.22498	1.22264	1.22037	1.21815
1760	1.24151	1.23885	1.23624	1.23370	1.23120	1.22877	1.22639	1.22405	1.22177	1.21952
1770	1.24303	1.24034	1.23774	1.23518	1.23268	1.23021	1.22781	1.22546	1.22315	1.22090
1780	1.24454	1.24185	1.23922	1.23666	1.23413	1.23166	1.22925	1.22687	1.22456	1.22228
1790	1.24609	1.24337	1.24071	1.23811	1.23558	1.23310	1.23067	1.22829	1.22594	1.22366
1800	1.24761	1.24489	1.24222	1.23960	1.23706	1.23455	1.23208	1.22970	1.22735	1.22504
1810	1.24915	1.24641	1.24371	1.24108	1.23851	1.23598	1.23353	1.23112	1.22874	1.22642
1820	1.25069	1.24793	1.24520	1.24257	1.23997	1.23743	1.23495	1.23251	1.23013	1.22781
1830	1.25222	1.24945	1.24672	1.24406	1.24145	1.23888	1.23640	1.23393	1.23154	1.22919
1840	1.25378	1.25095	1.24822	1.24555	1.24291	1.24034	1.23783	1.23535	1.23293	1.23058
1850	1.25531	1.25248	1.24971	1.24701	1.24437	1.24180	1.23925	1.23677	1.23435	1.23197
1860	1.25684	1.25401	1.25124	1.24850	1.24586	1.24325	1.24071	1.23820	1.23575	1.23336
1870	1.25840	1.25554	1.25274	1.25000	1.24733	1.24472	1.24214	1.23962	1.23714	1.23475
1880	1.25994	1.25707	1.25424	1.25150	1.24879	1.24615	1.24357	1.24105	1.23857	1.23615
1890	1.26151	1.25861	1.25577	1.25300	1.25029	1.24761	1.24503	1.24248	1.23997	1.23754
1900	1.26305	1.26014	1.25727	1.25450	1.25176	1.24908	1.24646	1.24391	1.24140	1.23894
1910	1.26459	1.26165	1.25878	1.25597	1.25323	1.25055	1.24790	1.24532	1.24280	1.24034
1920	1.26616	1.26319	1.26032	1.25748	1.25473	1.25202	1.24937	1.24675	1.24423	1.24174
1930	1.26771	1.26474	1.26183	1.25898	1.25620	1.25349	1.25081	1.24819	1.24563	1.24314
1940	1.26929	1.26628	1.26334	1.26049	1.25768	1.25493	1.25225	1.24963	1.24704	1.24454
1950	1.27084	1.26783	1.26488	1.26200	1.25919	1.25641	1.25372	1.25107	1.24848	1.24595
1960	1.27239	1.26938	1.26640	1.26351	1.26067	1.25788	1.25516	1.25251	1.24988	1.24735
1970	1.27397	1.27090	1.26791	1.26500	1.26215	1.25936	1.25664	1.25395	1.25132	1.24873
1980	1.27553	1.27245	1.26946	1.26651	1.26366	1.26084	1.25809	1.25539	1.25274	1.25014
1990	1.27709	1.27400	1.27098	1.26803	1.26514	1.26232	1.25953	1.25684	1.25418	1.25156
2000	1.27867	1.27556	1.27251	1.26955	1.26663	1.26378	1.26101	1.25826	1.25560	1.25297

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	500	505	510	515	520	525	530	535	540	545
2000	1.27867	1.27556	1.27251	1.26955	1.26663	1.26378	1.26101	1.25826	1.25560	1.25297
2010	1.28024	1.27711	1.27406	1.27107	1.26815	1.26526	1.26247	1.25971	1.25704	1.25438
2020	1.28183	1.27867	1.27559	1.27257	1.26964	1.26675	1.26392	1.26116	1.25846	1.25580
2030	1.28339	1.28024	1.27711	1.27409	1.27113	1.26824	1.26541	1.26261	1.25991	1.25722
2040	1.28496	1.28177	1.27867	1.27562	1.27265	1.26973	1.26686	1.26405	1.26133	1.25864
2050	1.28656	1.28333	1.28021	1.27714	1.27415	1.27122	1.26832	1.26552	1.26276	1.26006
2060	1.28813	1.28490	1.28174	1.27865	1.27565	1.27271	1.26981	1.26698	1.26421	1.26148
2070	1.28970	1.28647	1.28331	1.28018	1.27717	1.27418	1.27128	1.26844	1.26564	1.26290
2080	1.29131	1.28804	1.28484	1.28171	1.27867	1.27567	1.27274	1.26987	1.26707	1.26433
2090	1.29289	1.28961	1.28638	1.28325	1.28018	1.27717	1.27424	1.27133	1.26853	1.26576
2100	1.29449	1.29119	1.28795	1.28478	1.28168	1.27867	1.27570	1.27280	1.26996	1.26718
2110	1.29607	1.29274	1.28950	1.28632	1.28322	1.28018	1.27720	1.27427	1.27142	1.26862
2120	1.29766	1.29432	1.29104	1.28786	1.28472	1.28168	1.27867	1.27573	1.27286	1.27005
2130	1.29927	1.29590	1.29262	1.28938	1.28623	1.28319	1.28015	1.27720	1.27432	1.27148
2140	1.30085	1.29748	1.29417	1.29092	1.28778	1.28467	1.28165	1.27867	1.27576	1.27292
2150	1.30245	1.29906	1.29572	1.29247	1.28929	1.28617	1.28313	1.28015	1.27723	1.27435
2160	1.30407	1.30065	1.29730	1.29402	1.29080	1.28769	1.28461	1.28162	1.27867	1.27579
2170	1.30566	1.30224	1.29885	1.29557	1.29235	1.28920	1.28612	1.28310	1.28012	1.27723
2180	1.30728	1.30380	1.30041	1.29712	1.29387	1.29071	1.28760	1.28458	1.28159	1.27867
2190	1.30888	1.30539	1.30200	1.29864	1.29539	1.29220	1.28908	1.28603	1.28304	1.28012
2200	1.31048	1.30698	1.30356	1.30020	1.29694	1.29372	1.29060	1.28751	1.28452	1.28156
2210	1.31211	1.30858	1.30515	1.30176	1.29846	1.29524	1.29208	1.28899	1.28597	1.28301
2220	1.31371	1.31018	1.30671	1.30332	1.29999	1.29676	1.29357	1.29048	1.28745	1.28446
2230	1.31535	1.31178	1.30828	1.30488	1.30155	1.29828	1.29509	1.29196	1.28890	1.28591
2240	1.31695	1.31335	1.30985	1.30644	1.30308	1.29981	1.29658	1.29345	1.29036	1.28736
2250	1.31856	1.31495	1.31144	1.30798	1.30461	1.30134	1.29811	1.29494	1.29184	1.28881
2260	1.32020	1.31656	1.31302	1.30954	1.30617	1.30284	1.29960	1.29640	1.29330	1.29027
2270	1.32181	1.31817	1.31462	1.31111	1.30771	1.30437	1.30110	1.29790	1.29476	1.29172
2280	1.32343	1.31978	1.31619	1.31268	1.30924	1.30590	1.30263	1.29939	1.29625	1.29318
2290	1.32507	1.32139	1.31777	1.31426	1.31081	1.30744	1.30413	1.30089	1.29772	1.29464
2300	1.32669	1.32300	1.31935	1.31583	1.31235	1.30897	1.30563	1.30239	1.29921	1.29610
2310	1.32834	1.32459	1.32096	1.31738	1.31389	1.31051	1.30716	1.30389	1.30068	1.29757
2320	1.32996	1.32620	1.32254	1.31896	1.31547	1.31205	1.30867	1.30539	1.30218	1.29903
2330	1.33159	1.32782	1.32413	1.32054	1.31701	1.31356	1.31018	1.30689	1.30365	1.30050
2340	1.33325	1.32944	1.32575	1.32212	1.31856	1.31510	1.31172	1.30840	1.30512	1.30197
2350	1.33487	1.33107	1.32733	1.32370	1.32014	1.31665	1.31323	1.30988	1.30662	1.30341
2360	1.33650	1.33269	1.32892	1.32526	1.32169	1.31820	1.31474	1.31138	1.30810	1.30488
2370	1.33817	1.33432	1.33055	1.32684	1.32324	1.31974	1.31629	1.31290	1.30960	1.30635
2380	1.33980	1.33592	1.33214	1.32843	1.32483	1.32127	1.31780	1.31441	1.31108	1.30783
2390	1.34147	1.33755	1.33374	1.33003	1.32639	1.32282	1.31935	1.31592	1.31259	1.30930
2400	1.34311	1.33918	1.33537	1.33162	1.32794	1.32437	1.32087	1.31744	1.31407	1.31078
2410	1.34475	1.34082	1.33696	1.33321	1.32954	1.32593	1.32239	1.31896	1.31556	1.31226
2420	1.34642	1.34246	1.33857	1.33478	1.33110	1.32749	1.32395	1.32047	1.31707	1.31374
2430	1.34806	1.34410	1.34020	1.33638	1.33266	1.32905	1.32547	1.32200	1.31856	1.31522
2440	1.34971	1.34571	1.34181	1.33798	1.33426	1.33058	1.32700	1.32352	1.32008	1.31671
2450	1.35139	1.34735	1.34341	1.33958	1.33583	1.33214	1.32856	1.32504	1.32157	1.31819
2460	1.35304	1.34899	1.34505	1.34119	1.33740	1.33371	1.33009	1.32654	1.32309	1.31968
2470	1.35472	1.35064	1.34667	1.34280	1.33900	1.33527	1.33162	1.32807	1.32459	1.32117
2480	1.35638	1.35229	1.34828	1.34437	1.34057	1.33684	1.33318	1.32960	1.32608	1.32267
2490	1.35803	1.35394	1.34993	1.34598	1.34215	1.33841	1.33472	1.33113	1.32761	1.32416
2500	1.35972	1.35560	1.35154	1.34760	1.34375	1.33995	1.33629	1.33266	1.32911	1.32565

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	500	505	510	515	520	525	530	535	540	545
2500	1.35972	1.35560	1.35154	1.34760	1.34375	1.33995	1.33629	1.33266	1.32911	1.32565
2510	1.36138	1.35725	1.35316	1.34921	1.34533	1.34153	1.33783	1.33420	1.33064	1.32715
2520	1.36308	1.35888	1.35482	1.35080	1.34691	1.34311	1.33937	1.33573	1.33214	1.32865
2530	1.36474	1.36054	1.35644	1.35242	1.34850	1.34468	1.34094	1.33727	1.33367	1.33015
2540	1.36641	1.36220	1.35806	1.35404	1.35011	1.34626	1.34249	1.33878	1.33518	1.33165
2550	1.36811	1.36386	1.35972	1.35566	1.35170	1.34781	1.34403	1.34032	1.33669	1.33315
2560	1.36978	1.36553	1.36135	1.35728	1.35329	1.34940	1.34561	1.34187	1.33823	1.33466
2570	1.37145	1.36719	1.36301	1.35891	1.35491	1.35098	1.34716	1.34341	1.33974	1.33616
2580	1.37316	1.36883	1.36465	1.36054	1.35650	1.35257	1.34871	1.34496	1.34128	1.33767
2590	1.37483	1.37050	1.36628	1.36213	1.35809	1.35416	1.35030	1.34651	1.34280	1.33918
2600	1.37654	1.37218	1.36792	1.36377	1.35972	1.35575	1.35185	1.34806	1.34434	1.34070
2610	1.37822	1.37385	1.36959	1.36540	1.36132	1.35731	1.35341	1.34962	1.34586	1.34221
2620	1.37991	1.37553	1.37123	1.36704	1.36292	1.35891	1.35500	1.35117	1.34738	1.34372
2630	1.38162	1.37721	1.37287	1.36867	1.36455	1.36050	1.35656	1.35270	1.34893	1.34524
2640	1.38331	1.37886	1.37455	1.37031	1.36616	1.36210	1.35813	1.35425	1.35045	1.34676
2650	1.38500	1.38054	1.37620	1.37192	1.36779	1.36370	1.35972	1.35581	1.35201	1.34828
2660	1.38672	1.38223	1.37784	1.37357	1.36940	1.36531	1.36129	1.35738	1.35354	1.34980
2670	1.38842	1.38392	1.37953	1.37521	1.37101	1.36688	1.36286	1.35894	1.35506	1.35133
2680	1.39014	1.38561	1.38118	1.37686	1.37262	1.36848	1.36446	1.36050	1.35663	1.35282
2690	1.39184	1.38730	1.38283	1.37848	1.37426	1.37009	1.36603	1.36207	1.35816	1.35435
2700	1.39354	1.38899	1.38452	1.38013	1.37588	1.37170	1.36763	1.36361	1.35972	1.35588
2710	1.39528	1.39069	1.38618	1.38178	1.37753	1.37331	1.36921	1.36518	1.36126	1.35741
2720	1.39698	1.39236	1.38784	1.38344	1.37915	1.37493	1.37079	1.36675	1.36282	1.35894
2730	1.39869	1.39406	1.38954	1.38510	1.38077	1.37654	1.37240	1.36833	1.36436	1.36047
2740	1.40043	1.39576	1.39120	1.38676	1.38239	1.37816	1.37398	1.36990	1.36593	1.36201
2750	1.40214	1.39746	1.39287	1.38842	1.38404	1.37975	1.37556	1.37148	1.36748	1.36355
2760	1.40388	1.39917	1.39457	1.39005	1.38567	1.38137	1.37718	1.37306	1.36905	1.36509
2770	1.40559	1.40088	1.39624	1.39171	1.38730	1.38299	1.37876	1.37464	1.37060	1.36663
2780	1.40731	1.40256	1.39794	1.39338	1.38896	1.38462	1.38035	1.37623	1.37218	1.36817
2790	1.40906	1.40427	1.39962	1.39505	1.39059	1.38625	1.38197	1.37778	1.37373	1.36971
2800	1.41078	1.40598	1.40130	1.39672	1.39223	1.38784	1.38357	1.37937	1.37528	1.37126
2810	1.41251	1.40770	1.40301	1.39840	1.39389	1.38947	1.38519	1.38096	1.37686	1.37281
2820	1.41426	1.40942	1.40469	1.40004	1.39553	1.39111	1.38679	1.38255	1.37842	1.37436
2830	1.41599	1.41114	1.40637	1.40172	1.39717	1.39274	1.38839	1.38414	1.38000	1.37591
2840	1.41775	1.41286	1.40806	1.40340	1.39885	1.39438	1.39002	1.38573	1.38156	1.37746
2850	1.41948	1.41456	1.40978	1.40508	1.40049	1.39601	1.39162	1.38733	1.38312	1.37902
2860	1.42122	1.41628	1.41146	1.40673	1.40214	1.39762	1.39322	1.38893	1.38471	1.38057
2870	1.42298	1.41801	1.41316	1.40841	1.40382	1.39927	1.39486	1.39053	1.38628	1.38213
2880	1.42472	1.41974	1.41488	1.41010	1.40546	1.40091	1.39646	1.39210	1.38784	1.38369
2890	1.42649	1.42148	1.41658	1.41179	1.40712	1.40256	1.39807	1.39370	1.38944	1.38526
2900	1.42824	1.42321	1.41827	1.41348	1.40880	1.40420	1.39972	1.39531	1.39101	1.38682
2910	1.42998	1.42492	1.42001	1.41517	1.41046	1.40585	1.40133	1.39692	1.39261	1.38839
2920	1.43176	1.42666	1.42171	1.41687	1.41211	1.40747	1.40298	1.39852	1.39418	1.38995
2930	1.43351	1.42840	1.42341	1.41853	1.41381	1.40913	1.40459	1.40014	1.39579	1.39152
2940	1.43526	1.43014	1.42515	1.42023	1.41547	1.41078	1.40621	1.40175	1.39737	1.39309
2950	1.43704	1.43189	1.42686	1.42194	1.41713	1.41244	1.40786	1.40336	1.39894	1.39467
2960	1.43880	1.43364	1.42856	1.42364	1.41880	1.41410	1.40948	1.40498	1.40055	1.39624
2970	1.44059	1.43536	1.43031	1.42535	1.42050	1.41576	1.41111	1.40657	1.40214	1.39782
2980	1.44235	1.43711	1.43202	1.42705	1.42217	1.41739	1.41277	1.40819	1.40375	1.39939
2990	1.44411	1.43886	1.43374	1.42873	1.42384	1.41906	1.41439	1.40981	1.40534	1.40097
3000	1.44591	1.44062	1.43549	1.43044	1.42554	1.42072	1.41602	1.41143	1.40695	1.40256

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$r = 10^{(KH_{pg})/T_{mv}}$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	550	555	560	565	570	575	580	585	590	595
0	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
10	1.00113	1.00111	1.00111	1.00108	1.00108	1.00106	1.00106	1.00106	1.00104	1.00104
20	1.00224	1.00221	1.00219	1.00217	1.00217	1.00214	1.00212	1.00210	1.00207	1.00207
30	1.00337	1.00332	1.00330	1.00328	1.00323	1.00321	1.00318	1.00316	1.00314	1.00311
40	1.00448	1.00443	1.00441	1.00436	1.00431	1.00429	1.00425	1.00420	1.00418	1.00413
50	1.00561	1.00554	1.00550	1.00545	1.00540	1.00536	1.00531	1.00526	1.00522	1.00517
60	1.00672	1.00666	1.00661	1.00654	1.00649	1.00642	1.00638	1.00633	1.00626	1.00621
70	1.00786	1.00779	1.00772	1.00765	1.00758	1.00751	1.00744	1.00737	1.00733	1.00726
80	1.00897	1.00890	1.00881	1.00874	1.00867	1.00858	1.00851	1.00844	1.00837	1.00830
90	1.01011	1.01002	1.00993	1.00983	1.00974	1.00967	1.00958	1.00951	1.00942	1.00935
100	1.01123	1.01114	1.01104	1.01093	1.01083	1.01074	1.01065	1.01056	1.01046	1.01039
110	1.01237	1.01226	1.01214	1.01205	1.01193	1.01184	1.01172	1.01163	1.01153	1.01142
120	1.01349	1.01337	1.01326	1.01314	1.01302	1.01291	1.01279	1.01267	1.01258	1.01247
130	1.01464	1.01450	1.01438	1.01424	1.01412	1.01398	1.01386	1.01375	1.01363	1.01351
140	1.01576	1.01562	1.01548	1.01534	1.01522	1.01508	1.01494	1.01482	1.01468	1.01457
150	1.01690	1.01674	1.01660	1.01646	1.01630	1.01616	1.01601	1.01587	1.01576	1.01562
160	1.01803	1.01786	1.01772	1.01756	1.01740	1.01726	1.01709	1.01695	1.01681	1.01667
170	1.01918	1.01901	1.01883	1.01866	1.01850	1.01833	1.01817	1.01803	1.01786	1.01772
180	1.02030	1.02014	1.01995	1.01976	1.01960	1.01944	1.01925	1.01908	1.01892	1.01876
190	1.02146	1.02127	1.02108	1.02089	1.02070	1.02052	1.02033	1.02016	1.01998	1.01981
200	1.02261	1.02240	1.02219	1.02200	1.02179	1.02160	1.02141	1.02122	1.02106	1.02087
210	1.02374	1.02353	1.02332	1.02310	1.02289	1.02270	1.02249	1.02230	1.02212	1.02193
220	1.02490	1.02466	1.02445	1.02421	1.02400	1.02379	1.02358	1.02339	1.02318	1.02299
230	1.02603	1.02579	1.02556	1.02532	1.02511	1.02490	1.02466	1.02445	1.02424	1.02405
240	1.02719	1.02693	1.02669	1.02646	1.02622	1.02598	1.02575	1.02553	1.02532	1.02511
250	1.02832	1.02806	1.02780	1.02757	1.02733	1.02707	1.02683	1.02662	1.02638	1.02615
260	1.02948	1.02920	1.02894	1.02868	1.02842	1.02818	1.02792	1.02768	1.02744	1.02721
270	1.03062	1.03034	1.03008	1.02979	1.02953	1.02927	1.02901	1.02877	1.02851	1.02828
280	1.03179	1.03148	1.03119	1.03093	1.03065	1.03039	1.03010	1.02984	1.02960	1.02934
290	1.03293	1.03264	1.03233	1.03205	1.03176	1.03148	1.03119	1.03093	1.03067	1.03041
300	1.03409	1.03378	1.03348	1.03317	1.03288	1.03259	1.03229	1.03202	1.03174	1.03148
310	1.03524	1.03493	1.03459	1.03428	1.03400	1.03369	1.03340	1.03309	1.03281	1.03255
320	1.03641	1.03607	1.03574	1.03543	1.03509	1.03478	1.03450	1.03419	1.03390	1.03359
330	1.03755	1.03722	1.03688	1.03655	1.03622	1.03591	1.03560	1.03529	1.03498	1.03467
340	1.03872	1.03836	1.03800	1.03767	1.03734	1.03700	1.03669	1.03636	1.03605	1.03574
350	1.03987	1.03951	1.03915	1.03880	1.03846	1.03813	1.03779	1.03746	1.03712	1.03681
360	1.04105	1.04066	1.04030	1.03994	1.03958	1.03923	1.03889	1.03853	1.03822	1.03789
370	1.04220	1.04181	1.04143	1.04107	1.04069	1.04033	1.03999	1.03963	1.03930	1.03896
380	1.04337	1.04297	1.04258	1.04220	1.04181	1.04145	1.04109	1.04071	1.04037	1.04004
390	1.04455	1.04412	1.04373	1.04333	1.04294	1.04256	1.04220	1.04181	1.04145	1.04109
400	1.04571	1.04530	1.04486	1.04448	1.04407	1.04369	1.04330	1.04292	1.04253	1.04217
410	1.04689	1.04645	1.04602	1.04561	1.04520	1.04479	1.04441	1.04402	1.04364	1.04325
420	1.04805	1.04761	1.04718	1.04674	1.04633	1.04590	1.04551	1.04511	1.04472	1.04434
430	1.04923	1.04877	1.04831	1.04788	1.04744	1.04703	1.04662	1.04621	1.04580	1.04542
440	1.05039	1.04993	1.04947	1.04901	1.04858	1.04814	1.04773	1.04730	1.04689	1.04650
450	1.05157	1.05109	1.05063	1.05017	1.04971	1.04928	1.04884	1.04841	1.04800	1.04759
460	1.05274	1.05225	1.05177	1.05131	1.05085	1.05039	1.04995	1.04952	1.04908	1.04865
470	1.05393	1.05342	1.05293	1.05245	1.05199	1.05153	1.05106	1.05061	1.05017	1.04974
480	1.05509	1.05458	1.05410	1.05359	1.05313	1.05264	1.05218	1.05172	1.05126	1.05082
490	1.05628	1.05575	1.05524	1.05475	1.05424	1.05376	1.05329	1.05283	1.05237	1.05191
500	1.05745	1.05691	1.05640	1.05589	1.05538	1.05490	1.05441	1.05393	1.05346	1.05300

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$r = 10^{(KH_{pg})/T_{mv}}$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	550	555	560	565	570	575	580	585	590	595
500	1.05745	1.05691	1.05640	1.05589	1.05538	1.05490	1.05441	1.05393	1.05346	1.05300
510	1.05864	1.05811	1.05757	1.05704	1.05653	1.05601	1.05553	1.05504	1.05456	1.05410
520	1.05981	1.05928	1.05872	1.05818	1.05767	1.05716	1.05665	1.05614	1.05565	1.05519
530	1.06101	1.06045	1.05989	1.05935	1.05881	1.05828	1.05777	1.05726	1.05677	1.05626
540	1.06218	1.06162	1.06106	1.06050	1.05994	1.05940	1.05889	1.05838	1.05786	1.05735
550	1.06338	1.06280	1.06221	1.06165	1.06108	1.06055	1.06001	1.05947	1.05896	1.05845
560	1.06456	1.06397	1.06338	1.06280	1.06223	1.06167	1.06113	1.06060	1.06006	1.05955
570	1.06576	1.06515	1.06456	1.06397	1.06338	1.06282	1.06226	1.06172	1.06116	1.06064
580	1.06696	1.06633	1.06571	1.06512	1.06454	1.06395	1.06338	1.06282	1.06228	1.06174
590	1.06814	1.06751	1.06689	1.06628	1.06569	1.06510	1.06451	1.06395	1.06338	1.06285
600	1.06935	1.06869	1.06807	1.06743	1.06682	1.06623	1.06564	1.06505	1.06449	1.06392
610	1.07053	1.06987	1.06923	1.06861	1.06797	1.06736	1.06677	1.06618	1.06559	1.06503
620	1.07174	1.07108	1.07041	1.06977	1.06913	1.06851	1.06790	1.06731	1.06672	1.06613
630	1.07293	1.07226	1.07159	1.07093	1.07029	1.06965	1.06903	1.06842	1.06782	1.06723
640	1.07414	1.07345	1.07275	1.07209	1.07145	1.07080	1.07016	1.06955	1.06893	1.06834
650	1.07533	1.07463	1.07394	1.07325	1.07261	1.07194	1.07130	1.07066	1.07004	1.06945
660	1.07654	1.07582	1.07513	1.07443	1.07374	1.07310	1.07243	1.07179	1.07117	1.07053
670	1.07773	1.07701	1.07629	1.07560	1.07490	1.07424	1.07357	1.07293	1.07228	1.07164
680	1.07895	1.07820	1.07748	1.07676	1.07607	1.07538	1.07471	1.07404	1.07340	1.07275
690	1.08014	1.07939	1.07867	1.07793	1.07723	1.07654	1.07585	1.07518	1.07451	1.07387
700	1.08136	1.08059	1.07984	1.07912	1.07840	1.07768	1.07699	1.07632	1.07565	1.07498
710	1.08256	1.08178	1.08104	1.08029	1.07957	1.07885	1.07813	1.07743	1.07676	1.07609
720	1.08378	1.08298	1.08223	1.08146	1.08071	1.07999	1.07927	1.07857	1.07788	1.07721
730	1.08498	1.08420	1.08340	1.08263	1.08188	1.08114	1.08041	1.07969	1.07900	1.07833
740	1.08620	1.08540	1.08460	1.08383	1.03305	1.08231	1.08156	1.08084	1.08012	1.07942
750	1.08740	1.08660	1.08580	1.08500	1.08423	1.08345	1.08270	1.08198	1.08126	1.08054
760	1.08863	1.08780	1.08698	1.08618	1.08540	1.08463	1.08385	1.08310	1.08238	1.08166
770	1.08986	1.08901	1.08818	1.08735	1.08655	1.08578	1.08500	1.08425	1.08350	1.08278
780	1.09106	1.09021	1.08936	1.08855	1.08773	1.08693	1.08615	1.08540	1.08463	1.08390
790	1.09230	1.09142	1.09056	1.08973	1.08891	1.08810	1.08730	1.08653	1.08578	1.08503
800	1.09350	1.09262	1.09177	1.09091	1.09008	1.08926	1.08845	1.08768	1.08690	1.08613
810	1.09474	1.09383	1.09295	1.09209	1.09126	1.09044	1.08961	1.08883	1.08803	1.08725
820	1.09595	1.09504	1.09416	1.09328	1.09245	1.09159	1.09076	1.08996	1.08916	1.08838
830	1.09719	1.09625	1.09537	1.09449	1.09360	1.09275	1.09192	1.09111	1.09031	1.08951
840	1.09840	1.09746	1.09655	1.09567	1.09479	1.09393	1.09308	1.09224	1.09144	1.09064
850	1.09964	1.09870	1.09777	1.09686	1.09597	1.09509	1.09423	1.09340	1.09257	1.09177
860	1.10085	1.09992	1.09898	1.09804	1.09716	1.09628	1.09539	1.09456	1.09370	1.09290
870	1.10210	1.10113	1.10017	1.09926	1.09835	1.09744	1.09655	1.09570	1.09486	1.09403
880	1.10332	1.10235	1.10139	1.10045	1.09954	1.09863	1.09772	1.09686	1.09600	1.09514
890	1.10456	1.10357	1.10261	1.10164	1.10070	1.09979	1.09888	1.09802	1.09713	1.09628
900	1.10578	1.10479	1.10380	1.10283	1.10189	1.10098	1.10004	1.09916	1.09827	1.09741
910	1.10703	1.10601	1.10502	1.10405	1.10309	1.10215	1.10121	1.10032	1.09941	1.09855
920	1.10826	1.10724	1.10624	1.10525	1.10428	1.10332	1.10238	1.10146	1.10058	1.09969
930	1.10951	1.10846	1.10744	1.10645	1.10548	1.10451	1.10354	1.10263	1.10172	1.10083
940	1.11073	1.10969	1.10866	1.10764	1.10665	1.10568	1.10471	1.10380	1.10286	1.10197
950	1.11199	1.11091	1.10989	1.10887	1.10785	1.10685	1.10589	1.10494	1.10400	1.10309
960	1.11324	1.11217	1.11109	1.11007	1.10905	1.10805	1.10706	1.10611	1.10517	1.10423
970	1.11447	1.11340	1.11232	1.11127	1.11025	1.10923	1.10826	1.10726	1.10632	1.10538
980	1.11573	1.11463	1.11355	1.11247	1.11145	1.11043	1.10943	1.10843	1.10746	1.10652
990	1.11697	1.11586	1.11476	1.11370	1.11265	1.11160	1.11061	1.10961	1.10861	1.10767
1000	1.11823	1.11709	1.11599	1.11491	1.11383	1.11281	1.11178	1.11076	1.10979	1.10882

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$r = 10^{(KH_{pg})/T_{mv}}$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	550	555	560	565	570	575	580	585	590	595
1000	1.11823	1.11709	1.11599	1.11491	1.11383	1.11281	1.11178	1.11076	1.10979	1.10882
1010	1.11946	1.11833	1.11722	1.11612	1.11504	1.11399	1.11296	1.11194	1.11094	1.10994
1020	1.12073	1.11957	1.11843	1.11733	1.11625	1.11517	1.11414	1.11309	1.11209	1.11109
1030	1.12197	1.12080	1.11967	1.11854	1.11745	1.11637	1.11532	1.11427	1.11324	1.11224
1040	1.12323	1.12204	1.12091	1.11977	1.11866	1.11756	1.11650	1.11545	1.11440	1.11340
1050	1.12448	1.12329	1.12212	1.12099	1.11988	1.11877	1.11769	1.11661	1.11558	1.11455
1060	1.12575	1.12453	1.12336	1.12220	1.12106	1.11995	1.11887	1.11779	1.11673	1.11571
1070	1.12699	1.12580	1.12460	1.12341	1.12228	1.12117	1.12006	1.11897	1.11789	1.11686
1080	1.12826	1.12704	1.12582	1.12466	1.12349	1.12235	1.12124	1.12013	1.11905	1.11802
1090	1.12951	1.12829	1.12707	1.12587	1.12471	1.12354	1.12243	1.12132	1.12024	1.11915
1100	1.13078	1.12954	1.12831	1.12709	1.12593	1.12476	1.12362	1.12251	1.12140	1.12031
1110	1.13203	1.13078	1.12954	1.12831	1.12712	1.12595	1.12481	1.12367	1.12256	1.12148
1120	1.13331	1.13204	1.13078	1.12954	1.12834	1.12717	1.12600	1.12486	1.12372	1.12264
1130	1.13459	1.13329	1.13201	1.13078	1.12956	1.12837	1.12720	1.12603	1.12492	1.12380
1140	1.13585	1.13454	1.13326	1.13201	1.13078	1.12959	1.12839	1.12722	1.12608	1.12497
1150	1.13713	1.13580	1.13451	1.13324	1.13201	1.13078	1.12959	1.12842	1.12725	1.12613
1160	1.13839	1.13705	1.13574	1.13449	1.13321	1.13198	1.13078	1.12959	1.12842	1.12728
1170	1.13967	1.13831	1.13700	1.13572	1.13444	1.13321	1.13198	1.13078	1.12961	1.12844
1180	1.14093	1.13959	1.13826	1.13695	1.13566	1.13441	1.13318	1.13198	1.13078	1.12961
1190	1.14222	1.14085	1.13951	1.13818	1.13689	1.13564	1.13438	1.13316	1.13196	1.13078
1200	1.14348	1.14212	1.14075	1.13944	1.13813	1.13684	1.13559	1.13436	1.13313	1.13196
1210	1.14477	1.14338	1.14201	1.14067	1.13936	1.13805	1.13679	1.13553	1.13433	1.13313
1220	1.14604	1.14464	1.14325	1.14191	1.14059	1.13928	1.13799	1.13674	1.13551	1.13431
1230	1.14733	1.14591	1.14451	1.14314	1.14180	1.14049	1.13920	1.13794	1.13668	1.13546
1240	1.14860	1.14718	1.14578	1.14438	1.14304	1.14172	1.14041	1.13912	1.13786	1.13663
1250	1.14990	1.14844	1.14704	1.14564	1.14427	1.14293	1.14162	1.14033	1.13907	1.13781
1260	1.15117	1.14971	1.14829	1.14689	1.14551	1.14414	1.14283	1.14154	1.14025	1.13899
1270	1.15247	1.15099	1.14956	1.14813	1.14675	1.14538	1.14404	1.14272	1.14143	1.14017
1280	1.15377	1.15226	1.15080	1.14940	1.14797	1.14659	1.14525	1.14393	1.14262	1.14135
1290	1.15505	1.15353	1.15207	1.15064	1.14921	1.14784	1.14646	1.14512	1.14380	1.14251
1300	1.15633	1.15484	1.15335	1.15189	1.15046	1.14905	1.14768	1.14633	1.14501	1.14369
1310	1.15763	1.15611	1.15460	1.15313	1.15170	1.15027	1.14889	1.14755	1.14620	1.14488
1320	1.15891	1.15739	1.15587	1.15438	1.15295	1.15152	1.15011	1.14874	1.14739	1.14607
1330	1.16022	1.15867	1.15715	1.15566	1.15420	1.15274	1.15133	1.14995	1.14858	1.14726
1340	1.16150	1.15995	1.15840	1.15691	1.15542	1.15398	1.15255	1.15114	1.14977	1.14844
1350	1.16281	1.16123	1.15968	1.15816	1.15667	1.15521	1.15377	1.15236	1.15099	1.14964
1360	1.16413	1.16252	1.16097	1.15942	1.15792	1.15646	1.15499	1.15359	1.15218	1.15080
1370	1.16541	1.16380	1.16222	1.16070	1.15918	1.15768	1.15622	1.15478	1.15337	1.15199
1380	1.16673	1.16509	1.16351	1.16196	1.16043	1.15891	1.15744	1.15601	1.15457	1.15319
1390	1.16802	1.16638	1.16480	1.16322	1.16166	1.16014	1.15867	1.15723	1.15579	1.15438
1400	1.16934	1.16767	1.16606	1.16447	1.16292	1.16140	1.15990	1.15843	1.15699	1.15558
1410	1.17063	1.16899	1.16735	1.16574	1.16418	1.16265	1.16113	1.15966	1.15819	1.15678
1420	1.17195	1.17028	1.16864	1.16700	1.16544	1.16388	1.16236	1.16086	1.15942	1.15798
1430	1.17325	1.17157	1.16990	1.16829	1.16670	1.16512	1.16359	1.16209	1.16062	1.15915
1440	1.17457	1.17287	1.17120	1.16955	1.16797	1.16638	1.16482	1.16332	1.16182	1.16035
1450	1.17587	1.17417	1.17247	1.17082	1.16920	1.16762	1.16606	1.16453	1.16303	1.16156
1460	1.17720	1.17547	1.17376	1.17211	1.17047	1.16888	1.16729	1.16576	1.16426	1.16276
1470	1.17850	1.17677	1.17506	1.17338	1.17174	1.17012	1.16853	1.16700	1.16547	1.16397
1480	1.17983	1.17807	1.17636	1.17465	1.17301	1.17136	1.16977	1.16821	1.16668	1.16517
1490	1.18114	1.17937	1.17763	1.17593	1.17428	1.17263	1.17101	1.16945	1.16788	1.16638
1500	1.18247	1.18067	1.17894	1.17723	1.17555	1.17390	1.17225	1.17066	1.16910	1.16756

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	550	555	560	565	570	575	580	585	590	595
1500	1.18247	1.18067	1.17894	1.17723	1.17555	1.17390	1.17225	1.17066	1.16910	1.16756
1510	1.18378	1.18198	1.18024	1.17850	1.17679	1.17514	1.17349	1.17190	1.17033	1.16877
1520	1.18511	1.18331	1.18152	1.17978	1.17807	1.17639	1.17474	1.17314	1.17155	1.16998
1530	1.18642	1.18462	1.18282	1.18105	1.17934	1.17766	1.17598	1.17436	1.17276	1.17120
1540	1.18776	1.18593	1.18413	1.18236	1.18062	1.17891	1.17723	1.17560	1.17398	1.17241
1550	1.18910	1.18724	1.18541	1.18364	1.18190	1.18016	1.17847	1.17685	1.17522	1.17363
1560	1.19042	1.18856	1.18672	1.18492	1.18318	1.18144	1.17972	1.17807	1.17644	1.17484
1570	1.19176	1.18987	1.18804	1.18621	1.18443	1.18269	1.18100	1.17929	1.17766	1.17606
1580	1.19308	1.19119	1.18932	1.18749	1.18571	1.18397	1.18225	1.18054	1.17888	1.17725
1590	1.19443	1.19250	1.19064	1.18880	1.18700	1.18522	1.18350	1.18179	1.18010	1.17847
1600	1.19575	1.19382	1.19196	1.19009	1.18828	1.18651	1.18476	1.18304	1.18135	1.17970
1610	1.19710	1.19514	1.19325	1.19138	1.18957	1.18776	1.18601	1.18427	1.18258	1.18092
1620	1.19842	1.19647	1.19457	1.19270	1.19083	1.18902	1.18727	1.18552	1.18380	1.18214
1630	1.19978	1.19782	1.19589	1.19399	1.19212	1.19031	1.18853	1.18678	1.18503	1.18337
1640	1.20110	1.19914	1.19718	1.19528	1.19341	1.19157	1.18979	1.18801	1.18629	1.18460
1650	1.20246	1.20047	1.19851	1.19658	1.19470	1.19286	1.19105	1.18927	1.18752	1.18580
1660	1.20379	1.20179	1.19983	1.19790	1.19600	1.19413	1.19231	1.19050	1.18875	1.18703
1670	1.20515	1.20312	1.20113	1.19920	1.19729	1.19542	1.19358	1.19176	1.18998	1.18826
1680	1.20648	1.20445	1.20246	1.20049	1.19856	1.19669	1.19484	1.19303	1.19124	1.18949
1690	1.20784	1.20579	1.20376	1.20179	1.19986	1.19795	1.19611	1.19426	1.19248	1.19072
1700	1.20918	1.20712	1.20509	1.20310	1.20116	1.19925	1.19737	1.19553	1.19371	1.19196
1710	1.21054	1.20845	1.20642	1.20443	1.20246	1.20052	1.19864	1.19680	1.19495	1.19319
1720	1.21191	1.20979	1.20773	1.20573	1.20376	1.20182	1.19991	1.19804	1.19622	1.19440
1730	1.21325	1.21113	1.20907	1.20704	1.20506	1.20310	1.20119	1.19931	1.19746	1.19564
1740	1.21462	1.21250	1.21040	1.20834	1.20634	1.20437	1.20246	1.20055	1.19870	1.19688
1750	1.21596	1.21384	1.21171	1.20968	1.20765	1.20567	1.20373	1.20182	1.19994	1.19812
1760	1.21733	1.21518	1.21305	1.21099	1.20895	1.20695	1.20501	1.20310	1.20121	1.19936
1770	1.21868	1.21652	1.21440	1.21230	1.21026	1.20826	1.20629	1.20434	1.20246	1.20060
1780	1.22006	1.21787	1.21571	1.21361	1.21157	1.20954	1.20756	1.20562	1.20370	1.20185
1790	1.22141	1.21921	1.21705	1.21495	1.21286	1.21082	1.20884	1.20690	1.20495	1.20307
1800	1.22278	1.22056	1.21840	1.21627	1.21417	1.21213	1.21012	1.20815	1.20620	1.20431
1810	1.22414	1.22191	1.21972	1.21759	1.21549	1.21342	1.21141	1.20943	1.20748	1.20556
1820	1.22552	1.22326	1.22107	1.21891	1.21680	1.21473	1.21269	1.21068	1.20873	1.20681
1830	1.22687	1.22462	1.22242	1.22025	1.21812	1.21602	1.21398	1.21196	1.20999	1.20806
1840	1.22826	1.22597	1.22377	1.22157	1.21944	1.21731	1.21526	1.21325	1.21124	1.20932
1850	1.22965	1.22733	1.22510	1.22290	1.22073	1.21862	1.21655	1.21451	1.21252	1.21054
1860	1.23101	1.22871	1.22645	1.22422	1.22205	1.21992	1.21784	1.21579	1.21378	1.21180
1870	1.23237	1.23007	1.22778	1.22555	1.22338	1.22124	1.21913	1.21705	1.21504	1.21305
1880	1.23376	1.23143	1.22914	1.22690	1.22470	1.22253	1.22042	1.21834	1.21630	1.21431
1890	1.23515	1.23279	1.23050	1.22823	1.22603	1.22386	1.22172	1.21964	1.21759	1.21557
1900	1.23652	1.23416	1.23183	1.22956	1.22735	1.22515	1.22301	1.22090	1.21885	1.21683
1910	1.23791	1.23552	1.23319	1.23089	1.22866	1.22648	1.22431	1.22219	1.22011	1.21806
1920	1.23928	1.23689	1.23455	1.23225	1.22999	1.22778	1.22560	1.22349	1.22138	1.21933
1930	1.24068	1.23825	1.23589	1.23359	1.23132	1.22911	1.22690	1.22476	1.22267	1.22059
1940	1.24205	1.23962	1.23726	1.23492	1.23265	1.23041	1.22820	1.22606	1.22394	1.22186
1950	1.24345	1.24099	1.23863	1.23626	1.23399	1.23171	1.22950	1.22735	1.22521	1.22312
1960	1.24483	1.24237	1.23997	1.23763	1.23532	1.23302	1.23081	1.22863	1.22648	1.22439
1970	1.24624	1.24377	1.24134	1.23897	1.23663	1.23435	1.23211	1.22993	1.22775	1.22566
1980	1.24761	1.24515	1.24271	1.24031	1.23797	1.23566	1.23342	1.23120	1.22905	1.22693
1990	1.24902	1.24652	1.24406	1.24165	1.23931	1.23700	1.23472	1.23251	1.23033	1.22820
2000	1.25040	1.24790	1.24543	1.24303	1.24065	1.23831	1.23603	1.23381	1.23160	1.22945

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$r = 10^{(KH_{pg})/T_{mv}}$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	550	555	560	565	570	575	580	585	590	595
2000	1.25040	1.24790	1.24543	1.24303	1.24065	1.23831	1.23603	1.23381	1.23160	1.22945
2010	1.25181	1.24928	1.24681	1.24437	1.24200	1.23965	1.23734	1.23509	1.23288	1.23072
2020	1.25320	1.25066	1.24816	1.24572	1.24331	1.24097	1.23865	1.23640	1.23418	1.23200
2030	1.25461	1.25205	1.24954	1.24707	1.24466	1.24231	1.23997	1.23771	1.23546	1.23328
2040	1.25600	1.25343	1.25092	1.24845	1.24601	1.24363	1.24128	1.23900	1.23674	1.23455
2050	1.25742	1.25482	1.25228	1.24980	1.24735	1.24494	1.24260	1.24031	1.23803	1.23583
2060	1.25881	1.25620	1.25365	1.25115	1.24871	1.24629	1.24391	1.24160	1.23934	1.23709
2070	1.26023	1.25759	1.25502	1.25251	1.25006	1.24761	1.24523	1.24291	1.24062	1.23837
2080	1.26162	1.25901	1.25641	1.25387	1.25138	1.24894	1.24655	1.24423	1.24191	1.23965
2090	1.26305	1.26040	1.25780	1.25525	1.25274	1.25029	1.24787	1.24552	1.24320	1.24094
2100	1.26445	1.26180	1.25919	1.25661	1.25409	1.25164	1.24919	1.24684	1.24451	1.24222
2110	1.26587	1.26319	1.26055	1.25797	1.25545	1.25297	1.25052	1.24813	1.24580	1.24351
2120	1.26730	1.26459	1.26194	1.25933	1.25681	1.25430	1.25184	1.24945	1.24710	1.24477
2130	1.26870	1.26599	1.26334	1.26072	1.25817	1.25565	1.25317	1.25078	1.24839	1.24606
2140	1.27014	1.26739	1.26471	1.26209	1.25951	1.25698	1.25450	1.25207	1.24971	1.24735
2150	1.27154	1.26879	1.26611	1.26346	1.26087	1.25832	1.25583	1.25340	1.25101	1.24865
2160	1.27298	1.27019	1.26748	1.26482	1.26223	1.25968	1.25716	1.25473	1.25230	1.24994
2170	1.27438	1.27160	1.26888	1.26622	1.26360	1.26101	1.25849	1.25603	1.25360	1.25124
2180	1.27582	1.27300	1.27028	1.26759	1.26497	1.26238	1.25982	1.25736	1.25490	1.25254
2190	1.27723	1.27441	1.27169	1.26897	1.26631	1.26372	1.26119	1.25866	1.25623	1.25381
2200	1.27867	1.27585	1.27306	1.27034	1.26768	1.26509	1.26253	1.26000	1.25753	1.25510
2210	1.28009	1.27726	1.27447	1.27174	1.26905	1.26643	1.26386	1.26133	1.25884	1.25641
2220	1.28153	1.27867	1.27585	1.27312	1.27043	1.26777	1.26520	1.26264	1.26014	1.25771
2230	1.28295	1.28009	1.27726	1.27450	1.27180	1.26914	1.26654	1.26398	1.26148	1.25901
2240	1.28440	1.28150	1.27867	1.27588	1.27315	1.27049	1.26789	1.26529	1.26279	1.26032
2250	1.28582	1.28292	1.28006	1.27729	1.27453	1.27186	1.26923	1.26663	1.26409	1.26162
2260	1.28727	1.28434	1.28147	1.27867	1.27591	1.27321	1.27057	1.26797	1.26541	1.26290
2270	1.28869	1.28576	1.28289	1.28006	1.27729	1.27459	1.27192	1.26929	1.26675	1.26421
2280	1.29015	1.28718	1.28428	1.28145	1.27867	1.27594	1.27327	1.27063	1.26806	1.26552
2290	1.29158	1.28861	1.28570	1.28286	1.28006	1.27729	1.27462	1.27198	1.26938	1.26683
2300	1.29303	1.29003	1.28712	1.28425	1.28145	1.27867	1.27597	1.27330	1.27069	1.26815
2310	1.29449	1.29149	1.28852	1.28564	1.28280	1.28003	1.27732	1.27465	1.27204	1.26946
2320	1.29593	1.29292	1.28994	1.28703	1.28419	1.28142	1.27867	1.27600	1.27336	1.27078
2330	1.29739	1.29434	1.29137	1.28843	1.28558	1.28277	1.28003	1.27732	1.27468	1.27210
2340	1.29882	1.29578	1.29277	1.28985	1.28697	1.28416	1.28139	1.27867	1.27600	1.27339
2350	1.30029	1.29721	1.29420	1.29125	1.28837	1.28552	1.28274	1.28000	1.27732	1.27471
2360	1.30173	1.29864	1.29563	1.29265	1.28973	1.28689	1.28410	1.28136	1.27867	1.27603
2370	1.30320	1.30008	1.29703	1.29405	1.29113	1.28828	1.28546	1.28271	1.28000	1.27735
2380	1.30464	1.30152	1.29846	1.29548	1.29253	1.28964	1.28683	1.28404	1.28133	1.27867
2390	1.30611	1.30296	1.29990	1.29688	1.29393	1.29104	1.28819	1.28541	1.28266	1.28000
2400	1.30756	1.30440	1.30131	1.29828	1.29533	1.29241	1.28956	1.28677	1.28401	1.28130
2410	1.30903	1.30587	1.30275	1.29969	1.29673	1.29378	1.29092	1.28810	1.28535	1.28263
2420	1.31051	1.30731	1.30419	1.30113	1.29811	1.29518	1.29229	1.28947	1.28668	1.28396
2430	1.31196	1.30876	1.30560	1.30254	1.29951	1.29655	1.29366	1.29080	1.28801	1.28529
2440	1.31341	1.31021	1.30704	1.30395	1.30092	1.29796	1.29503	1.29217	1.28938	1.28662
2450	1.31489	1.31166	1.30849	1.30536	1.30233	1.29933	1.29640	1.29354	1.29071	1.28795
2460	1.31635	1.31311	1.30991	1.30677	1.30374	1.30074	1.29778	1.29488	1.29205	1.28929
2470	1.31783	1.31456	1.31135	1.30822	1.30515	1.30212	1.29915	1.29625	1.29339	1.29060
2480	1.31929	1.31601	1.31280	1.30963	1.30653	1.30350	1.30053	1.29763	1.29476	1.29193
2490	1.32078	1.31747	1.31423	1.31105	1.30795	1.30491	1.30191	1.29897	1.29610	1.29327
2500	1.32227	1.31892	1.31568	1.31250	1.30936	1.30629	1.30329	1.30035	1.29745	1.29461

TABLE 7.5 (CONTINUED)

Ratio of Sea-Level Pressure to Station Pressure as a Function of Geopotential of Station and Mean Virtual Temperature of the Air Column

$$r = 10^{(KH_{pg})/T_{mv}}$$

Geopotential of station H_{pg} (gpm)	Mean virtual temperature of air column (T_{mv}, in ° Rankine)									
	550	555	560	565	570	575	580	585	590	595
2500	1.32227	1.31892	1.31568	1.31250	1.30936	1.30629	1.30329	1.30035	1.29745	1.29461
2510	1.32373	1.32038	1.31713	1.31392	1.31078	1.30768	1.30467	1.30170	1.29879	1.29596
2520	1.32522	1.32184	1.31856	1.31535	1.31220	1.30909	1.30605	1.30308	1.30014	1.29730
2530	1.32669	1.32334	1.32002	1.31677	1.31359	1.31048	1.30743	1.30446	1.30152	1.29864
2540	1.32819	1.32480	1.32148	1.31820	1.31501	1.31190	1.30882	1.30581	1.30287	1.29996
2550	1.32966	1.32626	1.32291	1.31965	1.31644	1.31329	1.31021	1.30719	1.30422	1.30131
2560	1.33116	1.32773	1.32437	1.32108	1.31786	1.31468	1.31160	1.30855	1.30557	1.30266
2570	1.33263	1.32920	1.32581	1.32251	1.31929	1.31610	1.31299	1.30994	1.30695	1.30401
2580	1.33414	1.33067	1.32727	1.32395	1.32072	1.31750	1.31438	1.31132	1.30831	1.30536
2590	1.33561	1.33214	1.32874	1.32541	1.32212	1.31892	1.31577	1.31268	1.30966	1.30671
2600	1.33712	1.33361	1.33021	1.32684	1.32355	1.32032	1.31716	1.31407	1.31102	1.30807
2610	1.33860	1.33509	1.33165	1.32828	1.32498	1.32175	1.31856	1.31547	1.31241	1.30939
2620	1.34011	1.33656	1.33312	1.32972	1.32642	1.32315	1.31996	1.31683	1.31377	1.31075
2630	1.34159	1.33804	1.33457	1.33116	1.32785	1.32459	1.32136	1.31823	1.31513	1.31211
2640	1.34311	1.33952	1.33604	1.33263	1.32929	1.32599	1.32276	1.31959	1.31650	1.31347
2650	1.34459	1.34103	1.33752	1.33407	1.33070	1.32743	1.32416	1.32099	1.31789	1.31483
2660	1.34611	1.34252	1.33897	1.33552	1.33214	1.32883	1.32556	1.32239	1.31926	1.31619
2670	1.34760	1.34400	1.34045	1.33700	1.33358	1.33024	1.32697	1.32376	1.32063	1.31756
2680	1.34912	1.34549	1.34193	1.33844	1.33503	1.33168	1.32837	1.32517	1.32200	1.31889
2690	1.35064	1.34698	1.34341	1.33989	1.33647	1.33309	1.32978	1.32657	1.32337	1.32026
2700	1.35213	1.34847	1.34487	1.34134	1.33789	1.33454	1.33119	1.32794	1.32477	1.32163
2710	1.35366	1.34996	1.34636	1.34280	1.33934	1.33595	1.33260	1.32935	1.32614	1.32300
2720	1.35516	1.35145	1.34785	1.34428	1.34079	1.33737	1.33401	1.33073	1.32752	1.32437
2730	1.35669	1.35294	1.34930	1.34574	1.34224	1.33881	1.33543	1.33214	1.32889	1.32575
2740	1.35819	1.35444	1.35080	1.34719	1.34369	1.34023	1.33684	1.33355	1.33030	1.32712
2750	1.35972	1.35594	1.35229	1.34865	1.34515	1.34168	1.33826	1.33493	1.33168	1.32846
2760	1.36123	1.35747	1.35375	1.35014	1.34657	1.34311	1.33968	1.33635	1.33306	1.32984
2770	1.36276	1.35897	1.35525	1.35161	1.34803	1.34456	1.34110	1.33777	1.33444	1.33122
2780	1.36427	1.36047	1.35672	1.35307	1.34949	1.34598	1.34252	1.33915	1.33586	1.33260
2790	1.36581	1.36198	1.35822	1.35453	1.35095	1.34741	1.34394	1.34057	1.33724	1.33398
2800	1.36732	1.36348	1.35972	1.35603	1.35242	1.34887	1.34536	1.34196	1.33863	1.33537
2810	1.36886	1.36499	1.36119	1.35750	1.35388	1.35030	1.34679	1.34338	1.34002	1.33675
2820	1.37038	1.36650	1.36270	1.35897	1.35531	1.35173	1.34825	1.34481	1.34144	1.33810
2830	1.37192	1.36801	1.36421	1.36044	1.35678	1.35319	1.34968	1.34620	1.34283	1.33949
2840	1.37347	1.36953	1.36568	1.36195	1.35825	1.35463	1.35111	1.34763	1.34422	1.34088
2850	1.37499	1.37104	1.36719	1.36342	1.35972	1.35609	1.35254	1.34906	1.34561	1.34227
2860	1.37654	1.37256	1.36871	1.36490	1.36119	1.35753	1.35397	1.35045	1.34701	1.34366
2870	1.37807	1.37411	1.37019	1.36638	1.36264	1.35900	1.35541	1.35189	1.34843	1.34505
2880	1.37962	1.37562	1.37170	1.36789	1.36411	1.36044	1.35684	1.35329	1.34983	1.34645
2890	1.38115	1.37715	1.37322	1.36937	1.36559	1.36191	1.35828	1.35472	1.35123	1.34781
2900	1.38271	1.37867	1.37471	1.37085	1.36707	1.36336	1.35972	1.35616	1.35263	1.34921
2910	1.38424	1.38019	1.37623	1.37233	1.36855	1.36480	1.36116	1.35756	1.35407	1.35061
2920	1.38580	1.38172	1.37772	1.37382	1.37003	1.36628	1.36261	1.35900	1.35547	1.35201
2930	1.38733	1.38325	1.37924	1.37534	1.37148	1.36773	1.36405	1.36044	1.35688	1.35341
2940	1.38890	1.38478	1.38077	1.37683	1.37297	1.36921	1.36549	1.36185	1.35828	1.35482
2950	1.39043	1.38631	1.38229	1.37832	1.37445	1.37066	1.36694	1.36330	1.35972	1.35622
2960	1.39200	1.38784	1.38379	1.37981	1.37594	1.37211	1.36839	1.36471	1.36113	1.35759
2970	1.39354	1.38938	1.38532	1.38134	1.37743	1.37360	1.36984	1.36616	1.36254	1.35900
2980	1.39511	1.39095	1.38685	1.38283	1.37892	1.37505	1.37129	1.36760	1.36395	1.36041
2990	1.39666	1.39248	1.38835	1.38433	1.38038	1.37654	1.37275	1.36902	1.36540	1.36182
3000	1.39823	1.39402	1.38989	1.38583	1.38188	1.37800	1.37420	1.37047	1.36682	1.36323

TABLE 7.6.1

Auxiliary Data Used in Finding "Correction to Obtain Virtual Temperature." Tabular Values Represent Ratio e/P (See Table 7.6.2)

Vapor pressure (*e*)		Dew point °F	Pressure (millibars)							
			575.7	609.6	643.4	677.3	711.1	745.0	778.9	812.7
			Pressure (inches of mercury)							
mb.	in. Hg.		17	18	19	20	21	22	23	24
0.1891	0.005584	−40	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002	0.0002
.2003	.005915	−39	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002
.2121	.006263	−38	.0004	.0003	.0003	.0003	.0003	.0003	.0003	.0003
.2245	.006630	−37	.0004	.0004	.0003	.0003	.0003	.0003	.0003	.0003
.2376	.007016	−36	.0004	.0004	.0004	.0004	.0003	.0003	.0003	.0003
.2514	.007424	−35	.0004	.0004	.0004	.0004	.0004	.0003	.0003	.0003
.2658	.007849	−34	.0005	.0004	.0004	.0004	.0004	.0004	.0003	.0003
.2810	.008298	−33	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0003
.2970	.008770	−32	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004
.3139	.009270	−31	.0005	.0005	.0005	.0005	.0004	.0004	.0004	.0004
.3315	.009789	−30	.0006	.0005	.0005	.0005	.0005	.0004	.0004	.0004
.3501	.01034	−29	.0006	.0006	.0005	.0005	.0005	.0005	.0004	.0004
.3696	.01091	−28	.0006	.0006	.0006	.0005	.0005	.0005	.0005	.0005
.3901	.01152	−27	.0007	.0006	.0006	.0006	.0005	.0005	.0005	.0005
.4116	.01215	−26	.0007	.0007	.0006	.0006	.0006	.0006	.0005	.0005
.4342	.01282	−25	.0008	.0007	.0007	.0006	.0006	.0006	.0006	.0005
.4579	.01352	−24	.0008	.0008	.0007	.0007	.0006	.0006	.0006	.0006
.4827	.01425	−23	.0008	.0008	.0007	.0007	.0007	.0006	.0006	.0006
.5088	.01502	−22	.0009	.0008	.0008	.0008	.0007	.0007	.0007	.0006
.5361	.01583	−21	.0009	.0009	.0008	.0008	.0008	.0007	.0007	.0007
.5647	.01668	−20	.0010	.0009	.0009	.0008	.0008	.0008	.0007	.0007
.5948	.01756	−19	.0010	.0010	.0009	.0009	.0008	.0008	.0008	.0007
.6262	.01849	−18	.0011	.0010	.0010	.0009	.0009	.0008	.0008	.0008
.6591	.01946	−17	.0011	.0011	.0010	.0010	.0009	.0009	.0008	.0008
.6936	.02048	−16	.0012	.0011	.0011	.0010	.0010	.0009	.0009	.0009
.7297	.02155	−15	.0013	.0012	.0011	.0011	.0010	.0010	.0009	.0009
.7674	.02266	−14	.0013	.0013	.0012	.0011	.0011	.0010	.0010	.0009
.8070	.02383	−13	.0014	.0013	.0013	.0012	.0011	.0011	.0010	.0010
.8483	.02505	−12	.0015	.0014	.0013	.0013	.0012	.0011	.0011	.0010
.8915	.02633	−11	.0015	.0015	.0014	.0013	.0013	.0012	.0011	.0011
0.9368	0.02766	−10	.0016	.0015	.0015	.0014	.0013	.0013	.0012	.0012
.9840	.02906	− 9	.0017	.0016	.0015	.0015	.0014	.0013	.0013	.0012
1.0334	.03052	− 8	.0018	.0017	.0016	.0015	.0015	.0014	.0013	.0013
1.0850	.03204	− 7	.0019	.0018	.0017	.0016	.0015	.0015	.0014	.0013
1.1389	.03363	− 6	.0020	.0019	.0018	.0017	.0016	.0015	.0015	.0014
1.1952	.03529	− 5	.0021	.0020	.0019	.0018	.0017	.0016	.0015	.0015
1.2540	.03703	− 4	.0022	.0021	.0019	.0019	.0018	.0017	.0016	.0015
1.3154	.03884	− 3	.0023	.0022	.0020	.0019	.0018	.0018	.0017	.0016
1.3794	.04073	− 2	.0024	.0023	.0021	.0020	.0019	.0019	.0018	.0017
1.4462	.04271	− 1	.0025	.0024	.0022	.0021	.0020	.0019	.0019	.0018

TABLE 7.6.1 (CONTINUED)

Auxiliary Data Used in Finding "Correction to Obtain Virtual Temperature." Tabular Values Represent Ratio e/P (See Table 7.6.2)

			Pressure (millibars)							
			575.7	609.6	643.4	677.3	711.1	745.0	778.9	812.7
Vapor pressure (e)		Dew point °F	Pressure (inches of mercury)							
mb.	in. Hg.		17	18	19	20	21	22	23	24
1.5160	.04477	0	.0026	.0025	.0024	.0022	.0021	.0020	.0019	.0019
1.5887	.04691	1	.0028	.0026	.0025	.0023	.0022	.0021	.0020	.0020
1.6645	.04915	2	.0029	.0027	.0026	.0025	.0023	.0022	.0021	.0020
1.7435	.05149	3	.0030	.0029	.0027	.0026	.0025	.0023	.0022	.0021
1.8259	.05392	4	.0032	.0030	.0028	.0027	.0026	.0025	.0023	.0022
1.9118	.05646	5	.0033	.0031	.0030	.0028	.0027	.0026	.0025	.0024
2.0012	.05910	6	.0035	.0033	.0031	.0030	.0028	.0027	.0026	.0025
2.0944	.06185	7	.0036	.0034	.0033	.0031	.0029	.0028	.0027	.0026
2.1914	.06471	8	.0038	.0036	.0034	.0032	.0031	.0029	.0028	.0027
2.2924	.06769	9	.0040	.0038	.0036	.0034	.0032	.0031	.0029	.0028
2.3976	.07080	10	.0042	.0039	.0037	.0035	.0034	.0032	.0031	.0030
2.5071	.07403	11	.0044	.0041	.0039	.0037	.0035	.0034	.0032	.0031
2.6210	.07740	12	.0046	.0043	.0041	.0039	.0037	.0035	.0034	.0032
2.7394	.08089	13	.0048	.0045	.0043	.0040	.0039	.0037	.0035	.0034
2.8627	.08454	14	.0050	.0047	.0044	.0042	.0040	.0038	.0037	.0035
2.9909	.08832	15	.0052	.0049	.0046	.0044	.0042	.0040	.0038	.0037
3.1241	.09226	16	.0054	.0051	.0049	.0046	.0044	.0042	.0040	.0038
3.2626	.09634	17	.0057	.0054	.0051	.0048	.0046	.0044	.0042	.0040
3.4066	.10060	18	.0059	.0056	.0053	.0050	.0048	.0046	.0044	.0042
3.5562	.10501	19	.0062	.0058	.0055	.0053	.0050	.0048	.0046	.0044
3.7116	.10960	20	.0064	.0061	.0058	.0055	.0052	.0050	.0048	.0046
3.8731	.11437	21	.0067	.0064	.0060	.0057	.0054	.0052	.0050	.0048
4.0408	.11933	22	.0070	.0066	.0063	.0060	.0057	.0054	.0052	.0050
4.2148	.12446	23	.0073	.0069	.0066	.0062	.0059	.0057	.0054	.0052
4.3956	.12980	24	.0076	.0072	.0068	.0065	.0062	.0059	.0056	.0054
4.5832	.13534	25	.0080	.0075	.0071	.0068	.0064	.0062	.0059	.0056
4.7778	.14109	26	.0083	.0078	.0074	.0071	.0067	.0064	.0061	.0059
4.9798	.14705	27	.0086	.0082	.0077	.0074	.0070	.0067	.0064	.0061
5.1893	.15324	28	.0090	.0085	.0081	.0077	.0073	.0070	.0067	.0064
5.4066	.15966	29	.0094	.0089	.0084	.0080	.0076	.0073	.0069	.0067
5.6320	.16631	30	.0098	.0092	.0088	.0083	.0079	.0076	.0072	.0069
5.8656	.17321	31	.0102	.0096	.0091	.0087	.0082	.0079	.0075	.0072
6.1078	.18036	32	.0106	.0100	.0095	.0090	.0086	.0082	.0078	.0075
6.3588	.18778	33	.0110	.0104	.0099	.0094	.0089	.0085	.0082	.0078
6.6189	.19546	34	.0115	.0109	.0103	.0098	.0093	.0089	.0085	.0081
6.8884	.20342	35	.0120	.0113	.0107	.0102	.0097	.0092	.0088	.0085
7.1676	.21166	36	.0124	.0118	.0111	.0106	.0101	.0096	.0092	.0088
7.4567	.22020	37	.0130	.0122	.0116	.0110	.0105	.0100	.0096	.0092
7.7562	.22904	38	.0135	.0127	.0121	.0115	.0109	.0104	.0100	.0095
8.0662	.23819	39	.0140	.0132	.0125	.0119	.0113	.0108	.0104	.0099
8.3871	.24767	40	.0146	.0138	.0130	.0124	.0118	.0113	.0108	.0103
8.7192	.25748	41	.0151	.0143	.0136	.0129	.0123	.0117	.0112	.0107
9.0629	.26763	42	.0157	.0149	.0141	.0134	.0127	.0122	.0116	.0112
9.4186	.27813	43	.0164	.0155	.0146	.0139	.0132	.0126	.0121	.0116
9.7864	.28899	44	.0170	.0161	.0152	.0144	.0138	.0131	.0126	.0120
10.167	.30023	45	.0177	.0167	.0158	.0150	.0143	.0136	.0131	.0125
10.560	.31185	46	.0183	.0173	.0164	.0156	.0149	.0142	.0136	.0130
10.967	.32387	47	.0191	.0180	.0170	.0162	.0154	.0147	.0141	.0135
11.388	.33629	48	.0198	.0187	.0177	.0168	.0160	.0153	.0146	.0140
11.823	.34913	49	.0205	.0194	.0184	.0175	.0166	.0159	.0152	.0145

TABLE 7.6.1 (CONTINUED)

Auxiliary Data Used in Finding "Correction to Obtain Virtual Temperature." Tabular Values Represent Ratio e/P (See Table 7.6.2)

			Pressure (millibars)							
			575.7	609.6	643.4	677.3	711.1	745.0	778.9	812.7
Vapor pressure (*e*)		Dew point °F	Pressure (inches of mercury)							
mb.	in. Hg.		17	18	19	20	21	22	23	24
12.272	.36240	50	.0213	.0201	.0191	.0181	.0173	.0165	.0158	.0151
12.737	.37611	51	.0221	.0209	.0198	.0188	.0179	.0171	.0164	.0157
13.216	.39028	52	.0230	.0217	.0205	.0195	.0186	.0177	.0170	.0163
13.712	.40492	53	.0238	.0225	.0213	.0202	.0193	.0184	.0176	.0169
14.224	.42003	54	.0247	.0233	.0221	.0210	.0200	.0191	.0183	.0175
14.752	.43564	55	.0256	.0242	.0229	.0218	.0207	.0198	.0189	.0182
15.298	.45176	56	.0266	.0251	.0238	.0226	.0215	.0205	.0196	.0188
15.862	.46840	57	.0276	.0260	.0247	.0234	.0223	.0213	.0204	.0195
16.444	.48558	58	.0286	.0270	.0256	.0243	.0231	.0221	.0211	.0202
17.044	.50330	59	.0296	.0280	.0265	.0252	.0240	.0229	.0219	.0210
17.663	.52160	60	.0307	.0290	.0275	.0261	.0248	.0237	.0227	.0217
18.302	.54047	61	.0318	.0300	.0284	.0270	.0257	.0246	.0235	.0225
18.962	.55994	62	.0329	.0311	.0295	.0280	.0267	.0254	.0243	.0233
19.642	.58002	63	.0341	.0322	.0305	.0290	.0276	.0264	.0252	.0242
20.343	.60073	64	.0353	.0334	.0316	.0300	.0286	.0273	.0261	.0250
21.066	.62209	65	.0366	.0346	.0327	.0311	.0296	.0283	.0270	.0259
21.812	.64411	66	.0379	.0358	.0339	.0322	.0307	.0293	.0280	.0268
22.581	.66681	67	.0392	.0370	.0351	.0333	.0318	.0303	.0290	.0278
23.373	.69021	68	.0406	.0383	.0363	.0345	.0329	.0314	.0300	.0288
24.189	.71432	69	.0420	.0397	.0376	.0357	.0340	.0325	.0311	.0298
25.031	.73916	70	.0435	.0411	.0389	.0370	.0352	.0336	.0321	.0308
25.898	.76476	71	.0450	.0425	.0402	.0382	.0364	.0348	.0333	.0319
26.791	.79113	72	.0465	.0440	.0416	.0396	.0377	.0360	.0344	.0330
27.710	.81829	73	.0481	.0455	.0431	.0409	.0390	.0372	.0356	.0341
28.658	.84626	74	.0498	.0470	.0445	.0423	.0403	.0385	.0368	.0353
29.633	.87506	75	.0515	.0486	.0461	.0438	.0417	.0398	.0380	.0365
30.637	.90472	76	.0532	.0503	.0476	.0452	.0431	.0411	.0393	.0377
31.671	.93524	77	.0550	.0520	.0492	.0468	.0445	.0425	.0407	.0390
32.735	.96666	78	.0569	.0537	.0509	.0483	.0460	.0439	.0420	.0403
33.830	.99900	79	.0588	.0555	.0526	.0500	.0476	.0454	.0434	.0416
34.957	1.0323	80	.0607	.0574	.0543	.0516	.0492	.0469	.0449	.0430
36.116	1.0665	81	.0627	.0593	.0561	.0533	.0508	.0485	.0464	.0444
37.309	1.1017	82	.0648	.0612	.0580	.0551	.0525	.0501	.0479	.0459
38.536	1.1380	83	.0669	.0632	.0599	.0569	.0542	.0517	.0495	.0474
39.798	1.1752	84	.0691	.0653	.0619	.0588	.0560	.0534	.0511	.0490
41.096	1.2136	85	.0714	.0674	.0639	.0607	.0578	.0552	.0528	.0506
42.430	1.2530	86	.0737	.0696	.0659	.0627	.0597	.0569	.0545	.0522
43.802	1.2935	87	.0761	.0719	.0681	.0647	.0616	.0588	.0562	.0539
45.213	1.3351	88	.0785	.0742	.0703	.0668	.0636	.0607	.0581	.0556
46.662	1.3779	89	.0810	.0766	.0725	.0689	.0656	.0626	.0599	.0574
48.152	1.4219	90	.0836	.0790	.0748	.0711	.0677	.0646	.0618	.0593
49.683	1.4671	91	.0863	.0815	.0772	.0734	.0699	.0667	.0638	.0611
51.256	1.5136	92	.0890	.0841	.0797	.0757	.0721	.0688	.0658	.0631
52.872	1.5613	93	.0918	.0867	.0822	.0781	.0743	.0710	.0679	.0651
54.532	1.6103	94	.0947	.0895	.0848	.0805	.0767	.0732	.0700	.0671
56.236	1.6607	95	.0977	.0923	.0874	.0830	.0791	.0755	.0722	.0692

TABLE 7.6.1 (CONTINUED)

Auxiliary Data Used in Finding "Correction to Obtain Virtual Temperature." Tabular Values Represent Ratio e/P (See Table 7.6.2)

Vapor pressure (*e*)		Dew point °F	Pressure (millibars)							
			812.7	846.6	880.5	914.3	948.2	982.1	1015.9	1049.8
			Pressure (inches of mercury)							
mb.	in. Hg.		24	25	26	27	28	29	30	31
0.1891	0.005584	−40	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
.2003	.005915	−39	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002
.2121	.006263	−38	.0003	.0003	.0002	.0002	.0002	.0002	.0002	.0002
.2245	.006630	−37	.0003	.0003	.0003	.0002	.0002	.0002	.0002	.0002
.2376	.007016	−36	.0003	.0003	.0003	.0003	.0003	.0002	.0002	.0002
.2514	.007424	−35	.0003	.0003	.0003	.0003	.0003	.0003	.0002	.0002
.2658	.007849	−34	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003
.2810	.008298	−33	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003
.2970	.008770	−32	.0004	.0004	.0003	.0003	.0003	.0003	.0003	.0003
.3139	.009270	−31	.0004	.0004	.0004	.0003	.0003	.0003	.0003	.0003
.3315	.009789	−30	.0004	.0004	.0004	.0004	.0003	.0003	.0003	.0003
.3501	.01034	−29	.0004	.0004	.0004	.0004	.0004	.0004	.0003	.0003
.3696	.01091	−28	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0004
.3901	.01152	−27	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004
.4116	.01215	−26	.0005	.0005	.0005	.0005	.0004	.0004	.0004	.0004
.4342	.01282	−25	.0005	.0005	.0005	.0005	.0005	.0004	.0004	.0004
.4579	.01352	−24	.0006	.0005	.0005	.0005	.0005	.0005	.0005	.0004
.4827	.01425	−23	.0006	.0006	.0005	.0005	.0005	.0005	.0005	.0005
.5088	.01502	−22	.0006	.0006	.0006	.0006	.0005	.0005	.0005	.0005
.5361	.01583	−21	.0007	.0006	.0006	.0006	.0006	.0005	.0005	.0005
.5647	.01668	−20	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005
.5948	.01756	−19	.0007	.0007	.0007	.0007	.0006	.0006	.0006	.0006
.6262	.01849	−18	.0008	.0007	.0007	.0007	.0007	.0006	.0006	.0006
.6591	.01946	−17	.0008	.0008	.0007	.0007	.0007	.0007	.0006	.0006
.6936	.02048	−16	.0009	.0008	.0008	.0008	.0007	.0007	.0007	.0007
.7297	.02155	−15	.0009	.0009	.0008	.0008	.0008	.0007	.0007	.0007
.7674	.02266	−14	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007
.8070	.02383	−13	.0010	.0010	.0009	.0009	.0009	.0008	.0008	.0008
.8483	.02505	−12	.0010	.0010	.0010	.0009	.0009	.0009	.0008	.0008
.8915	.02633	−11	.0011	.0011	.0010	.0010	.0009	.0009	.0009	.0008
.9368	.02766	−10	.0012	.0011	.0011	.0010	.0010	.0010	.0009	.0009
.9840	.02906	− 9	.0012	.0012	.0011	.0011	.0010	.0010	.0010	.0009
1.0334	.03052	− 8	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
1.0850	.03204	− 7	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010
1.1389	.03363	− 6	.0014	.0013	.0013	.0012	.0012	.0012	.0011	.0011
1.1952	.03529	− 5	.0015	.0014	.0014	.0013	.0013	.0012	.0012	.0011
1.2540	.03703	− 4	.0015	.0015	.0014	.0014	.0013	.0013	.0012	.0012
1.3154	.03884	− 3	.0016	.0016	.0015	.0014	.0014	.0013	.0013	.0013
1.3794	.04073	− 2	.0017	.0016	.0016	.0015	.0015	.0014	.0014	.0013
1.4462	.04271	− 1	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014

TABLE 7.6.1 (CONTINUED)

Auxiliary Data Used in Finding "Correction to Obtain Virtual Temperature." Tabular Values Represent Ratio e/P (See Table 7.6.2)

Vapor pressure (*e*)		Dew point °F	Pressure (millibars)							
			812.7	846.6	880.5	914.3	948.2	982.1	1015.9	1049.8
			Pressure (inches of mercury)							
mb.	in. Hg.		24	25	26	27	28	29	30	31
1.5160	.04477	0	.0019	.0018	.0017	.0017	.0016	.0015	.0015	.0014
1.5887	.04691	1	.0020	.0019	.0018	.0017	.0017	.0016	.0016	.0015
1.6645	.04915	2	.0020	.0020	.0019	.0018	.0018	.0017	.0016	.0016
1.7435	.05149	3	.0021	.0021	.0020	.0019	.0018	.0018	.0017	.0017
1.8259	.05392	4	.0022	.0022	.0021	.0020	.0019	.0019	.0018	.0017
1.9118	.05646	5	.0024	.0023	.0022	.0021	.0020	.0019	.0019	.0018
2.0012	.05910	6	.0025	.0024	.0023	.0022	.0021	.0020	.0020	.0019
2.0944	.06185	7	.0026	.0025	.0024	.0023	.0022	.0021	.0021	.0020
2.1914	.06471	8	.0027	.0026	.0025	.0024	.0023	.0022	.0022	.0021
2.2924	.06769	9	.0028	.0027	.0026	.0025	.0024	.0023	.0023	.0022
2.3976	.07080	10	.0030	.0028	.0027	.0026	.0025	.0024	.0024	.0023
2.5071	.07403	11	.0031	.0030	.0028	.0027	.0026	.0026	.0025	.0024
2.6210	.07740	12	.0032	.0031	.0030	.0029	.0028	.0027	.0026	.0025
2.7394	.08089	13	.0034	.0032	.0031	.0030	.0029	.0028	.0027	.0026
2.8627	.08454	14	.0035	.0034	.0033	.0031	.0030	.0029	.0028	.0027
2.9909	.08832	15	.0037	.0035	.0034	.0033	.0032	.0030	.0029	.0028
3.1241	.09226	16	.0038	.0037	.0035	.0034	.0033	.0032	.0031	.0030
3.2626	.09634	17	.0040	.0039	.0037	.0036	.0034	.0033	.0032	.0031
3.4066	.10060	18	.0042	.0040	.0039	.0037	.0036	.0035	.0034	.0032
3.5562	.10501	19	.0044	.0042	.0040	.0039	.0037	.0036	.0035	.0034
3.7116	.10960	20	.0046	.0044	.0042	.0041	.0039	.0038	.0037	.0035
3.8731	.11437	21	.0048	.0046	.0044	.0042	.0041	.0039	.0038	.0037
4.0408	.11933	22	.0050	.0048	.0046	.0044	.0043	.0041	.0040	.0038
4.2148	.12446	23	.0052	.0050	.0048	.0046	.0044	.0043	.0041	.0040
4.3956	.12980	24	.0054	.0052	.0050	.0048	.0046	.0045	.0043	.0042
4.5832	.13534	25	.0056	.0054	.0052	.0050	.0048	.0047	.0045	.0044
4.7778	.14109	26	.0059	.0056	.0054	.0052	.0050	.0049	.0047	.0046
4.9798	.14705	27	.0061	.0059	.0057	.0054	.0053	.0051	.0049	.0047
5.1893	.15324	28	.0064	.0061	.0059	.0057	.0055	.0053	.0051	.0049
5.4066	.15966	29	.0067	.0064	.0061	.0059	.0057	.0055	.0053	.0052
5.6320	.16631	30	.0069	.0067	.0064	.0062	.0059	.0057	.0055	.0054
5.8656	.17321	31	.0072	.0069	.0067	.0064	.0062	.0060	.0058	.0056
6.1078	.18036	32	.0075	.0072	.0069	.0067	.0064	.0062	.0060	.0058
6.3588	.18778	33	.0078	.0075	.0072	.0070	.0067	.0065	.0063	.0061
6.6189	.19546	34	.0081	.0078	.0075	.0072	.0070	.0067	.0065	.0063
6.8884	.20342	35	.0085	.0081	.0078	.0075	.0073	.0070	.0068	.0066
7.1676	.21166	36	.0088	.0085	.0081	.0078	.0076	.0073	.0071	.0068
7.4567	.22020	37	.0092	.0088	.0085	.0082	.0079	.0076	.0073	.0071
7.7562	.22904	38	.0095	.0092	.0088	.0085	.0082	.0079	.0076	.0074
8.0662	.23819	39	.0099	.0095	.0092	.0088	.0085	.0082	.0079	.0077
8.3871	.24767	40	.0103	.0099	.0095	.0092	.0088	.0085	.0083	.0080
8.7192	.25748	41	.0107	.0103	.0099	.0095	.0092	.0089	.0086	.0083
9.0629	.26763	42	.0112	.0107	.0103	.0099	.0096	.0092	.0089	.0086
9.4186	.27813	43	.0116	.0111	.0107	.0103	.0099	.0096	.0093	.0090
9.7864	.28899	44	.0120	.0116	.0111	.0107	.0103	.0100	.0096	.0093
10.167	.30023	45	.0125	.0120	.0115	.0111	.0107	.0104	.0100	.0097
10.560	.31185	46	.0130	.0125	.0120	.0116	.0111	.0108	.0104	.0101
10.967	.32387	47	.0135	.0130	.0125	.0120	.0116	.0112	.0108	.0104
11.388	.33629	48	.0140	.0135	.0129	.0125	.0120	.0116	.0112	.0108
11.823	.34913	49	.0145	.0140	.0134	.0129	.0125	.0120	.0116	.0113

TABLE 7.6.1 (CONTINUED)

Auxiliary Data Used in Finding "Correction to Obtain Virtual Temperature." Tabular Values Represent Ratio e/P (See Table 7.6.2)

Vapor pressure (*e*)		Dew point °F	Pressure (millibars)							
			812.7	846.6	880.5	914.3	948.2	982.1	1015.9	1049.8
			Pressure (inches of mercury)							
mb.	in. Hg.		24	25	26	27	28	29	30	31
12.272	.36240	50	.0151	.0145	.0139	.0134	.0129	.0125	.0121	.0117
12.737	.37611	51	.0157	.0150	.0145	.0139	.0134	.0130	.0125	.0121
13.216	.39028	52	.0163	.0156	.0150	.0145	.0139	.0135	.0130	.0126
13.712	.40492	53	.0169	.0162	.0156	.0150	.0145	.0140	.0135	.0131
14.224	.42003	54	.0175	.0168	.0162	.0156	.0150	.0145	.0140	.0136
14.752	.43564	55	.0182	.0174	.0168	.0161	.0156	.0150	.0145	.0141
15.298	.45176	56	.0188	.0181	.0174	.0167	.0161	.0156	.0151	.0146
15.862	.46840	57	.0195	.0187	.0180	.0173	.0167	.0162	.0156	.0151
16.444	.48558	58	.0202	.0194	.0187	.0180	.0173	.0167	.0162	.0157
17.044	.50330	59	.0210	.0201	.0194	.0186	.0180	.0174	.0168	.0162
17.663	.52160	60	.0217	.0209	.0201	.0193	.0186	.0180	.0174	.0168
18.302	.54047	61	.0225	.0216	.0208	.0200	.0193	.0186	.0180	.0174
18.962	.55994	62	.0233	.0224	.0215	.0207	.0200	.0193	.0187	.0181
19.642	.58002	63	.0242	.0232	.0223	.0215	.0207	.0200	.0193	.0187
20.343	.60073	64	.0250	.0240	.0231	.0223	.0215	.0207	.0200	.0194
21.066	.62209	65	.0259	.0249	.0239	.0230	.0222	.0214	.0207	.0201
21.812	.64411	66	.0268	.0258	.0248	.0239	.0230	.0222	.0215	.0208
22.581	.66681	67	.0278	.0267	.0256	.0247	.0238	.0230	.0222	.0215
23.373	.69021	68	.0288	.0276	.0265	.0256	.0246	.0238	.0230	.0223
24.189	.71432	69	.0298	.0286	.0275	.0265	.0255	.0246	.0238	.0230
25.031	.73916	70	.0308	.0296	.0284	.0274	.0264	.0255	.0246	.0238
25.898	.76476	71	.0319	.0306	.0294	.0283	.0273	.0264	.0255	.0247
26.791	.79113	72	.0330	.0316	.0304	.0293	.0283	.0273	.0264	.0255
27.710	.81829	73	.0341	.0327	.0315	.0303	.0292	.0282	.0273	.0264
28.658	.84626	74	.0353	.0339	.0325	.0313	.0302	.0292	.0282	.0273
29.633	.87506	75	.0365	.0350	.0337	.0324	.0312	.0302	.0292	.0282
30.637	.90472	76	.0377	.0362	.0348	.0335	.0323	.0312	.0302	.0292
31.671	.93524	77	.0390	.0374	.0360	.0346	.0334	.0322	.0312	.0302
32.735	.96666	78	.0403	.0387	.0372	.0358	.0345	.0333	.0322	.0312
33.830	.99900	79	.0416	.0400	.0384	.0370	.0357	.0344	.0333	.0322
34.957	1.0323	80	.0430	.0413	.0397	.0382	.0369	.0356	.0344	.0333
36.116	1.0665	81	.0444	.0427	.0410	.0395	.0381	.0368	.0355	.0344
37.309	1.1017	82	.0459	.0441	.0424	.0408	.0393	.0380	.0367	.0355
38.536	1.1380	83	.0474	.0455	.0438	.0422	.0406	.0392	.0379	.0367
39.798	1.1752	84	.0490	.0470	.0452	.0435	.0420	.0405	.0392	.0379
41.096	1.2136	85	.0506	.0485	.0467	.0450	.0433	.0418	.0404	.0392
42.430	1.2530	86	.0522	.0501	.0482	.0464	.0447	.0432	.0418	.0404
43.802	1.2935	87	.0539	.0517	.0497	.0479	.0462	.0446	.0431	.0417
45.213	1.3351	88	.0556	.0534	.0513	.0495	.0477	.0460	.0445	.0431
46.662	1.3779	89	.0574	.0551	.0530	.0510	.0492	.0475	.0459	.0445
48.152	1.4219	90	.0593	.0569	.0547	.0527	.0508	.0490	.0474	.0459
49.683	1.4671	91	.0611	.0587	.0564	.0543	.0524	.0506	.0489	.0473
51.256	1.5136	92	.0631	.0605	.0582	.0561	.0541	.0522	.0504	.0488
52.872	1.5613	93	.0651	.0625	.0600	.0578	.0558	.0538	.0520	.0504
54.532	1.6103	94	.0671	.0644	.0619	.0596	.0575	.0555	.0537	.0519
56.236	1.6607	95	.0692	.0664	.0639	.0615	.0593	.0573	.0554	.0536

TABLE 7.6.2

Correction "(in °F.)" to Obtain Virtual Temperature

$\frac{e}{P}$	Temperature, t ° F.									
	−40°	−30°	−20°	−10°	0°	+10°	20°	30°	40°	50°
0	0	0	0	0	0	0	0	0	0	0
.001	.16	.16	.17	.17	.17	.18	.18	.19	.19	.19
.002	.32	.32	.33	.34	.35	.36	.36	.37	.38	.39
.003	.48	.49	.50	.51	.52	.53	.54	.56	.57	.58
.004	.63	.65	.66	.68	.70	.71	.73	.74	.76	.77
.005	.79	.81	.83	.85	.87	.89	.91	.93	.94	.96
.006	.95	.97	1.00	1.02	1.04	1.07	1.09	1.11	1.13	1.16
.007	1.11	1.14	1.16	1.19	1.22	1.24	1.27	1.30	1.32	1.35
.008	1.27	1.30	1.33	1.36	1.39	1.42	1.45	1.48	1.51	1.54
.009	1.43	1.46	1.50	1.53	1.56	1.60	1.63	1.67	1.70	1.73
.010	1.59	1.62	1.66	1.70	1.74	1.78	1.81	1.85	1.89	1.93
.011	1.75	1.79	1.83	1.87	1.91	1.95	1.99	2.04	2.08	2.12
.012	1.90	1.95	1.99	2.04	2.09	2.13	2.18	2.22	2.27	2.31
.013	2.06	2.11	2.16	2.21	2.26	2.31	2.36	2.41	2.46	2.50
.014	2.22	2.27	2.33	2.38	2.43	2.49	2.54	2.59	2.64	2.70
.015	2.38	2.44	2.49	2.55	2.61	2.66	2.72	2.78	2.83	2.89
.016	2.54	2.60	2.66	2.72	2.78	2.84	2.90	2.96	3.02	3.08
.017	2.70	2.76	2.83	2.89	2.95	3.02	3.08	3.15	3.21	3.28
.018	2.86	2.92	2.99	3.06	3.13	3.20	3.26	3.33	3.40	3.47
.019	3.01	3.09	3.16	3.23	3.30	3.37	3.45	3.52	3.59	3.66
.020	3.17	3.25	3.32	3.40	3.48	3.55	3.63	3.70	3.78	3.85
.021	3.33	3.41	3.49	3.57	3.65	3.73	3.81	3.89	3.97	4.05
.022	3.49	3.57	3.66	3.74	3.82	3.91	3.99	4.07	4.16	4.24
.023	3.65	3.74	3.82	3.91	4.00	4.08	4.17	4.26	4.34	4.43
.024	3.81	3.90	3.99	4.08	4.17	4.26	4.35	4.44	4.53	4.62
.025	3.97	4.06	4.16	4.25	4.34	4.44	4.53	4.63	4.72	4.82
.026	4.13	4.22	4.32	4.42	4.52	4.62	4.71	4.81	4.91	5.01
.027	4.28	4.39	4.49	4.59	4.69	4.79	4.90	5.00	5.10	5.20
.028	4.44	4.55	4.65	4.76	4.87	4.97	5.08	5.18	5.29	5.39
.029	4.60	4.71	4.82	4.93	5.04	5.15	5.26	5.37	5.48	5.59
.030	4.76	4.87	4.99	5.10	5.21	5.33	5.44	5.55	5.67	5.78

TABLE 7.6.2 (CONTINUED)

Correction "(in °F.)" to Obtain Virtual Temperature

$\frac{e}{P}$	Temperature, t ° F.									
	−40°	−30°	−20°	−10°	0°	+10°	20°	30°	40°	50°
0.030	4.76	4.87	4.99	5.10	5.21	5.33	5.44	5.55	5.67	5.78
.031	4.92	5.04	5.15	5.27	5.39	5.50	5.62	5.74	5.86	5.97
.032	5.08	5.20	5.32	5.44	5.56	5.68	5.80	5.92	6.04	6.17
.033	5.24	5.36	5.49	5.61	5.73	5.86	5.98	6.11	6.23	6.36
.034	5.39	5.52	5.65	5.78	5.91	6.04	6.17	6.29	6.42	6.55
.035	5.55	5.69	5.82	5.95	6.08	6.21	6.35	6.48	6.61	6.74
.036	5.71	5.85	5.98	6.12	6.26	6.39	6.53	6.66	6.80	6.94
.037	5.87	6.01	6.15	6.29	6.43	6.57	6.71	6.85	6.99	7.13
.038	6.03	6.17	6.32	6.46	6.60	6.75	6.89	7.03	7.18	7.32
.039	6.19	6.33	6.48	6.63	6.78	6.92	7.07	7.22	7.37	7.51
.040	6.35	6.50	6.65	6.80	6.95	7.10	7.25	7.40	7.56	7.71
.041	6.50	6.66	6.81	6.97	7.12	7.28	7.43	7.59	7.74	7.90
.042	6.66	6.82	6.98	7.14	7.30	7.46	7.62	7.77	7.93	8.09
.043	6.82	6.98	7.15	7.31	7.47	7.63	7.80	7.96	8.12	8.29
.044	6.98	7.15	7.31	7.48	7.65	7.81	7.98	8.15	8.31	8.48
.045	7.14	7.31	7.48	7.65	7.82	7.99	8.16	8.33	8.50	8.67
.046	7.30	7.47	7.65	7.82	7.99	8.17	8.34	8.52	8.69	8.86
.047	7.46	7.63	7.81	7.99	8.17	8.35	8.52	8.70	8.88	9.06
.048	7.62	7.80	7.98	8.16	8.34	8.52	8.70	8.89	9.07	9.25
.049	7.77	7.96	8.14	8.33	8.52	8.70	8.89	9.07	9.26	9.44
.050	7.93	8.12	8.31	8.50	8.69	8.88	9.07	9.26	9.44	9.63
.051	8.09	8.28	8.48	8.67	8.86	9.06	9.25	9.44	9.63	9.83
.052	8.25	8.45	8.64	8.84	9.04	9.23	9.43	9.63	9.82	10.02
.053	8.41	8.61	8.81	9.01	9.21	9.41	9.61	9.81	10.01	10.21
.054	8.57	8.77	8.98	9.18	9.38	9.59	9.79	10.00	10.20	10.40
.055	8.73	8.93	9.14	9.35	9.56	9.77	9.97	10.18	10.39	10.60
.056	8.88	9.10	9.31	9.52	9.73	9.94	10.15	10.37	10.58	10.79
.057	9.04	9.26	9.47	9.69	9.91	10.12	10.34	10.55	10.77	10.98
.058	9.20	9.42	9.64	9.86	10.08	10.30	10.52	10.74	10.96	11.18
.059	9.36	9.58	9.81	10.03	10.25	10.48	10.70	10.92	11.14	11.37
.060	9.52	9.75	9.97	10.20	10.43	10.65	10.88	11.11	11.33	11.56

TABLE 7.6.2 (CONTINUED)

Correction "(in °F.)" to Obtain Virtual Temperature

$\frac{e}{P}$	Temperature, t ° F.									
	+50°	60°	70°	80°	90°	100°	110°	120°	130°	140°
0	0	0	0	0	0	0	0	0	0	0
.001	.19	.19	.19	.20	.20	.20	.20	.21	.21	.21
.002	.39	.39	.40	.41	.42	.42	.43	.44	.45	.45
.003	.58	.59	.60	.61	.62	.63	.65	.66	.67	.68
.004	.77	.79	.80	.82	.83	.85	.86	.88	.89	.91
.005	.96	.98	1.00	1.02	1.04	1.06	1.08	1.10	1.11	1.13
.006	1.16	1.18	1.20	1.22	1.25	1.27	1.29	1.31	1.34	1.36
.007	1.35	1.38	1.40	1.43	1.45	1.48	1.51	1.53	1.56	1.59
.008	1.54	1.57	1.60	1.63	1.66	1.69	1.72	1.75	1.78	1.81
.009	1.73	1.77	1.80	1.84	1.87	1.90	1.94	1.97	2.01	2.04
.010	1.93	1.96	2.00	2.04	2.08	2.12	2.15	2.19	2.23	2.27
.011	2.12	2.16	2.20	2.24	2.29	2.33	2.37	2.41	2.45	2.49
.012	2.31	2.36	2.40	2.45	2.49	2.54	2.58	2.63	2.68	2.72
.013	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85	2.90	2.95
.014	2.70	2.75	2.80	2.86	2.91	2.96	3.02	3.07	3.12	3.17
.015	2.89	2.95	3.00	3.06	3.12	3.17	3.23	3.29	3.34	3.40
.016	3.08	3.14	3.20	3.26	3.32	3.39	3.45	3.51	3.57	3.63
.017	3.28	3.34	3.40	3.47	3.53	3.60	3.66	3.73	3.79	3.85
.018	3.47	3.54	3.60	3.67	3.74	3.81	3.88	3.94	4.01	4.08
.019	3.66	3.73	3.80	3.88	3.95	4.02	4.09	4.16	4.24	4.31
.020	3.85	3.93	4.00	4.08	4.16	4.23	4.31	4.38	4.46	4.53
.021	4.05	4.13	4.20	4.28	4.36	4.44	4.52	4.60	4.68	4.76
.022	4.24	4.32	4.41	4.49	4.57	4.65	4.74	4.82	4.90	4.99
.023	4.43	4.52	4.61	4.69	4.78	4.87	4.95	5.04	5.13	5.21
.024	4.62	4.71	4.81	4.90	4.99	5.08	5.17	5.26	5.35	5.44
.025	4.82	4.91	5.01	5.10	5.19	5.29	5.38	5.48	5.57	5.67
.026	5.01	5.11	5.21	5.30	5.40	5.50	5.60	5.70	5.80	5.89
.027	5.20	5.30	5.41	5.51	5.61	5.71	5.81	5.92	6.02	6.12
.028	5.39	5.50	5.61	5.71	5.82	5.92	6.03	6.14	6.24	6.35
.029	5.59	5.70	5.81	5.92	6.03	6.14	6.25	6.36	6.46	6.57
.030	5.78	5.89	6.01	6.12	6.23	6.35	6.46	6.57	6.69	6.80

TABLE 7.6.2 (CONTINUED)

Correction "(in °F.)" to Obtain Virtual Temperature

$\frac{e}{P}$	Temperature, t ° F.									
	+50°	60°	70°	80°	90°	100°	110°	120°	130°	140°
0.030	5.78	5.89	6.01	6.12	6.23	6.35	6.46	6.57	6.69	6.80
.031	5.97	6.09	6.21	6.32	6.44	6.56	6.68	6.79	6.91	7.03
.032	6.17	6.29	6.41	6.53	6.65	6.77	6.89	7.01	7.13	7.25
.033	6.36	6.48	6.61	6.73	6.86	6.98	7.11	7.23	7.36	7.48
.034	6.55	6.68	6.81	6.94	7.07	7.19	7.32	7.45	7.58	7.71
.035	6.74	6.88	7.01	7.14	7.27	7.41	7.54	7.67	7.80	7.93
.036	6.94	7.07	7.21	7.34	7.48	7.62	7.75	7.89	8.03	8.16
.037	7.13	7.27	7.41	7.55	7.69	7.83	7.97	8.11	8.25	8.39
.038	7.32	7.47	7.61	7.75	7.90	8.04	8.18	8.33	8.47	8.61
.039	7.51	7.66	7.81	7.96	8.10	8.25	8.40	8.55	8.69	8.84
.040	7.71	7.86	8.01	8.16	8.31	8.46	8.61	8.77	8.92	9.07
.041	7.90	8.05	8.21	8.36	8.52	8.67	8.83	8.98	9.14	9.29
.042	8.09	8.25	8.41	8.57	8.73	8.89	9.05	9.20	9.36	9.52
.043	8.29	8.45	8.61	8.77	8.94	9.10	9.26	9.42	9.59	9.75
.044	8.48	8.64	8.81	8.98	9.14	9.31	9.48	9.64	9.81	9.97
.045	8.67	8.84	9.01	9.18	9.35	9.52	9.69	9.86	10.03	10.20
.046	8.86	9.04	9.21	9.38	9.56	9.73	9.91	10.08	10.25	10.43
.047	9.06	9.23	9.41	9.59	9.77	9.94	10.12	10.30	10.48	10.65
.048	9.25	9.43	9.61	9.79	9.97	10.16	10.34	10.52	10.70	10.88
.049	9.44	9.63	9.81	10.00	10.18	10.37	10.55	10.74	10.92	11.11
.050	9.63	9.82	10.01	10.20	10.39	10.58	10.77	10.96	11.15	11.34
.051	9.83	10.02	10.21	10.40	10.60	10.79	10.98	11.18	11.37	11.56
.052	10.02	10.22	10.41	10.61	10.81	11.00	11.20	11.40	11.59	11.79
.053	10.21	10.41	10.61	10.81	11.01	11.21	11.41	11.61	11.81	12.02
.054	10.40	10.61	10.81	11.02	11.22	11.43	11.63	11.83	12.04	12.24
.055	10.60	10.81	11.01	11.22	11.43	11.64	11.84	12.05	12.26	12.47
.056	10.79	11.00	11.21	11.43	11.64	11.85	12.06	12.27	12.48	12.70
.057	10.98	11.20	11.41	11.63	11.84	12.06	12.28	12.49	12.71	12.92
.058	11.18	11.39	11.61	11.83	12.05	12.27	12.49	12.71	12.93	13.15
.059	11.37	11.59	11.81	12.04	12.26	12.48	12.71	12.93	13.15	13.38
.060	11.56	11.79	12.01	12.24	12.47	12.69	12.92	13.15	13.38	13.60

TABLE 7.7

Table of factor $10^{-0.0001587\,(H_{gl}-H_{gs})}$ *as a function of* $(H_{gl}-H_{gs})$*, for positive and negative values of* $(H_{gl}-H_{gs})$

[Note: The factor is used in Hann's equation for the variation of vapor pressure (e) with respect to height:

$$e_l = e_s\,10^{-0.0001587\,(H_{gl}-H_{gs})}$$

where e_s is value at geopotential H_{gs}, and e_l value at geopotential H_{gl}, in gpm.]

$(H_{gl}-H_{gs})$	Factor	$(H_{gl}-H_{gs})$	Factor	$(H_{gl}-H_{gs})$	Factor	$(H_{gl}-H_{gs})$	Factor
gpm		gpm		gpm		gpm	
0	1.0000	+2500	0.4010	0	1.0000	−2500	2.4936
+ 100	0.9641	+2600	0.3866	− 100	1.0372	−2600	2.5864
+ 200	0.9295	+2700	0.3728	− 200	1.0758	−2700	2.6827
+ 300	0.8962	+2800	0.3594	− 300	1.1159	−2800	2.7826
+ 400	0.8640	+2900	0.3465	− 400	1.1574	−2900	2.8861
+ 500	0.8330	+3000	0.3340	− 500	1.2005	−3000	2.9936
+ 600	0.8031	+3100	0.3221	− 600	1.2452	−3100	3.1050
+ 700	0.7743	+3200	0.3105	− 700	1.2915	−3200	3.2206
+ 800	0.7465	+3300	0.2994	− 800	1.3396	−3300	3.3405
+ 900	0.7197	+3400	0.2886	− 900	1.3895	−3400	3.4648
+1000	0.6939	+3500	0.2783	−1000	1.4412	−3500	3.5938
+1100	0.6690	+3600	0.2683	−1100	1.4949	−3600	3.7276
+1200	0.6449	+3700	0.2586	−1200	1.5505	−3700	3.8664
+1300	0.6218	+3800	0.2494	−1300	1.6082	−3800	4.0103
+1400	0.5995	+3900	0.2404	−1400	1.6681	−3900	4.1596
+1500	0.5780	+4000	0.2318	−1500	1.7302	−4000	4.3144
+1600	0.5572	+4100	0.2235	−1600	1.7946	−4100	4.4750
+1700	0.5372	+4200	0.2154	−1700	1.8614	−4200	4.6416
+1800	0.5179	+4300	0.2077	−1800	1.9307	−4300	4.8144
+1900	0.4994	+4400	0.2003	−1900	2.0026	−4400	4.9936
+2000	0.4814	+4500	0.1931	−2000	2.0771	−4500	5.1795
+2100	0.4642	+4600	0.1861	−2100	2.1544	−4600	5.3723
+2200	0.4475	+4700	0.1795	−2200	2.2346	−4700	5.5723
+2300	0.4314	+4800	0.1730	−2300	2.3178	−4800	5.7797
+2400	0.4160	+4900	0.1668	−2400	2.4041	−4900	5.9948
+2500	0.4010	+5000	0.1608	−2500	2.4936	−5000	6.2180

TABLE 8.1

Standard Atmosphere Table in Accordance With Specifications of ICAO (International Civil Aviation Organization)

Tabular values give altitude (in feet) in the standard atmosphere as a function of pressure (inches of mercury, shown as side and top argument).
Note: Altitudes are strictly in terms of "standard geopotential feet."

Pressure, inches of mercury	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.
15.0	17906	17890	17874	17858	17842	17825	17809	17793	17777	17761
15.1	17745	17729	17713	17697	17681	17664	17648	17632	17616	17600
15.2	17584	17568	17552	17536	17520	17504	17488	17473	17457	17441
15.3	17425	17409	17393	17377	17361	17345	17329	17313	17298	17282
15.4	17266	17250	17234	17218	17203	17187	17171	17155	17140	17124
15.5	17108	17092	17077	17061	17045	17029	17014	16998	16982	16967
15.6	16951	16935	16920	16904	16888	16873	16857	16841	16826	16810
15.7	16795	16779	16763	16748	16732	16717	16701	16686	16670	16655
15.8	16639	16624	16608	16593	16577	16562	16546	16531	16515	16500
15.9	16484	16469	16454	16438	16423	16407	16392	16377	16361	16346
16.0	16330	16315	16300	16284	16269	16254	16238	16223	16208	16193
16.1	16177	16162	16147	16132	16116	16101	16086	16071	16055	16040
16.2	16025	16010	15995	15979	15964	15949	15934	15919	15904	15888
16.3	15873	15858	15843	15828	15813	15798	15783	15768	15753	15737
16.4	15722	15707	15692	15677	15662	15647	15632	15617	15602	15587
16.5	15572	15557	15542	15527	15512	15498	15483	15468	15453	15438
16.6	15423	15408	15393	15378	15363	15349	15334	15319	15304	15289
16.7	15274	15259	15245	15230	15215	15200	15185	15171	15156	15141
16.8	15126	15112	15097	15082	15067	15053	15038	15023	15008	14994
16.9	14979	14964	14950	14935	14920	14906	14891	14876	14862	14847
17.0	14833	14818	14803	14789	14774	14760	14745	14730	14716	14701
17.1	14687	14672	14658	14643	14629	14614	14600	14585	14571	14556
17.2	14542	14527	14513	14498	14484	14469	14455	14440	14426	14412
17.3	14397	14383	14368	14354	14340	14325	14311	14296	14282	14268
17.4	14253	14239	14225	14210	14196	14182	14167	14153	14139	14125
17.5	14110	14096	14082	14067	14053	14039	14025	14010	13996	13982
17.6	13968	13954	13939	13925	13911	13897	13883	13868	13854	13840
17.7	13826	13812	13798	13784	13769	13755	13741	13727	13713	13699
17.8	13685	13671	13657	13643	13629	13614	13600	13586	13572	13558
17.9	13544	13530	13516	13502	13488	13474	13460	13446	13432	13418
18.0	13404	13390	13377	13363	13349	13335	13321	13307	13293	13279
18.1	13265	13251	13237	13224	13210	13196	13182	13168	13154	13140
18.2	13127	13113	13099	13085	13071	13057	13044	13030	13016	13002
18.3	12989	12975	12961	12947	12933	12920	12906	12892	12879	12865
18.4	12851	12837	12824	12810	12796	12783	12769	12755	12742	12728
18.5	12714	12701	12687	12673	12660	12646	12633	12619	12605	12592
18.6	12578	12565	12551	12537	12524	12510	12497	12483	12470	12456
18.7	12442	12429	12415	12402	12388	12375	12361	12348	12334	12321
18.8	12307	12294	12281	12267	12254	12240	12227	12213	12200	12186
18.9	12173	12160	12146	12133	12119	12106	12093	12079	12066	12053
19.0	12039	12026	12012	11999	11986	11972	11959	11946	11932	11919
19.1	11906	11893	11879	11866	11853	11839	11826	11813	11800	11786
19.2	11773	11760	11747	11733	11720	11707	11694	11681	11667	11654
19.3	11641	11628	11615	11601	11588	11575	11562	11549	11536	11522
19.4	11509	11496	11483	11470	11457	11444	11431	11417	11404	11391
19.5	11378	11365	11352	11339	11326	11313	11300	11287	11274	11261
19.6	11248	11235	11222	11209	11196	11183	11170	11157	11144	11131
19.7	11118	11105	11092	11079	11066	11053	11040	11027	11014	11001
19.8	10988	10975	10962	10949	10937	10924	10911	10898	10885	10872
19.9	10859	10846	10834	10821	10808	10795	10782	10769	10757	10744

TABLE 8.1 (CONTINUED)

Standard Atmosphere Table in Accordance With Specifications of ICAO (International Civil Aviation Organization)

Tabular values give altitude (in feet) in the standard atmosphere as a function of pressure (inches of mercury, shown as side and top argument).
Note: Altitudes are strictly in terms of "standard geopotential feet."

Pressure, inches of mercury	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.
20.0	10731	10718	10705	10692	10680	10667	10654	10641	10629	10616
20.1	10603	10590	10577	10565	10552	10539	10526	10514	10501	10488
20.2	10476	10463	10450	10437	10425	10412	10399	10387	10374	10361
20.3	10349	10336	10323	10311	10298	10285	10273	10260	10248	10235
20.4	10222	10210	10197	10185	10172	10159	10147	10134	10122	10109
20.5	10096	10084	10071	10059	10046	10034	10021	10009	9996	9984
20.6	9971	9959	9946	9934	9921	9909	9896	9884	9871	9859
20.7	9846	9834	9821	9809	9796	9784	9772	9759	9747	9734
20.8	9722	9709	9697	9685	9672	9660	9647	9635	9623	9610
20.9	9598	9586	9573	9561	9549	9536	9524	9512	9499	9487
21.0	9475	9462	9450	9438	9425	9413	9401	9388	9376	9364
21.1	9352	9339	9327	9315	9303	9290	9278	9266	9254	9241
21.2	9229	9217	9205	9192	9180	9168	9156	9144	9131	9119
21.3	9107	9095	9083	9071	9058	9046	9034	9022	9010	8998
21.4	8986	8973	8961	8949	8937	8925	8913	8901	8889	8877
21.5	8864	8852	8840	8828	8816	8804	8792	8780	8768	8756
21.6	8744	8732	8720	8708	8696	8684	8672	8660	8648	8636
21.7	8624	8612	8600	8588	8576	8564	8552	8540	8528	8516
21.8	8504	8492	8480	8468	8456	8444	8432	8420	8408	8397
21.9	8385	8373	8361	8349	8337	8325	8313	8301	8289	8278
22.0	8266	8254	8242	8230	8218	8206	8195	8183	8171	8159
22.1	8147	8136	8124	8112	8100	8088	8076	8065	8053	8041
22.2	8029	8018	8006	7994	7982	7971	7959	7947	7935	7924
22.3	7912	7900	7888	7877	7865	7853	7841	7830	7818	7806
22.4	7795	7783	7771	7760	7748	7736	7725	7713	7701	7690
22.5	7678	7666	7655	7643	7631	7620	7608	7597	7585	7573
22.6	7562	7550	7538	7527	7515	7504	7492	7481	7469	7457
22.7	7446	7434	7423	7411	7400	7388	7376	7365	7353	7342
22.8	7330	7319	7307	7296	7284	7273	7261	7250	7238	7227
22.9	7215	7204	7192	7181	7169	7158	7146	7135	7124	7112
23.0	7101	7089	7078	7066	7055	7043	7032	7021	7009	6998
23.1	6986	6975	6964	6952	6941	6929	6918	6907	6895	6884
23.2	6873	6861	6850	6839	6827	6816	6804	6793	6782	6770
23.3	6759	6748	6736	6725	6714	6703	6691	6680	6669	6657
23.4	6646	6635	6624	6612	6601	6590	6578	6567	6556	6545
23.5	6533	6522	6511	6500	6488	6477	6466	6455	6444	6432
23.6	6421	6410	6399	6388	6376	6365	6354	6343	6332	6320
23.7	6309	6298	6287	6276	6265	6253	6242	6231	6220	6209
23.8	6198	6187	6176	6164	6153	6142	6131	6120	6109	6098
23.9	6087	6076	6064	6053	6042	6031	6020	6009	5998	5987
24.0	5976	5965	5954	5943	5932	5921	5910	5899	5888	5877
24.1	5866	5854	5843	5832	5821	5810	5799	5788	5777	5766
24.2	5756	5745	5734	5723	5712	5701	5690	5679	5668	5657
24.3	5646	5635	5624	5613	5602	5591	5580	5569	5558	5548
24.4	5537	5526	5515	5504	5493	5482	5471	5460	5449	5439
24.5	5428	5417	5406	5395	5384	5373	5363	5352	5341	5330
24.6	5319	5308	5297	5287	5276	5265	5254	5243	5233	5222
24.7	5211	5200	5189	5179	5168	5157	5146	5135	5125	5114
24.8	5103	5092	5082	5071	5060	5049	5039	5028	5017	5006
24.9	4996	4985	4974	4963	4953	4942	4931	4921	4910	4899

TABLE 8.1 (CONTINUED)

Standard Atmosphere Table in Accordance With Specifications of ICAO (International Civil Aviation Organization)

Tabular values give altitude (in feet) in the standard atmosphere as a function of pressure (inches of mercury, shown as side and top argument).
Note: Altitudes are strictly in terms of "standard geopotential feet."

Pressure, inches of mercury	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.
25.0	4888	4878	4867	4856	4846	4835	4824	4814	4803	4792
25.1	4782	4771	4760	4750	4739	4728	4718	4707	4696	4686
25.2	4675	4665	4654	4643	4633	4622	4611	4601	4590	4580
25.3	4569	4559	4548	4537	4527	4516	4506	4495	4484	4474
25.4	4463	4453	4442	4432	4421	4411	4400	4389	4379	4368
25.5	4358	4347	4337	4326	4316	4305	4295	4284	4274	4263
25.6	4253	4242	4232	4221	4211	4200	4190	4179	4169	4158
25.7	4148	4138	4127	4117	4106	4096	4085	4075	4064	4054
25.8	4044	4033	4023	4012	4002	3991	3981	3971	3960	3950
25.9	3939	3929	3919	3908	3898	3888	3877	3867	3856	3846
26.0	3836	3825	3815	3805	3794	3784	3774	3763	3753	3743
26.1	3732	3722	3712	3701	3691	3681	3670	3660	3650	3639
26.2	3629	3619	3608	3598	3588	3578	3567	3557	3547	3537
26.3	3526	3516	3506	3495	3485	3475	3465	3454	3444	3434
26.4	3424	3414	3403	3393	3383	3373	3362	3352	3342	3332
26.5	3322	3311	3301	3291	3281	3271	3260	3250	3240	3230
26.6	3220	3210	3199	3189	3179	3169	3159	3149	3138	3128
26.7	3118	3108	3098	3088	3078	3067	3057	3047	3037	3027
26.8	3017	3007	2997	2987	2976	2966	2956	2946	2936	2926
26.9	2916	2906	2896	2886	2876	2866	2855	2845	2835	2825
27.0	2815	2805	2795	2785	2775	2765	2755	2745	2735	2725
27.1	2715	2705	2695	2685	2675	2665	2655	2645	2635	2625
27.2	2615	2605	2595	2585	2575	2565	2555	2545	2535	2525
27.3	2515	2505	2495	2485	2475	2465	2455	2445	2435	2426
27.4	2416	2406	2396	2386	2376	2366	2356	2346	2336	2326
27.5	2316	2307	2297	2287	2277	2267	2257	2247	2237	2227
27.6	2218	2208	2198	2188	2178	2168	2158	2148	2139	2129
27.7	2119	2109	2099	2089	2080	2070	2060	2050	2040	2030
27.8	2021	2011	2001	1991	1981	1972	1962	1952	1942	1932
27.9	1923	1913	1903	1893	1884	1874	1864	1854	1844	1835
28.0	1825	1815	1805	1796	1786	1776	1766	1757	1747	1737
28.1	1727	1718	1708	1698	1689	1679	1669	1659	1650	1640
28.2	1630	1621	1611	1601	1592	1582	1572	1562	1553	1543
28.3	1533	1524	1514	1504	1495	1485	1475	1466	1456	1446
28.4	1437	1427	1417	1408	1398	1389	1379	1369	1360	1350
28.5	1340	1331	1321	1312	1302	1292	1283	1273	1264	1254
28.6	1244	1235	1225	1216	1206	1196	1187	1177	1168	1158
28.7	1149	1139	1129	1120	1110	1101	1091	1082	1072	1063
28.8	1053	1044	1034	1024	1015	1005	996	986	977	967
28.9	958	948	939	929	920	910	901	891	882	872
29.0	863	853	844	834	825	815	806	796	787	778
29.1	768	759	749	740	730	721	711	702	693	683
29.2	674	664	655	645	636	627	617	608	598	589
29.3	579	570	561	551	542	532	523	514	504	495
29.4	486	476	467	457	448	439	429	420	411	401
29.5	392	382	373	364	354	345	336	326	317	308
29.6	298	289	280	270	261	252	242	233	224	215
29.7	205	196	187	177	168	159	149	140	131	122
29.8	112	103	94	85	75	66	57	47	38	29
29.9	20	10	1	−8	−17	−27	−36	−45	−54	−64

TABLE 8.1 (CONTINUED)

Standard Atmosphere Table in Accordance With Specifications of ICAO (International Civil Aviation Organization)

Tabular values give altitude (in feet) in the standard atmosphere as a function of pressure (inches of mercury, shown as side and top argument).
Note: Altitudes are strictly in terms of "standard geopotential feet."

Pressure, inches of mercury	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.
30.0	−73	−82	−91	−100	−110	−119	−128	−137	−146	−156
30.1	−165	−174	−183	−193	−202	−211	−220	−229	−238	−248
30.2	−257	−266	−275	−284	−294	−303	−312	−321	−330	−339
30.3	−348	−358	−367	−376	−385	−394	−403	−413	−422	−431
30.4	−440	−449	−458	−467	−476	−486	−495	−504	−513	−522
30.5	−531	−540	−549	−558	−567	−577	−586	−595	−604	−613
30.6	−622	−631	−640	−649	−658	−667	−676	−686	−695	−704
30.7	−713	−722	−731	−740	−749	−758	−767	−776	−785	−794
30.8	−803	−812	−821	−830	−839	−848	−857	−866	−875	−884
30.9	−893	−902	−911	−920	−929	−938	−947	−956	−965	−974
31.0	−983	−992	−1001	−1010	−1019	−1028	−1037	−1046	−1055	−1064
31.1	−1073	−1082	−1091	−1100	−1109	−1118	−1127	−1136	−1145	−1154
31.2	−1163	−1172	−1181	−1189	−1198	−1207	−1216	−1225	−1234	−1243
31.3	−1252	−1261	−1270	−1279	−1288	−1297	−1305	−1314	−1323	−1332
31.4	−1341	−1350	−1359	−1368	−1377	−1385	−1394	−1403	−1412	−1421
31.5	−1430	−1439	−1448	−1456	−1465	−1474	−1483	−1492	−1501	−1510
31.6	−1518	−1527	−1536	−1545	−1554	−1563	−1571	−1580	−1589	−1598
31.7	−1607	−1616	−1624	−1633	−1642	−1651	−1660	−1669	−1677	−1686
31.8	−1695	−1704	−1713	−1721	−1730	−1739	−1748	−1757	−1765	−1774
31.9	−1783	−1792	−1800	−1809	−1818	−1827	−1836	−1844	−1853	−1862
32.0	−1871	−1879	−1888	−1897	−1906	−1914	−1923	−1932	−1941	−1949
32.1	−1958	−1967	−1976	−1984	−1993	−2002	−2010	−2019	−2028	−2037
32.2	−2045	−2054	−2063	−2071	−2080	−2089	−2098	−2106	−2115	−2124
32.3	−2132	−2141	−2150	−2158	−2167	−2176	−2184	−2193	−2202	−2210
32.4	−2219	−2228	−2236	−2245	−2254	−2262	−2271	−2280	−2288	−2297
32.5	−2306	−2314	−2323	−2332	−2340	−2349	−2358	−2366	−2375	−2384
32.6	−2392	−2401	−2409	−2418	−2427	−2435	−2444	−2452	−2461	−2470
32.7	−2478	−2487	−2496	−2504	−2513	−2521	−2530	−2539	−2547	−2556
32.8	−2564	−2573	−2581	−2590	−2599	−2607	−2616	−2624	−2633	−2641
32.9	−2650	−2659	−2667	−2676	−2684	−2693	−2701	−2710	−2718	−2727

TABLE 8.1.1

*Altimeter-Setting Reduction Constants**

(for various station elevations (H_p), in whole feet, with respect to mean sea level).

Station elevation	Altimeter-setting reduction constant	Station elevation	Altimeter-setting reduction constant	Station elevation	Altimeter-setting reduction constant
H_p feet	in. Hg	H_p feet	in. Hg	H_p feet	in. Hg
1	−0.010	21	0.012	41	0.034
2	− .009	22	.013	42	.035
3	− .008	23	.014	43	.036
4	− .006	24	.015	44	.037
5	− .005	25	.016	45	.038
6	− .004	26	.017	46	.039
7	− .003	27	.018	47	.040
8	− .002	28	.019	48	.041
9	− .001	29	.021	49	.042
10	.000	30	.022	50	.043
11	+0.001	31	.023	51	.044
12	.002	32	.024	52	.045
13	.003	33	.025	53	.046
14	.004	34	.026	54	.048
15	.005	35	.027	55	.049
16	.006	36	.028	56	.050
17	.008	37	.029	57	.051
18	.009	38	.030	58	.052
19	.010	39	.031	59	.053
20	.011	40	.032	60	.054

* *Explanation:* When an altimeter-setting reduction constant indicated for any particular station elevation H_p is applied algebraically to the existing station pressure P in inches of mercury pertinent to that height above sea level, it yields the corresponding altimeter setting, in the same units.

INDEX

NOTES REGARDING INDEX

(a) Index covers Chapters 1 through 8, 12 and 13. Tables in Chapter 14 are listed in the Table of Contents.

(b) Initial boldface number refers to chapter. Arabic number following dash refers to page in indicated chapter.

(c) Boldface A preceding chapter number refers to Annex of indicated chapter.

(d) Boldface number following **12. App.** refers to appendix number.

(e) **13. F.** followed by boldface number refers to a form contained in Chapter 13 under specified number.

(f) **14. Tab.** followed by boldface number refers to table of specified number in Chapter 14.

(g) Plus sign (+) after a page signifies that reference should be made to the indicated page and those immediately following relevant to the subject.

(h) Notation (*see* —) following subordinated subject is intended as a direction to refer to this subject listed elsewhere as a main (nonsubordinated) item. The notation (*see also* —) is a similar suggestion.

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