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**METEOROLOGICAL OBSERVER'S
HANDBOOK, 1942**

LONDON

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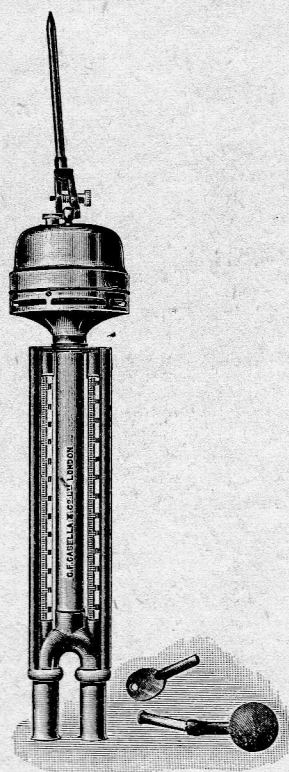
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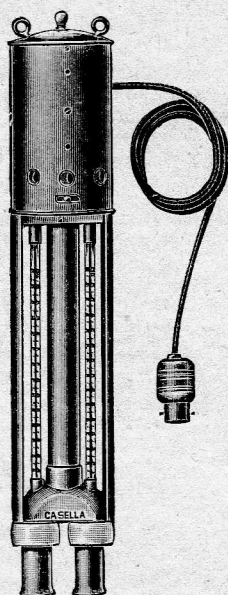
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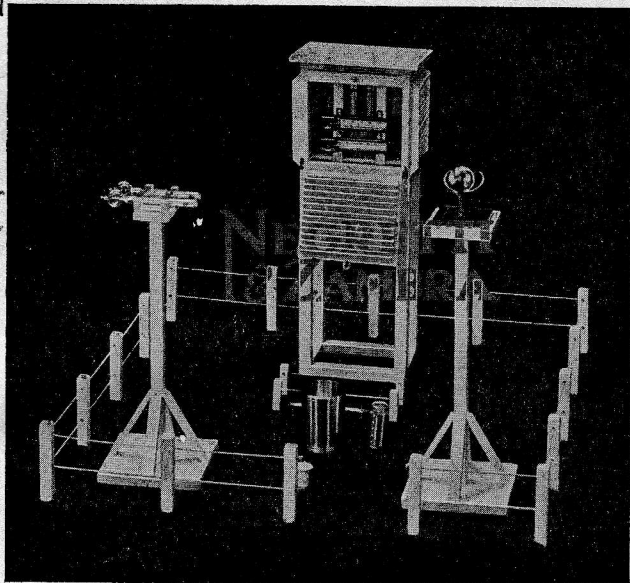
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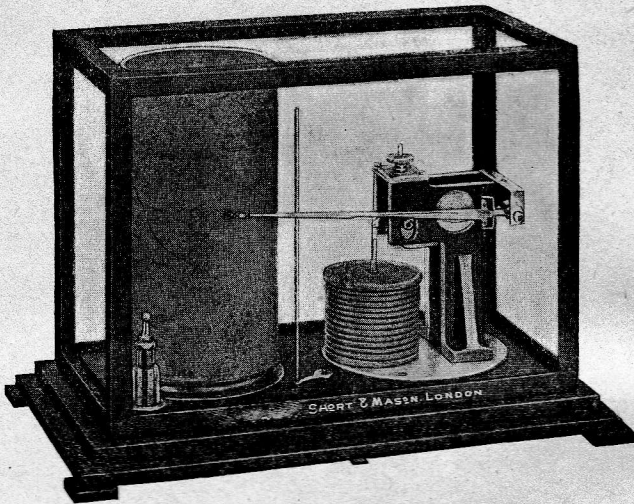
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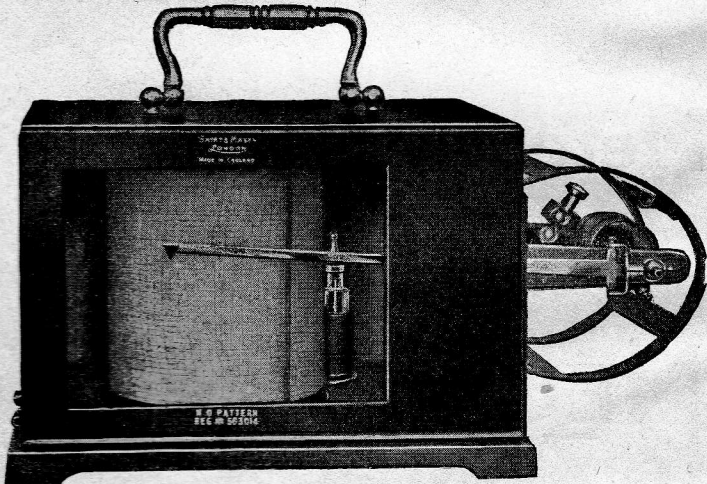
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M.O. 191 (1942)

AIR MINISTRY—METEOROLOGICAL OFFICE

METEOROLOGICAL OBSERVER'S HANDBOOK

1942 EDITION

(Reprinted incorporating Amendment Lists Nos. 1 and 2)

Published by the Authority of the Meteorological Committee

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ERRATUM

This reprint of the 1942 Edition incorporates
Amendment Lists Nos. 1, 2 and 3 (*not* Nos.
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PREFACE

The "Meteorological Observer's Handbook," in continuation of Dr. Scott's "Instructions in the Use of Meteorological Instruments," 1875, reprinted 1885, which in turn succeeded Sir H. James's "Instructions for taking Meteorological Observations" (1851, 2nd edition 1861), was originally issued in 1908. The first edition was exhausted rapidly, and in the following year arrangements were made for the issue of an annual edition of 100 copies with a view to providing opportunity for incorporating in the standard instructions without loss of time such improvements and modifications as circumstances, and the development of meteorological stations, should render desirable. By this means it was possible to give effect without delay to any decisions bearing on meteorological practice in this country which might be taken at International Conferences. It has not been practicable to adhere strictly to the original programme of an annual edition, but editions have appeared in 1909, 1910, 1911, 1913, 1914, 1915, 1917, 1918, 1919, 1921, 1926, 1934 and 1939.

After the termination of the war it became necessary to review the position. The demands for special information had given rise to a certain amount of specialization in the work of many stations, which involved the issue of alternative instructions to observers on points of detail, more particularly in those arising in the preparation of monthly and annual summaries. To incorporate all these in a single handbook was to risk confusion, and moreover, would have added materially to the length and consequently, also, to the cost of the book. The original intention of making the handbook a comprehensive guide not merely to the art of observing but also to the preparation for publication in approved form of summaries was, therefore, modified in 1926. The later editions aim at giving complete instruction in the care and manipulation of meteorological instruments, and in the making of observations, at ground level, both instrumental and non-instrumental. The conventions depending on the hours selected for observing, and detailed instructions for the preparation of summaries, are only briefly referred to or omitted altogether. Full information on such points is given in separate supplements prepared to meet the requirements of stations of different types.

The Handbook is addressed primarily to observers in the British Isles, but in order to meet the requirements of those observers in Crown Colonies who are not in close touch with the meteorological services of any of the Dominions, modifications in the practice commonly followed at home, which are made necessary by differences of climate, are referred to in footnotes or otherwise. Throughout the book the necessity which every meteorologist feels for uniformity of practice has been kept in view. The decisions of International Conferences have generally been followed, wherever they bear on meteorological practice in this country.

The book is divided into three parts. Part I contains instructions for making the observations which constitute the routine of a normal climatological station. Part II is devoted to autographic instruments and Part III consists of tables. In the 1934 edition the most important change occurred in the section on clouds, which was revised in accordance with the new "International Atlas of Clouds and of States of the Sky," published in 1932. In the 1939 edition, the chief additions were a description of the distant-reading anemometer and its care and an account of the standard Meteorological Office clocks and drums, while the instructions relating to visibility observations made at night and to the state of the ground were modified in accordance with the decisions of the International Meteorological Organisation at Warsaw (1935) and Salzburg (1937) respectively. In the present edition the chief change is the omission of Admiral Beaufort's specification of the Beaufort Scale (1805) and the substitution of the "Provisional specification of the Beaufort Scale for use at sea" agreed to at the meeting of the International Meteorological Organisation at Berlin in 1939, together with the limits of speed for the Beaufort Scale for 6m. as well as for 10m.

Regarded as a handbook for making meteorological observations of all kinds, the book is incomplete in one important respect. It makes no mention of observations in the free atmosphere which now form a most important part of the work of many stations. Such observations are of highly specialized character, and it would not be practicable to include instructions for making them with the general instructions for carrying on the routine of a normal station. For information on this subject reference should be made to other publications of the Office.

Considerable divergence of practice still prevails among British meteorologists in the matter of units. The units in common use for the various elements and the abbreviations conventionally used when designating them are set out in the following table :—

Element	Old Unit	Modern unit or units adopted in publications of the Meteorological Office
Pressure (including vapour pressure)	Inch of mercury at 32°F. and at sea level in lat. 45° (in.)	Millibar (mb.)
Temperature ...	Degree Fahrenheit (°F.)	(1) Degree Fahrenheit (°F.) (2) Degree Absolute (°A.)
Rainfall	Inch (in.)	(1) Inch (in.) (2) Millimetre (mm.)
Wind Velocity ...	(1) Mile per hour (mi./hr.) (2) Foot per second (ft./sec.)	(1) Mile per hour (mi./hr. or m.p.h.) (2) Metre per second (m./sec.) (3) Kilometre per hour (Km./hr.) (4) Knot
Sunshine	Hour (hr.)	Hour (hr.)

* * * Tables of conversion from one unit to another of the same kind are printed in Forms 3080, 3081 and 3082.

Pressure.—A millibar (mb.) is one thousand dynes per square centimetre, and is an absolute unit independent of the locality and the material used for measuring the pressure. 1,000 mb. = 29.53 mercury-inches at 32° F. in lat. 45° and is not far from the normal pressure at ground level.

Temperature.—Normal freezing point of water = 32° F. = 273° A. = 0° Centigrade. Normal boiling point of water = 212° F. = 373° A. = 100° Centigrade.

In dealing with temperature differences nine Fahrenheit degrees are equal to five Absolute degrees. The Absolute scale of temperature is the same as the Centigrade scale increased by the constant quantity 273.

Rainfall.—1 inch = 25.40 mm.

Wind Velocity.—1 mi./hr. = 0.44704 m./sec. = 1.467 ft./sec. = 1.609 Km./hr. = 0.8684 knots.

The millibar is now used exclusively in all publications of the Meteorological Office for the specification of pressure, including vapour pressure. The Fahrenheit scale of temperature and the mile per hour as the unit for wind velocity are adopted in the majority of publications of the Office, but the absolute scale of temperature and the metre per second are used in the *Observatories' Year Book* in order that the data may be in a form convenient to workers in science who normally use units based on the C.G.S. system. The foot per second is still largely used by professional writers on ballistics and in many branches of engineering practice. The kilometre per hour is largely used in aeronautical publications. The knot is universally used at sea. Except in *British Rainfall*, where the inch is employed, measurements of rainfall are given in millimetres in the official publications of the Office, the equivalent in inches being shown in parallel columns in some issues. The instructions in this handbook have been drawn up in the first instance for use with instruments graduated in the units now adopted in the publications addressed to the general public, but wherever necessary sections have been added to make them applicable also to instruments graduated in other units.

"The Meteorological Observer's Handbook" is intended to represent the results of the experience of all who are concerned with meteorological observations in connexion with the Office, so that many persons in their various ways contribute to its pages directly or indirectly. Suggestions for its improvement from those who use it are gladly welcomed.

METEOROLOGICAL OFFICE,

May, 1942.

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THE METEOROLOGICAL OBSERVER'S HANDBOOK

PART I.—EYE OBSERVATIONS

§ 1. CLASSIFICATION OF STATIONS

The classification of meteorological stations is guided by resolutions of the International Congress of Meteorologists which assembled at Vienna in 1873. It is based on the scheme of observations to be taken. Three orders of stations are defined, under the following headings :—

(1) **First Order Stations of the International Classification—Normal Meteorological Observatories** at which continuous records or hourly readings of pressure, temperature, wind, sunshine and rain, with eye observations at fixed hours of the amount, form and motion of clouds and notes on the weather, are taken.

(2) **Second Order Stations of the International Classification—Normal Climatological Stations** at which are recorded daily, at two fixed hours at least, observations of pressure, temperature (dry and wet bulb), wind, cloud and weather, with the daily maxima and minima of temperature, the daily rainfall and remarks on the weather. At some stations the duration of bright sunshine is also registered.

(3) **Third Order Stations of the International Classification—Auxiliary Climatological Stations** at which the observations are of the same kind as at the normal climatological stations, but (a) less full, or (b) taken once a day only, or (c) taken at other than the recognised hours.

The same Congress specified various combinations of hours as suitable for adoption at normal climatological stations. The combinations were selected with a view to the deduction of a satisfactory value for the mean temperature for the day from the observations at the fixed hours combined with the extreme readings. The approved combinations are not given here for the reason that at many British stations combinations of hours are used which are not included in those recommended by the Congress. The extended use of thermographs, which was not practicable in 1873, affords the

means of determining accurately the mean temperature for the day in cases in which the approximation, often made in this country, of taking the arithmetic mean of the maximum and minimum temperatures is not considered to be sufficiently close.

The classification of stations is reproduced as a matter of historical interest and because it still indicates the principal headings under which observations are made.

§ 2. THE REQUIREMENTS OF A NORMAL CLIMATOLOGICAL STATION

INSTRUMENTS

The instrumental equipment of a normal station consists of the following instruments :—

Mercury barometer reading to .1 millibar or .002 inch.

Dry-bulb thermometer

Wet " "

Maximum "

Minimum "

Rain-gauge with glass measure.

*Sunshine recorder.

*Grass minimum thermometer.

*Earth thermometers.

} in Stevenson screen.

The barometer and thermometers should be provided with certificates from the National Physical Laboratory. The sunshine recorders in use at Meteorological Office stations are of the Campbell-Stokes pattern. The sphere of the sunshine recorder, the rain-gauge and measure should be certified by the Meteorological Office.

A lamp is required to read the instruments at night. An electric hand lamp worked by a dry battery is often used.

A pair of tinted goggles is necessary for observations of clouds.

EXPOSURE OF THE INSTRUMENTS

Barometer.—The barometer should be kept indoors, but a good light and a uniform temperature are required, and it should also be protected against rough usage.

A position against a wall (specially plugged if necessary), bookcase, or other support in an unheated and little used room having a north aspect is very suitable. Should a sitting-room be selected, the instrument should be so placed that it is not affected by direct heat from fires, hot water pipes, etc. A good light may often be secured by selecting a position near a window, but the instrument should be

* At some stations these are not included.

shielded from the sun's rays at all hours of the day throughout the year. As a general rule it is advisable to use artificial light for all observations. This may with advantage take the form of a self-contained "barometer illuminator" (see p. 14).

The height of the cistern of the barometer above mean sea level must be accurately determined by careful levelling (see p. 8). From the table given on p. 135 it will be seen that a difference of level of 1 foot gives rise to a difference in the reading of the barometer of about .03 mb. An error of 2 or 3 ft. would make an appreciable error in the calculated pressure "reduced to sea level," and therefore the height of the barometer cistern above mean sea level should be known to the nearest foot.

Rain-gauge.—The quantity of rain collected in a rain-gauge depends to some extent upon the exposure of the gauge. In order that observations at different stations may be comparable, the exposures must be comparable. The gauge should be placed on level ground, not upon a slope or terrace and certainly not on a wall or roof. A gauge should on no account be placed so that the ground falls away steeply on the side of the prevailing wind. Its distance from every object should be not less than twice the height of the object above the rim of the gauge. This rule should be particularly borne in mind if the gauge is placed in a garden where flowers or vegetables are growing.

Provided the above conditions are satisfied, a position sheltered from wind is preferable to an exposed one. Especially at mountain, moorland and coast stations great care should be taken that gauges are not unduly exposed to the sweep of the wind. A belt of trees, or a wall on the side of the prevailing wind at a distance conforming with the rule stated in the last paragraph usually forms an efficient shelter. If this is not available a level stretch of ground in a slight hollow should be selected. In some cases it is necessary to build a turf wall, about 12 in. high, surrounding the gauge at a distance of about 5 ft. (See also p. 91.)

The gauge should be set up so that its rim is level and at a height of 1 ft. above the ground, which should be covered with short grass.

Thermometers.—The best site for a thermometer screen is a level piece of ground covered with short grass, in the shape of a rectangle, 30 ft. by 20 ft.

The plot should be upon generally level ground. A station on a steep slope, or in a hollow, is subject to exceptional meteorological conditions.

The screen should be freely exposed to sun and wind; it should not be shaded by trees or buildings. When the screen is placed on the same plot as the rain-gauge, the rain-gauge should be not less than 10 ft. distant from the screen.

For a rural station the most unrestricted exposure should be aimed at, as the observations are intended to be comparable with other

rural stations, and are of general meteorological interest. For urban stations local meteorological conditions are of importance, and an open space near the middle of the town is desirable. Exposures on roofs are not appropriate for meteorological comparisons.

The above considerations are general. Each case in which they cannot be complied with requires special consideration.

At some climatological stations, observations of earth temperature are taken with thermometers specially arranged for the purpose. The depths usually selected in this country for statistical purposes in relation to agriculture and public health are 1 ft. and 4 ft. Observations at 4 in., 8 in. and 2 ft. are sometimes made for agricultural purposes, generally at crop weather stations. The borings for the thermometers can be within the plot designed for the screen and rain-gauge. The plot of grass will also accommodate the grass minimum thermometer.

Anemometer.—A normal climatological station is not usually provided with an anemometer. The velocity of wind near the surface is so much affected by obstructions of all kinds, that a satisfactory exposure for an anemometer is often difficult to obtain. The standard anemometer exposure adopted by the Meteorological Office is at the height of 10 metres (33 ft.) above the ground at the top of a mast or skeleton tower and well removed from all buildings or trees. If such an exposure cannot be obtained the anemometer should be not less than 20 ft. above the top of buildings or trees in its neighbourhood. Each individual case requires special consideration. The ridge of a steep roof should be avoided.

Observations of wind force, which are sufficiently comparable with those of other stations, are obtained by estimation after the observer has had sufficient practice.

Sunshine recorder.—This requires a free horizon between north-east and south-east on the east side, and between north-west and south-west on the west side, these being approximately the limits of the position of the rising and setting sun in the British Isles. Obstruction to the south should not be higher than from one-eighth to one-third of its distance from the instrument, according to the latitude of the station. Obstruction to the northward between north-east and north-west is of no consequence. For the Southern Hemisphere the words south and north in the above description should be interchanged. A suitable exposure may often be obtained on the roof of a building. (For further particulars, see p. 97.)

Other observations.—In addition to accommodation for the instruments mentioned, provision must be made for ascertaining the direction of the wind by day and by night; this may be either by a wind vane or by some fixed marks which enable the direction of smoke, etc., to be estimated with sufficient accuracy. For observations of visibility a series of 13 objects varying in distance from

27 yards to some 30 miles should be selected, each of which can be seen from a convenient place or places near the site of the rain-gauge (see pp. 59 to 62). For observing the state of the ground a patch of bare ground about 6 ft. square is required (see p. 96).

LAY-OUT OF A METEOROLOGICAL STATION

A grass plot about 30 ft. by 20 ft. represents the usual provision for the accommodation of the out-door instruments. It is generally found necessary to fence the plot to protect the instruments from unauthorised interference. Such fencing should be as open as

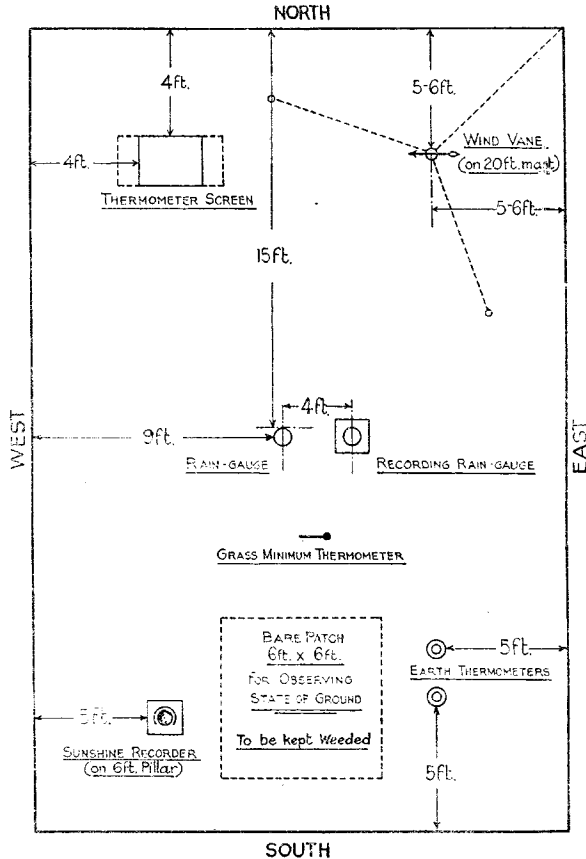


FIG. 1. LAY-OUT OF A METEOROLOGICAL STATION

Suggested arrangement of instruments in a fenced plot 30 feet by 20 feet.

possible and preferably not more than 4 ft. high. A plot of the size indicated provides adequate spacing* for the screen, rain-gauge, grass minimum thermometer, earth thermometers, sunshine recorder on a pillar about 6 ft. high and a wind vane on a mast about 20 ft.

* This space is however insufficient if a Besson nephoscope (see p. 88) is also included.

high. Sufficient space is also available for a recording rain-gauge and for a bare patch 6 ft. square for observing the state of the ground. A sketch plan showing how the various instruments may be arranged is shown in Fig. 1. The main point to bear in mind is that the rain-gauges and grass minimum thermometer should be as far as possible from the fencing and from any substantial structures such as the screen and the sunshine pillar. Paths are not shown in Fig. 1, but it is convenient and permissible to add narrow paths so that most of the instruments can be approached without stepping on the grass.

THE OBSERVER

The services of a competent observer are required at the fixed observing hour or hours each day. His occupation should be such as to enable him to note the general character of the weather during the intervals between the observations at fixed hours. A competent deputy should be trained to take observations in the case of illness or absence of the regular observer.

§ 3. TIME

Punctuality is a matter of great importance in making meteorological observations. Public clocks in this country are regulated by time signals from the Royal Observatory at Greenwich, which are relayed daily at 10 a.m. by telegraph to all postal telegraph offices. Time signals are also broadcast daily by the British Broadcasting Corporation.

It is of the utmost importance to avoid ambiguity in the specification of times in meteorological returns, and the standard of time adopted for the observations should, therefore, be stated on each document.

STANDARD TIME

Standard time in Great Britain is the local mean time appropriate to the meridian of Greenwich. This is called Greenwich mean time (G.M.T.).

SUMMER TIME

The passing of the Summer Time Act, under which all public clocks are set one hour in advance of G.M.T. during the summer months, has introduced a source of confusion and uncertainty into meteorological records. It is impossible to use observations of any element showing diurnal variation for the purpose of comparing the conditions of one season with those of another, unless the same hour of observation is adhered to throughout, as we cannot disentangle the effect of changes in the meteorological conditions from effects introduced by the change in the hour of observing. Unless observers can arrange to make their observations one hour later by the clock during the months when summer time is in force, a great part of the utility of their observations is sacrificed. Unless this condition is fulfilled, observations are not accepted for inclusion in the tables of the *Monthly Weather Report* giving monthly summaries of observations at fixed hours of the day.

In any event, whether the observer is able to adapt his routine to the altered circumstances or not, it is most important that the standard of time to which the observations are referred should be explicitly stated on all meteorological documents. The possibility of ambiguity in specifying the times of occurrence of noteworthy phenomena, such as thunderstorms, or the times of commencement and end of heavy rains should also be kept in mind. The only completely satisfactory method of avoiding such ambiguity is to enter G.M.T. or B.S.T. (standing for British summer time), as the case may be, against each entry. Thus, if a phenomenon were observed at 12h. 45m. by the clock on a day when summer time was in force, it would be set down either as "at 12h. 45m. B.S.T." or else as "at 1145 G.M.T."*

NUMBERING OF THE HOURS

At meteorological observatories the hours are numbered consecutively from midnight 0h. to midnight 24h., the hours after noon are 13h., 14h. and so on. Times of 1.25 p.m. and 1.25 a.m. G.M.T., for example, are expressed either as 1325 and 0125 G.M.T. or as 13h. 25m. and 1h. 25m. G.M.T. respectively.

HOURS OF OBSERVATION

The International Congress held in Vienna in 1873 laid down that the hours of observing at second-order stations should be referred to local mean time in order that observations made at different stations of elements showing diurnal variations might be in the same phase, and therefore more directly comparable with one another. Zonal time is now very generally adopted and it has been decided that Greenwich mean time (G.M.T.) should be the standard time for British stations.

The following are the hours of observation in general use at stations of different types in Great Britain :—

Telegraphic reporting stations :—

Greenwich mean time	Summer time
0, 3, 6, 9, 12, 15, 18, 21	1, 4, 7, 10, 13, 16, 19, 22

Intermediate hourly observations are also made by some stations.

Climatological stations (second or third order) reporting daily observations by post only :—

Greenwich mean time	Summer time
9, 15, 21	10, 16, 22
9, 15	10, 16
9, 21	10, 22
9	10

* The introduction of double summer time in 1941 has made it more important still that the standard of time to which the observations refer should always be clearly stated. The abbreviation D.S.T. is suggested for double summer time.

Climatological stations (second or third order) reporting observations at 17h. daily by telegraph in addition to reports by post (health-resort stations) :—

Greenwich mean time	Summer time
9, 18*, 21	10, 18, 22
9, 18*	10, 18

§ 4. SITE AND ORIENTATION

The particulars required for the specification of the site of a meteorological station are its latitude and longitude, and the height above mean sea level of the site of the rain-gauge and of the cistern of the barometer.

Latitude and longitude can be taken from a 6-in. ordnance map and should be given to the nearest minute. It may be noted in this connexion that a degree of latitude corresponds nearly with sixty-nine statute miles, a degree of longitude in latitude 60° with half that distance.

Levels can be taken from an ordnance map which gives the exact height of a number of "Bench Marks." These are actually symbols ∇ cut in walls, milestones, and other permanent landmarks, generally speaking at the roadside, and are indicated in the ordnance map by the letters B.M. with the height in feet. A spirit level, a straight edge and a graduated staff enable an experienced observer to "run a line of levels" from the nearest mark to his station, but the local surveyor should be consulted.

The Irish Ordnance Survey datum is different from that of the English Ordnance Survey; all heights of Irish stations published by the Meteorological Office are corrected by subtracting 7 ft. from the height referred to local bench marks.

The height of the "observatory" is to be entered as the height of the ground on which the rain-gauge stands.

The orientation (points of the compass) may be determined by the following methods :—

(1) Determine from an ordnance survey map, the bearings with regard to the station of a number of conspicuous objects in the neighbourhood, such as church steeples or prominent points in the landscape features. The map on the scale of six inches to the mile will be found most suitable. The one-inch map may serve if the position of the station can be exactly identified upon it. The observer will then have little difficulty in identifying the directions of the principal points, north, east, south and west, and the intermediate points.

* Normally, but 1700 G.M.T. during summer time.

(2) Another method is based on the position of the Pole star, which is easily identified on any clear night. This star marks the north point with sufficient accuracy. The plane of the meridian, or in other words, the north-south plane, passes through the Pole star, the zenith and the observer.

(3) The method of determining the direction of the plane of the meridian from the position of the sun at noon, local apparent time (see p. 100) can be used. In this connexion the shadow thrown by a stick, carefully adjusted to be vertical, can be usefully employed to identify the meridian position of the sun.

(4) The orientation of a station can be and often is accurately determined by the magnetic compass; but the matter requires careful attention to the following points. A compass needle does not point to true north, the amount of the divergence differs slightly for different places, and it is also not absolutely constant for one and the same place. In the British Isles at the present time the magnetic needle points to the west of true north, and the amount of divergence for any place can be read off on the map (Fig. 2), on which the lines of equal declination or variation from true north are shown. All directions determined by compass bearing must be corrected by this amount before being adopted in meteorological work. True bearings are obtained by *subtracting* the westerly declination from the compass bearings.

The amount of the declination or variation from true north is at present decreasing by about 10 minutes per annum in the neighbourhood of the British Isles.

A second and more dangerous source of error in the determination of direction by means of a magnetic compass is connected with the disturbing effects which may be introduced by the presence of iron or steel bodies, or of powerful electric currents. When using a compass the observer must satisfy himself that all such possible sources of disturbance are absent. Even the presence of such small objects as iron nails in the support on which the compass is placed, or of knives or keys in the observer's pockets may cause serious errors of unknown magnitude.

SPECIFICATION OF DIRECTION

There are two methods of specifying direction :—

- (a) by compass points ;
- (b) by degrees.

(a) The thirty-two points of the compass are N., N. by E., NNE., etc. Every alternate point is shown in Fig. 3. For meteorological purposes the setting of the compass dial should be according to geographical, not magnetic bearings.

ISOAGONALS OR LINES OF EQUAL WESTERLY MAGNETIC
DECLINATION, 1942·5 (June, 1942)

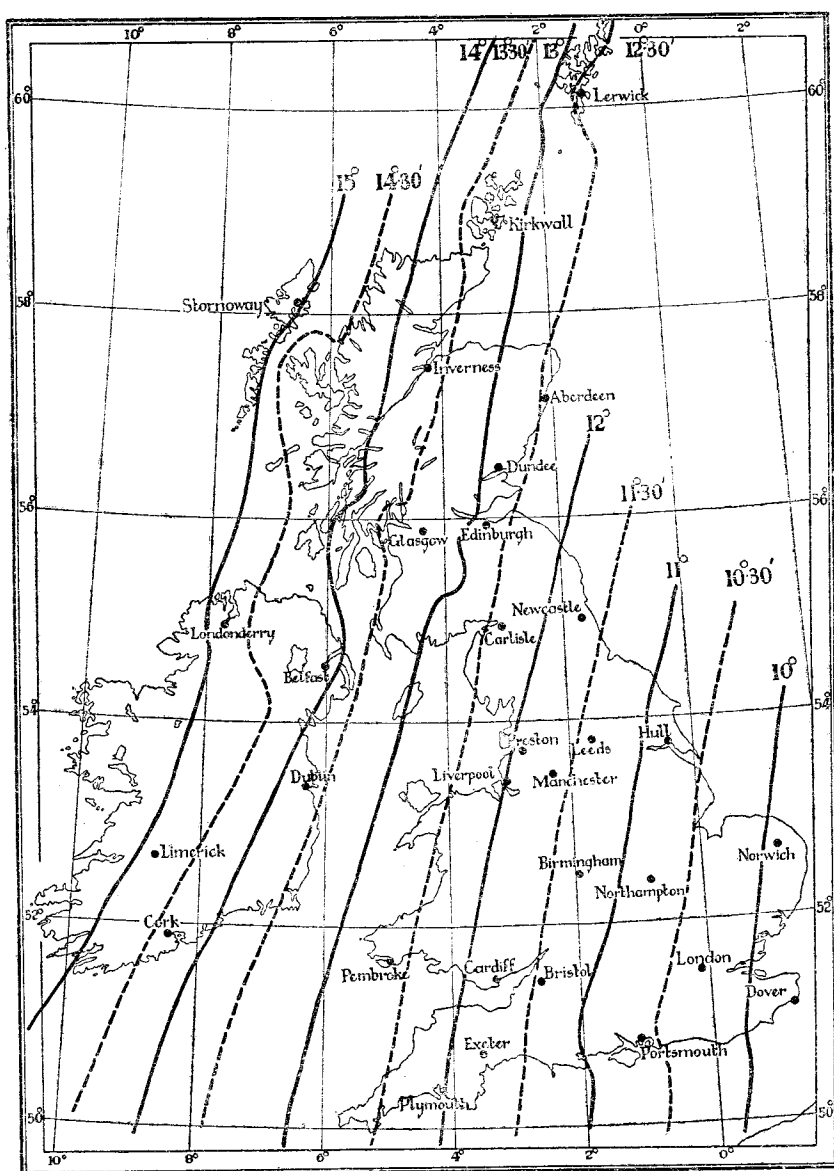


FIG. 2

The lines are redrawn from the magnetic ordnance survey map for 1933·5 adjusted to the epoch 1942·5 with the aid of observations for 1942 at the British Observatories, Lerwick ($60^{\circ}1' \text{ N.}, 1^{\circ}2' \text{ W.}$), Eskdalemuir ($55^{\circ}3' \text{ N.}, 3^{\circ}2' \text{ W.}$) and Abinger ($51^{\circ}2' \text{ N.}, 0^{\circ}4' \text{ W.}$). The annual change of magnetic declination varies from about $-9'$ to $-12'$ increasing from south-east to north-west.

(b) When direction is specified by degrees the zero of reckoning is geographical north, and the measurement is carried round the complete circle in a clockwise direction. For example, east is 90° , south is 180° , west is 270° and north 360° . The scheme is shown in Fig. 3.

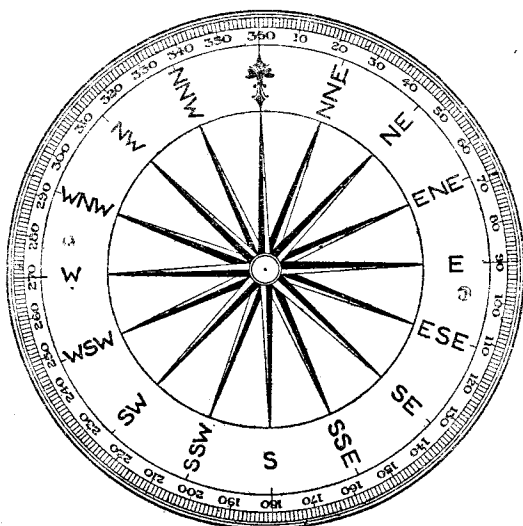


FIG. 3

§ 5. THE POCKET REGISTER

All the original observations should be written down at the time of observation in a properly ruled note-book, which should be preserved for reference in case any question should subsequently arise about them. Pocket registers suitably ruled for the requirements of different types of stations are obtainable through the Meteorological Office. The readings should not be jotted down on odd scraps of paper with the intention of copying them subsequently. In general, all observations made at any one particular hour should be written on the same line of the pocket register.

Doubtful entries should be marked with a query. Should observations be missed altogether, the words "no observations" should be written in the corresponding columns.

Punctuality is of the greatest importance. Should the observations be taken more than 10 minutes earlier or later than the fixed hour, a note to that effect should be made in the margin.

In addition to the observations at fixed hours, unusual phenomena such as fogs, thunder, or hailstorms, etc., and the time and day of their occurrence and their duration, should be noted in the "remarks" column at the time or as soon thereafter as practicable. It is important to state the standard of time used (*see* p. 6).

The pocket register should also contain a record of all changes in the equipment of the station or in the exposure of the instruments,

and of the times when the latter are cleaned or adjusted. The most trivial details of actual fact in these matters frequently prove useful at a later date.

A clear record of changes in the hours of observation owing to the recurrence of summer time should also be kept.

§ 6. THE PERMANENT REGISTER*

The observations entered in the pocket register should be copied in ink into appropriately ruled permanent registers. The Meteorological Office issues to its observers monthly forms appropriate for the requirements of different types of stations, in which the arrangement of the columns follows closely that of the forms recommended by the International Meteorological Committee in 1874, which, though modified in details, is still followed in essentials in the meteorological publications of most countries. From such forms the monthly means and summaries can be prepared with a minimum of labour.

It should be remembered that, as the name implies, the permanent register, if carefully compiled, forms a record which will retain its usefulness long after the observer and the officials at the central office to which it is sent for custody have yielded up their places to others. It is, therefore, important that the position of the station, its height above mean sea level, the standard of time to which the observations are referred and other details which it is necessary to know for a proper interpretation of the observations should be entered on each form.

Especial care is necessary in stating the hours of observation in summer, when civil time (*i.e.*, railway and Post Office time) differs from Greenwich time. The headings of most of the columns are self-explanatory. Should any alteration be necessary in any heading in order to describe more accurately the observations entered under it, the change should be made on *each form*. In copying from the pocket register care should be taken to enter corresponding figures vertically under each other so that the columns may be added easily, and to show clearly for each entry the position of the decimal point. The latter is of particular importance when entering the figures for rainfall and sunshine. Queries appended in the pocket register to doubtful readings should be copied on to the permanent register. The permanent register should be despatched to the Meteorological Office within a week of the close of the month to which it refers, and observers are strongly recommended to keep it up to date in readiness.

§ 7. THE MERCURY BAROMETER

The barometer in general use in the British Isles is the Kew pattern station barometer. We shall, therefore, first give instructions for that instrument and subsequently indicate how to manage the Fortin barometer, which is another type of instrument suitable for stations, but more difficult to handle.

* Detailed instructions regarding the method of completing each of the different kinds of form for the permanent register are issued as Supplements to this Handbook.

GENERAL CAUTION

Attention may at this stage be called to the necessity for exercising great care in handling a barometer. Should it be required to move the instrument, first incline it very gently, so as to allow the mercury to flow very slowly to the top of the tube. With the tube thus filled the barometer may be transported with safety in a horizontal or in an inverted position (cistern end uppermost), provided it is not subjected to sudden concussions. If carried upright in its usual position, *i.e.*, with a free mercury surface in the tube, the heavy mercury striking against the glass will probably cause breakage. In a Fortin barometer the plunger, which will be found at the base of the cistern, must be screwed up until the mercury very nearly fills the tube, before the instrument is moved. (See p. 21.)

TO MOUNT THE INSTRUMENT

Having selected a position in accordance with the instructions given on p. 2, screw the socket, which will be found in the case, to the support. Lift the barometer carefully from its case and slip the hinged part of the suspension arm into the socket. Take care that the screws which secure the instrument in its gimbals are screwed home, otherwise it may slip through its supports. The method of suspension in gimbals secures that the scale is vertical *when the instrument is hanging quite freely*. Any deviation from the vertical causes the reading to be too great.

When in position the barometer should be at such a height that the observer can read the scale comfortably while standing upright. To facilitate setting, a white screen or a sheet of white paper should be fixed to the wall behind the scale.

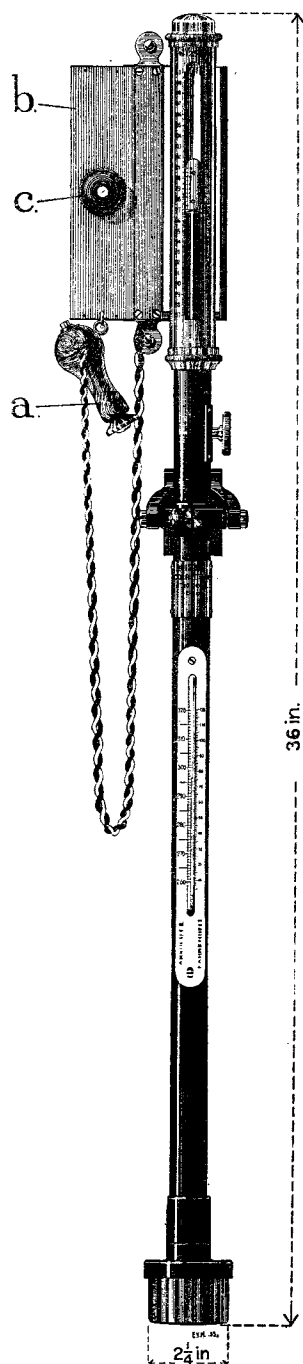


FIG. 4.
NEW PATTERN BAROMETER
WITH ILLUMINATOR

No observation should be taken until at least two hours have elapsed after fixing, in order that the mercury may have time to acquire the temperature of the air.

UNITS OF GRADUATION

Mercurial barometers for this country were at one time graduated to give the height in inches of the mercurial column which balances the pressure of the atmosphere. Later the advantages of graduating the instruments in units of pressure instead of units of length have been recognised, and barometers of the Meteorological Office are now graduated in millibars. As explained later (p. 17) the inch and millibar scales on a barometer are graduated to read correctly at different temperatures and the uncorrected readings may therefore appear not to agree.

TO TAKE AN OBSERVATION

(1) **Attached thermometer.**—Observe and note in the appropriate column of the pocket register the temperature of the thermometer attached to the barometer. The temperature should be read on the scale graduated from about 265° A. to 305° A. The temperature should be noted to the *nearest half-degree*.

The reading of the attached thermometer should be noted before setting and reading the barometer as changes in temperature due to the presence of the observer are likely to affect the thermometer more quickly than the mercury in the tube.

(2) **Tap the instrument** two or three times with the pads of the fingers.

(3) **Illumination.**—If the natural illumination is insufficient to set the barometer, illuminate *the white screen or paper behind the instrument*. If the fixed lights are not conveniently placed for this use a hand lamp, held in the left hand in front and slightly to the left side of the barometer. *Do not place a lighted match or other naked light behind the instrument*, as this frequently leads to very inaccurate setting.

Barometer Illuminator.—A self-contained illuminator, designed in the Meteorological Office, is shown in Fig. 4. It consists of two parts: (a) a small hand light for reading the attached thermometer and the scales, (b) a fitting to be attached to the wall behind the upper part of the barometer tube. This fitting is provided with a strip of opal glass, illuminated from behind by means of two small flash-lamp bulbs, the current for these and for the hand light being supplied from a small dry battery accommodated within the case of the illuminator. The bulbs are caused to glow by pressing a bell-push (c).

When fitting the illuminator, the bell-push should be on the left, as shown in the illustration, and if the length of the supporting arm is insufficient to provide enough space between the wall and the barometer, a wooden packing-piece should be inserted between the wall and the bracket.

(4) **Setting the vernier scale.**—Turn the milled head at the side of the instrument until the lower edge of the small moveable scale, called the vernier, and also the lower edge of the sliding piece at the back of the instrument which moves with the vernier, appear in the same straight line and apparently touch the uppermost part of the domed surface of the mercury.

Care must be taken to touch the instrument as lightly as possible and on no account to set it when displaced from the vertical position.

When the adjustment has been made, no part of the mercury should be hidden by the vernier, and yet it should be impossible to see the white paper (*see* p. 13) between the bottom of the vernier and the *highest* point of the mercury surface. As the latter is curved the paper will of course be visible at the sides (*see* Fig. 5.)

The object of the sliding piece at the back of the instrument is to ensure that the observer's eye is at the same level as the top of the mercury column; if this is not the case, serious errors are made. Errors of this nature which are liable to be made whenever the index and the scale on which it is read are not in the same plane are known as **errors of parallax**.

NOTE.—The scale of the Kew pattern barometer is graduated so as to allow for variations in the level of the mercury in the cistern and no adjustment is therefore needed for such changes.

(5) **Reading the Scale.**—The operation of reading consists of two parts. *First.*—Note the value of the scale division *next below* the

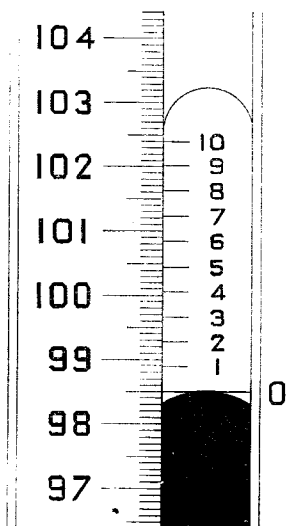


FIG. 5 READING THE SCALE
(Millibar Graduations.)

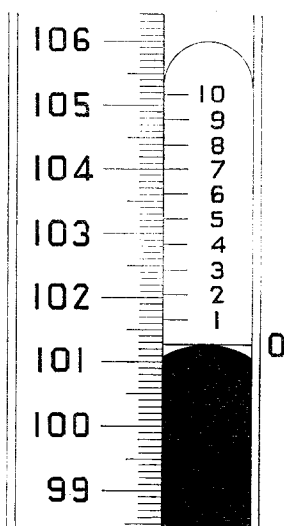


FIG. 6

zero division on the vernier which is marked O in Figs. 5 and 6. The scale is graduated in *millibars*, but to save engraving the final "0" is omitted on many barometers from each of the values engraved on the fixed scale, so that the mark opposite 98, for example, indicates 980 millibars. In modern Meteorological Office pattern instruments however the O is engraved after the other figures. In Fig. 5 O is supposed to be in the same straight line as the fifth (the long) division above the scale division numbered 98, in other words with the graduation 985 millibars. In Fig. 6 the graduation next below O is the second above the graduation numbered 101; its value is therefore 1012 millibars.

Second.—Look along the vernier for a division which is in one and the same straight line with a scale division. The value of this division on the vernier gives the decimal place. In Fig. 5 the vernier division 0 (or 10) is exactly coincident with a scale division; the reading of the barometer is therefore 985.0. In Fig. 6 the vernier division 7 is exactly opposite a scale division; the barometer reading is therefore 1012.7. Enter the reading in the pocket register.

Caution.—Always check the reading after entering it in the pocket register. Be very careful to avoid errors of 5 or 10 mb.

Inch graduations.—The normal method of subdividing the scale and vernier of an inch barometer is illustrated in Fig. 7. The scale is divided into tenths and twentieths of an inch. The method of reading is as follows:—

Having set the lower edge of the vernier plate into coincidence with the top of the mercury meniscus, read the value of the scale division next below the vernier zero. In the example (Fig. 7) this value is 29.650 in. Next look along the vernier and note the graduation which coincides with a scale division. The main divisions (marked 1, 2, 3 ---) on the vernier each represents ten thousandths, *i.e.*, .010 in., and the smaller, intermediate divisions each represents two thousandths, *i.e.*, .002 in. In the example, the third small division above the main division marked 3 is seen to coincide with a scale division. The vernier reading is, therefore, $.030 + 3 \times .002$ or .036 in. This is to be added to the scale reading, 29.650, thus:—

Reading on scale	...	...	...	...	29.650
Reading on vernier	...	...	...	...	00.036
Reading to be entered	...	...	...	...	29.686 in.

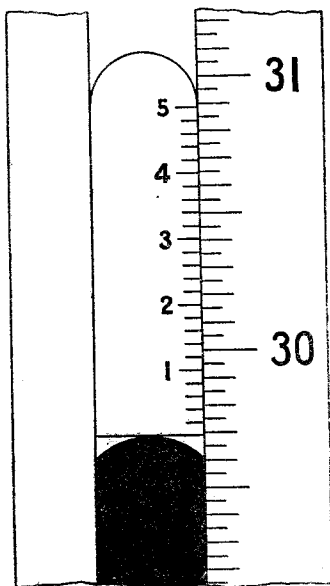


FIG. 7.
READING THE SCALE
(Inch Graduations.)

When no vernier division is in exact coincidence with a scale division, the mean of the readings of the two vernier divisions nearest to coincidence should be adopted.

Special Caution.—The attention of the observer is drawn to the fact that errors of 0.05, or less frequently of 0.10 inch, *i.e.*, errors in counting the number of divisions on the fixed scale, are very liable to occur unless great care is taken.

REDUCTION OF BAROMETER READINGS

Before readings taken at different times and in different places can be compared with one another, it is necessary to apply to them certain corrections or reductions. These comprise—

- (1) the correction for index error,
- (2) the correction for temperature,
- (3) the reduction for latitude
necessitated by the variation
of gravity with latitude,
- (4) the reduction for height above
sea level.

Index error.—The residual errors in the graduation of the scale are determined for each instrument at the National Physical Laboratory by direct comparison with the standard instruments of that institution, and are set out in official certificates. The certificates issued by the Laboratory are of two forms. Those for instruments tested subsequently to January 1, 1924, state the corrections in millibars to be applied at different points in the scale. Certificates issued before that date specify the *standard temperature* for different parts of the scale at which the instrument would read correctly. The standard temperatures are usually in the neighbourhood of 285°A. , that being the temperature at which a perfect instrument gives correct readings in latitude 45° . The corrections given in certificates in the old form may be converted to index corrections by the following table, which applies to instruments of the Kew pattern :—

Standard temperature.	Barometer reading (mb.).					Standard temperature.
	880	920	960	1000	1040	
Index Correction	(mb.).	(For sign	of correc	tion, see	below.)	
$^{\circ}\text{A.}$						$^{\circ}\text{A.}$
282.0	.45	.47	.49	.51	.53	288.0
282.5	.37	.39	.41	.43	.45	287.5
283.0	.30	.32	.33	.34	.36	287.0
283.5	.23	.24	.25	.26	.27	286.5
284.0	.15	.16	.17	.17	.18	286.0
284.5	.07	.08	.08	.09	.09	285.5
285.0	0	0	0	0	0	285.0

The correction is negative for all the standard temperatures in the left-hand margin, and positive for all the standard temperatures in the right-hand margin.

Correction for temperature.—The millibar scale of a barometer is graduated in most cases to read correctly (after due application of the correction for index error) at a temperature of 285°A. , and if the temperature of the instrument, as indicated by the attached thermometer, differs from that value a correction must be applied in order to allow for the expansion or contraction of the mercury and the scale. The amount of the correction is shown in Tables I, II and III for mercury barometers with brass scales (pp. 138–41.)

A few of the earlier millibar barometers were, however, graduated to read correctly when the temperature of the instrument was 0°C. Barometers of the Fortin type graduated in inches should read correctly when the temperature of the whole instrument is 28.6°F. ,

this temperature being equivalent, so far as the instrument is concerned, to the combination of temperatures of 62° F. for the brass scale and 32° F. for the mercury (62° F. is the temperature at which the English unit of length is defined, 0° C. the corresponding temperature for the metric scale). For inch barometers of the Kew pattern the table of temperature corrections supplied with the instrument should be used.

Reduction for latitude.—The force of gravity varies slightly with latitude, and a correction has to be applied on this account to the readings of mercury barometers. Barometers are graduated to read correctly (after due application of the corrections for index error and temperature) in latitude 45° N. or S. The amount of the correction, appropriate at sea level, in different latitudes is given in Table VI (p. 148). The force of gravity also varies with height above sea level, but the amount of the variation is so small that it may in general be neglected. It should, however, be included when dealing with observations made at great heights. Appropriate tables will be found in the "International Meteorological Tables."

Reduction to mean sea level.—Barometer readings taken at places at different levels cannot be directly compared until they have been reduced to the same level. Synoptic charts are based on simultaneous readings taken at a large number of stations and the readings have to be reduced to a common level before they are entered on the charts. Mean sea level is the common level adopted by general agreement for countries where the majority of the stations are below a level of about 500 metres. To make the reduction the observed reading (duly corrected for index error, temperature and latitude) has to be increased by an amount equal to the pressure exerted by a column of air equal in height to the height of the station, under corresponding conditions of pressure and temperature. Table IV (p. 142) gives the amount of the correction for selected heights up to 1,000 ft., corresponding with certain dry-bulb temperatures, when the pressure at station level is 1000mb. For other pressures the correction is in proportion. Conditions appropriate for intermediate heights and dry-bulb temperatures not given in the table, can be found by interpolation. Table V (pp. 144-7) gives similar information for barometers graduated in mercury inches.

Barometer correction cards.—The reduction tables given on pp. 138-48 are not intended for regular daily use by observers. The frequent interpolations which they necessitate would be cumbersome in the extreme. As each observer always uses the same barometer, set up in a fixed position, it is better to prepare for his use a special set of tables of reduction in such detail as to render any necessary interpolation easy.

The Meteorological Office issues to its observers suitable detailed tables on receipt of the following particulars—

- (1) copy of the certificate from the National Physical Laboratory,
- (2) height of cistern of barometer above mean sea level,
- (3) latitude of the station.

Two forms of table are in use, one for barometers graduated in millibars and used at stations at heights up to about 500 ft., and one for barometers graduated in mercury inches and for barometers graduated in millibars at heights exceeding 500 ft. The former (A.M. Form 1270) follows the method described in the *Quarterly Journal of the Royal Meteorological Society*, **40**, 1914, p. 185. The corrections for index error, temperature, latitude and a correction for level appropriate to a standard air temperature are combined into a single main table with arguments pressure and attached thermometer, while variations of air temperature are allowed for in a preliminary table in which the attached thermometer is adjusted by an amount depending on the dry bulb reading.

It is the **adjusted** attached thermometer which is used as argument in the main table.

A specimen reduction table of this type is appended, p. 20, and the following example will show how it is used :—

Example—Attached thermometer $287^{\circ}\text{A}.$; barometer as read $1012\cdot3\text{mb.}$; dry bulb $54^{\circ}\text{F}.$

The adjustment to the attached thermometer corresponding with a dry bulb of $54^{\circ}\text{F}.$ is $+1^{\circ}\text{A}.$ The adjusted reading of the attached thermometer is therefore $288^{\circ}\text{A}.$ The barometer correction corresponding with 1020mb. , the nearest value in the table to the observed value $1012\cdot3\text{mb.}$ and an attached thermometer reading of $288^{\circ}\text{A}.$ is $+2\cdot9\text{mb.}$ The corrected reading of the barometer is therefore $1015\cdot2\text{mb.}$

A.M. Form 1270.

SPECIMEN BAROMETER CORRECTION CARD (Millibar Scale)
 BAROMETRIC CORRECTION AND REDUCTION TO MEAN
 SEA LEVEL

Place—South Kensington

Latitude—51° 30' N.

Height above M.S.L.—66 ft.

Barometer—No. M.O. 1701.

(1) Adjust the reading of the attached thermometer by **adding** the amounts given below :—

Dry bulb
in screen.Correction
to attached
thermometer.Dry bulb
in screen.Correction
to attached
thermometer.

Below 24° F.

0° A.

56°–94° F.

+2° A.

24°–55°

+1

(2) Apply to the observed reading of the barometer the correction of the following table corresponding most nearly with the barometer reading and the adjusted reading of the attached thermometer.

Adjusted Reading of Attached Thermometer.	Correction to be applied.						Adjusted Reading of Attached Thermometer.	Correction to be applied.					
	940	960	980	1000	1020	1040		940	960	980	1000	1020	1040
°A	mb.	mb.	mb.	mb.	mb.	mb.	°A	mb.	mb.	mb.	mb.	mb.	mb.
271	+5.5	+5.6	+5.7	+5.8	+5.8	+5.9	291	+2.3	+2.3	+2.3	+2.3	+2.3	+2.3
272	5.4	5.4	5.5	5.6	5.6	5.7	292	2.1	2.1	2.2	2.2	2.2	2.2
273	5.2	5.3	5.4	5.4	5.5	5.6	293	2.0	2.0	2.0	2.0	2.0	2.0
274	5.0	5.1	5.2	5.3	5.3	5.4	294	1.8	1.8	1.8	1.8	1.8	1.8
275	4.9	5.0	5.0	5.1	5.1	5.2	295	1.7	1.7	1.7	1.7	1.6	1.6
276	4.7	4.8	4.9	4.9	4.9	5.0	296	1.5	1.5	1.5	1.5	1.5	1.5
277	4.6	4.6	4.7	4.7	4.8	4.8	297	1.3	1.3	1.3	1.3	1.3	1.3
278	4.4	4.5	4.5	4.6	4.6	4.7	298	1.2	1.2	1.2	1.2	1.1	1.1
279	4.2	4.3	4.4	4.4	4.4	4.5	299	1.0	1.0	1.0	1.0	0.9	0.9
280	4.1	4.1	4.2	4.2	4.2	4.3	300	0.9	0.8	0.8	0.8	0.8	0.7
281	3.9	4.0	4.0	4.1	4.1	4.1	301	0.7	0.7	0.7	0.6	0.6	0.6
282	3.8	3.8	3.9	3.9	3.9	4.0	302	0.5	0.5	0.5	0.5	0.4	0.4
283	3.6	3.6	3.7	3.7	3.7	3.8	303	0.4	0.3	0.3	0.3	0.2	+0.2
284	3.4	3.5	3.5	3.5	3.5	3.6	304	0.2	+0.2	+0.2	+0.1	+0.1	0.0
285	3.3	3.3	3.3	3.4	3.4	3.4	305	+0.1	0.0	0.0	0.0	-0.1	-0.2
286	3.1	3.1	3.2	3.2	3.2	3.2	306	-0.1	-0.2	-0.2	-0.2	0.3	0.3
287	3.0	3.0	3.0	3.0	3.0	3.1	307	0.3	0.3	0.4	0.4	0.5	0.5
288	2.8	2.8	2.8	2.9	2.9	2.9	308	0.4	0.5	0.5	0.6	0.6	0.7
289	2.6	2.6	2.7	2.7	2.7	2.7	309	0.6	0.7	0.7	0.7	0.8	0.9
290	+2.5	+2.5	+2.5	+2.5	+2.5	+2.5	310	-0.8	-0.8	-0.9	-0.9	-1.0	-1.0

Amounts entered in **BLACK** type must be added. Amounts entered in **ORDINARY** type must be subtracted.

The cards supplied for reducing barometric observations made in inches (Form 1121) or in millibars at heights above 500 ft. contain two main tables.

By means of the first, Table A (which is printed as Table III of this handbook) the reading is reduced to a temperature of 32° F. The reading corrected for temperature is then corrected for gravity, altitude and index error by reference to Table B.

THE FORTIN BAROMETER

This instrument differs from the Kew pattern barometer—

- (1) in the method of suspension,
- (2) in the fact that it is necessary to adjust the surface of the mercury in the cistern to a fixed level before taking an observation.

Instructions for mounting and handling.—To mount the barometer, fix the board which is supplied with it in the selected position, taking care that it is *vertical*. Both top and bottom of the board must be securely fixed to the wall by means of the lugs provided. Then lift the instrument out of its case and suspend it from the hook fixed to the upper part of the board. The lower end should be passed through the ring attached to the lower portion of the board.

The barometer is so constructed that the scale is vertical *when the instrument is hanging freely*. It should be permanently fixed in the vertical position by adjusting the length of the three screws which will be found on the ring through which the lower end passes until their ends just touch but do not displace the barometer. Any displacement from the vertical will cause the reading to be too great. The correctness of the adjustment should be tested from time to time by loosening the screws until the instrument hangs quite freely and then screwing them carefully up again. The screws must be kept clean and, if necessary, they may be slightly oiled; if they work stiffly it is impossible to make the adjustment satisfactorily.



FIG. 3.—FORTIN
BAROMETER

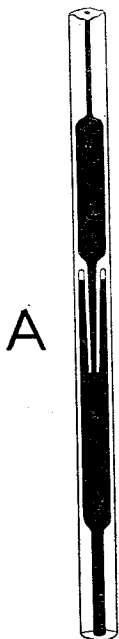
If a Fortin barometer is to be dismantled, the plunger, which will be found at the base of the cistern, should first be screwed up until the mercury very nearly fills the barometer tube. When this has been done the instrument may be transported in a similar manner to a Kew pattern barometer.

The scale of the Fortin barometer is so fixed that its zero coincides with a fixed index, called the **fiducial point**, in the cistern. Before taking an observation the surface of the mercury in the cistern must be made flush with the fiducial point, which usually takes the form of an ivory point or knife-edge. The adjustment is made by screwing the plunger at the base of the cistern until the ivory point is exactly coincident with its image in the mercury. A good light is as essential in making this adjustment as in setting the vernier, and artificial light should always be used whenever good daylight fails.

The adjustment should be made immediately after reading the attached thermometer. To prevent fouling of the mercury by prolonged contact with the index, the plunger should be unscrewed after each observation so as to leave the mercury surface well below the point of the ivory index.

If a dirt trap is fitted in the cistern of the barometer it should be used when necessary to clean the surface of the mercury in the cistern by unscrewing the plunger until the mercury surface falls below the trap and then screwing up the plunger until the trap is covered with mercury again.

In the Newman type of barometer, in use at many observatories, the scale is rigidly attached to the fiducial point which forms the zero of the scale. The adjustment is made by moving the scale up or down by means of a rack and pinion, and not by altering the position of the mercury surface.



DEFECTS OF BAROMETERS

The chief defect to which mercury barometers are subject is due to the accumulation of air in the space above the mercury. The presence of air may be detected by slightly inclining the tube so as to allow the mercury to flow slowly to the top of it. If a sharp metallic "click" is heard as the mercury strikes against the glass it may be assumed that no air is present. To expel air when present the instrument should be carefully inverted (the precautions described above being taken, *see* p. 13) and gently tapped while in this position. In the case of Fortin barometers this treatment generally suffices to remove the air, but in the case of a Kew pattern barometer in which the tube is very much constricted, it may be necessary to send it to an instrument maker for repair. It should be sent subsequently to the National Physical Laboratory, for a redetermination of the index error.

To prevent air and moisture working their way into the "vacuum" of a Kew pattern barometer, a small funnel or "pipette" is inserted between the cistern and the top of the mercury column (*see* Fig. 9). With this arrangement the air gets entrapped at the shoulder A and does not appreciably affect the reading of the barometer.

THE TESTING OF A BAROMETER BY MEANS OF DAILY WEATHER CHARTS

The accuracy of a barometer may be tested roughly by comparing its indications with the pressure values deduced from the isobaric charts published in the *Daily Weather Report*. For this purpose readings should be taken at 0600 G.M.T., corrected for temperature, and reduced to mean sea level and latitude 45° by the methods given above. The height of the barometer cistern above M.S.L. must be known. On the charts the isobars or lines of equal pressure are given for M.S.L. for the epoch 0600 on the day of the chart. The position of the station on the map being known, the approximate pressure at it can be read off from the isobars. Suppose for instance that the station lies between the isobars marked respectively 1010 and 1012, and suppose further that the perpendicular distance of the station from the isobar for 1010 is three-fourths of the whole distance between the isobars; the reading at the station may then be taken as 1011.5 millibars. As a general rule the pressure can be determined in this manner with an error of not more than 1 millibar, but as the method involves some uncertainty a series of comparisons should be made. If observations for a complete calendar month are available, the *Monthly Weather Report* should be consulted.

§ 8. THE THERMOMETERS AND THEIR EXPOSURE

The normal equipment of a climatological station includes two "ordinary" thermometers (for use as dry and wet bulb), a maximum thermometer and a minimum thermometer. It is important that these thermometers should be of suitable design and robust construction. The pattern recommended is the "sheathed" pattern, examples of which are illustrated at A, D and E of Fig. 10 (*see also* p. 31). In this pattern the engraved stem of the thermometer is enclosed in an outer glass sheath terminating in a flat button which provides, in the case of the dry and wet bulbs, a means of suspending the thermometer in the screen. Apart from the protection to the graduations given by the outer sheath, the absence of wooden or porcelain mounts makes it easy to place the thermometers in the screen so that the whole range of graduations is visible and so that the bulbs of the four thermometers are nearly in the same plane.

If thermometers mounted on porcelain or wooden bases are used, care should be taken to see that the "tens" as marked on the mounts are in register with the corresponding graduations on the stem. After a period of use the stem of the thermometer may work loose and slip relatively to the mount, thus introducing a possibility

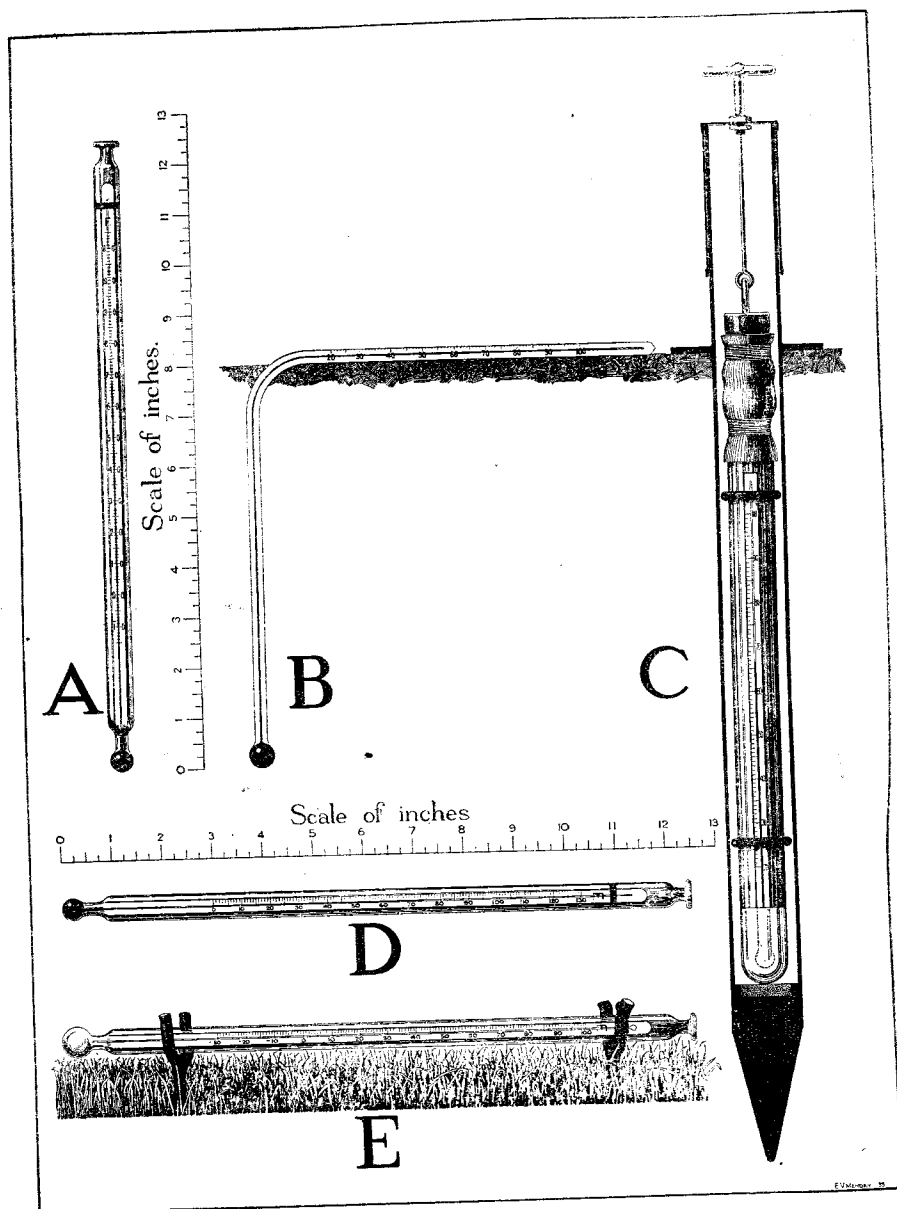


FIG. 10. STANDARD PATTERNS OF THERMOMETERS

- A—Sheathed pattern dry or wet bulb thermometer.
- B—Bent-stem earth thermometer.
- C—Symons pattern earth thermometer and steel tube.
- D—Sheathed pattern maximum thermometer.
- E—Sheathed pattern minimum thermometer on grass.

of error in reading. Cases have even been known in which a thermometer has been repaired by fitting a new tube to an old mount on which the tens graduations were quite inappropriate.

Other points of importance in selecting thermometers for meteorological purposes are—

- (a) the range of graduations should be suitable,
- (b) the scale of graduation should be sufficiently open to permit of estimation to 0.1° F. without difficulty,
- (c) the bulb should be of standard dimensions.

The ranges appropriate to different types of thermometers are given below under the respective headings. In regard to (b) the Meteorological Office uses thermometers of the maximum, minimum and ordinary types made in accordance with the British Standard Institution Specification No. 692-1936, which provides for a length of stem of not less than 7.5 in. for 130° range. In regard to (c) the approved diameters of bulbs are between 0.35 in. and 0.45 in. for ordinary and maximum thermometers and not exceeding 0.65 in. for minimum thermometers.

STEVENSON SCREEN

The dry bulb, the wet bulb, and the maximum and minimum thermometers require to be exposed in a screen of approved pattern. The screen in general use in this country and in the Colonies is the Stevenson screen; it is a box or cupboard with double louvred sides (see Fig. 11). The clear internal dimensions of the standard screen are :—height $16\frac{1}{2}$ in., width 18 in., depth 12 in. A large screen, the width of which is 3 ft. 5 in., but which is otherwise of similar design, has been introduced to provide accommodation for a thermograph and a hygrograph, as well as for the four thermometers. Details of the screen are given in Form 63, "Instructions for making thermometer screens of the Stevenson type"*. A somewhat smaller type of screen designed to take four thermometers of the sheathed pattern all lying horizontally has also been introduced (see Fig. 11A).

Exposure.—The conditions which the exposure of the screen should satisfy have been described on p. 3. It should be firmly screwed to the stands which consists of four legs, either of wood or steel, so that its base is about 3 ft. 6 in. above the level of the ground. The legs must be sufficiently rigid and be buried sufficiently deeply in the ground to prevent shaking during gales. To prevent rot the portions below ground should be creosoted or otherwise treated if the legs are of wood. There should be no boarding or slab under the base of the screen. The opening of the screen should face towards the north (south in southern hemisphere) or, preferably, somewhat east of north so that the sun may not shine on the instruments while observations are being taken in the evening.

Arrangement of the thermometers in the screen.—In arranging the thermometers in the screen the following points must be borne in mind :—

- (1) There should be a space of at least 3 in. between the bulbs of the thermometers and the top, bottom or sides of the screen.

* Form 63 can be obtained from H.M. Stationery Office, price 6d.; post free 7d.

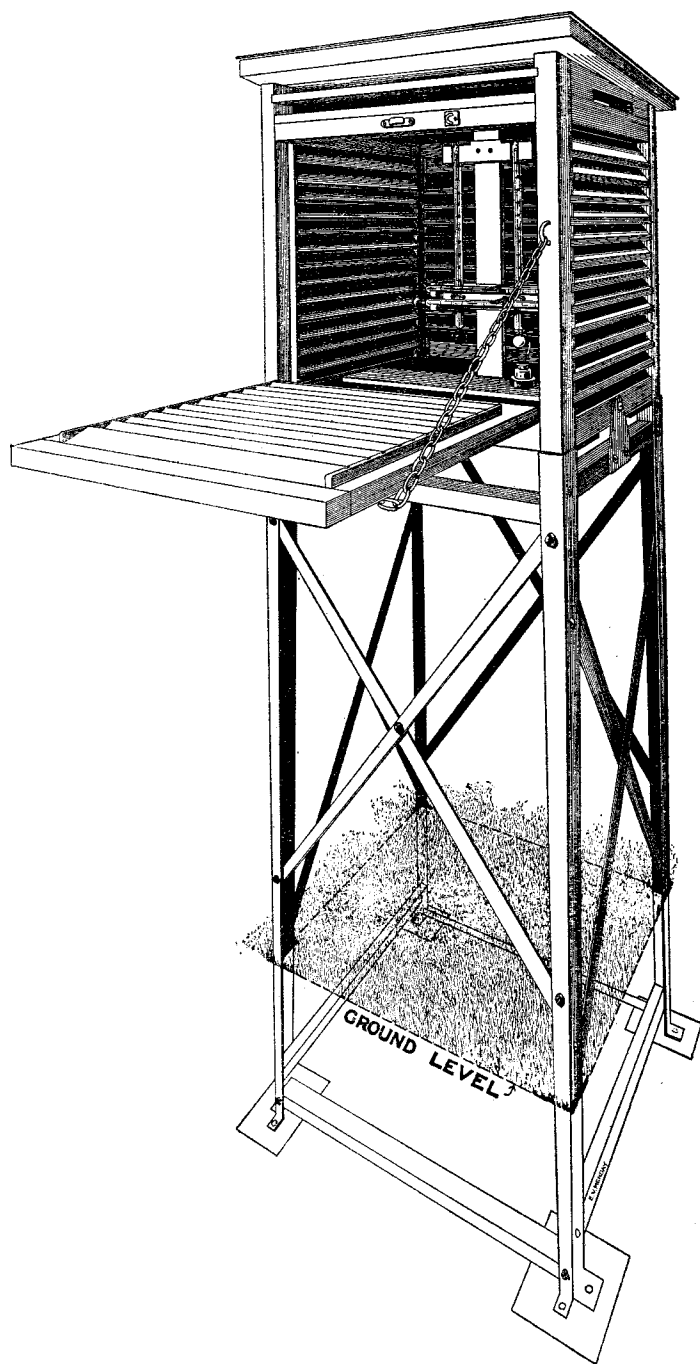


FIG. 11. STEVENSON SCREEN WITH SHEATHED THERMOMETERS
AND STEEL STAND

- (2) The thermometers should be so arranged that all parts of their scales can be read without the necessity for moving any one of them, or for viewing the stem at an angle.
 - (3) The maximum and minimum thermometers should be arranged so that strong winds cannot shake them, as jolting often leads to displacement of the indices. The instruments require to be moved once a day for setting, and therefore cannot be permanently fixed in position.
- A suitable arrangement is shown in Fig. 11.

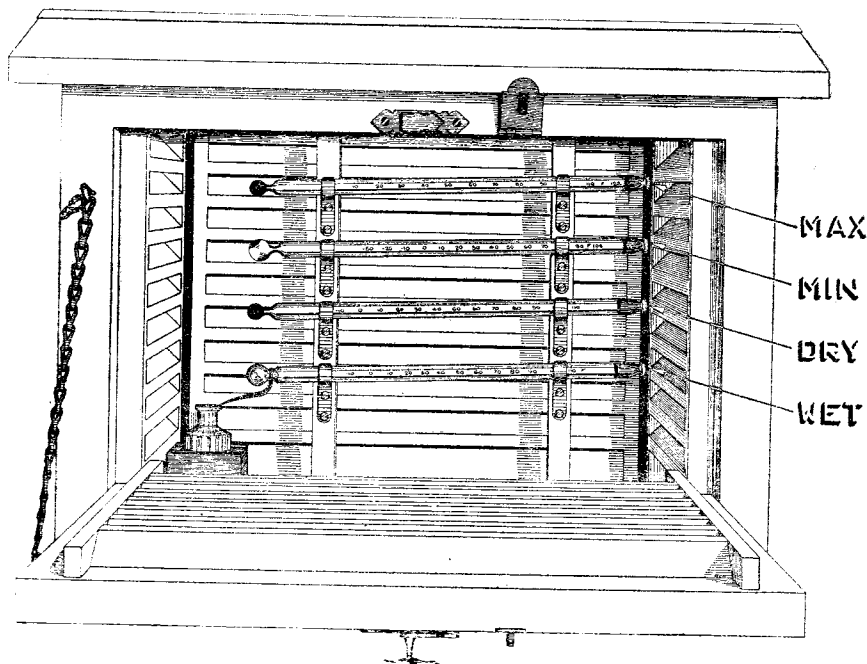


FIG. 11A. BILHAM SCREEN
MAXIMUM THERMOMETER

The maximum thermometer is designed to record the highest temperature experienced during a given period. In the pattern adopted by the Meteorological Office the tube is reduced in bore about 1 in. from the bulb. The reduction is made either by drawing the tube or by the insertion of a small piece of glass. The thermometer is hung nearly horizontally with the bulb end slightly lower than the other. (*See also* p. 28.) As the temperature rises the mercury expands and is forced past the constriction, but, when a subsequent fall of temperature causes a contraction of the mercury, the thread breaks at the constriction so that its upper end remains in position and registers the highest temperature reached.

The stem of the maximum thermometer should be graduated from 0° F. to 130° F. for use in temperate climates.

MINIMUM THERMOMETER

The minimum thermometer records the lowest reading experienced in a given interval. The most common type of instrument is a spirit thermometer having a small index immersed in the spirit in the stem. It is hung like the maximum thermometer. As the temperature falls the index is carried towards the bulb by the spirit, but if the spirit subsequently expands, in consequence of a rise of temperature, it flows past the index, which is left in position to indicate the lowest temperature reached.

The stem of the minimum thermometer should be graduated from -30° F. to 100° F. for use in temperate climates.

GENERAL HINTS ON THE MANAGEMENT OF THERMOMETERS

The thermometers should be kept clean and the bulbs bright. If water has condensed on any of the thermometers it should be wiped off, and several minutes should be allowed to elapse before the readings are taken.

Blacking the scale.—Should the divisions of the scale become indistinct they may be renovated by rubbing a shoemaker's "heel-ball" or a dark-coloured crayon along the tube. The need for such renovation does not arise in the case of "sheathed" thermometers.

Bubbles in stem of spirit thermometers.—Spirit thermometers should be regularly examined for the presence of bubbles in the stem or bulb, or of drops of liquid in the upper part of the stem or in the small bulb at its end. To remedy this defect when present, swing the thermometer briskly at arm's length in a quadrant of a circle. By repeating this treatment several times detached globules of spirit may be made gradually to approach the main bulk of spirit, and ultimately the whole thread becomes continuous. Another method is to hold the thermometer upright with its bulb in a vessel of water which should then be slowly heated. Allow the spirit to rise until it passes into but does not fill the "safety chamber" at the top of the tube. The air bubbles can thus be caused to travel up the stem into the safety chamber. During this process it is advantageous to shake the thermometer occasionally. After all visible drops or bubbles have been removed the thermometer should be left for some hours in a vertical position, bulb downwards, to allow any liquid which may have collected on the walls of the tube to drain down to the main column. The presence of condensed spirit on the walls of the tube causes the thermometer to read low and this defect cannot always be cured by leaving the instrument to drain in a vertical position. In such a case the upper part of the stem should be carefully warmed and the treatment should be repeated until on testing in water the reading of the thermometer agrees with that of the dry bulb to within two or three tenths of a degree F.

Mercury thermometer with broken column.—Occasionally the thread of a mercury thermometer is found to be broken; the defect may generally be remedied by swinging as described above

Defects of maximum thermometers.—Maximum thermometers are subject to two defects—

- (1) The mercury may recede from its maximum position when the temperature falls below the maximum to a greater or a less extent. The observer should accordingly test his instrument occasionally by gently heating it and noting whether the mercury column retains its position in the tube. The test should be made with the stem nearly horizontal.
- (2) The mercury may slip forward when the instrument is brought into a horizontal position after setting.

Both these defects may in most cases be remedied by altering the inclination at which the instrument hangs.

The management of the wet-bulb thermometer will be discussed under the heading "Hygrometers." (See p. 34.)

READING THE THERMOMETERS

Sighting. Errors of parallax.—As the mercury thread and the scale of the thermometer are not in the same plane, errors of **parallax** (see p. 15) will be made unless the observer is careful that the straight line joining his eye to the top of the mercury or spirit column is at right angles to the stem of the instrument. This condition will be fulfilled if he places his eye at the same level as the end of the mercury column if the thermometer be vertical, or directly in front of it if it be horizontal.

Degree of accuracy required.—To obtain satisfactory values for the vapour pressure and relative humidity from readings of dry

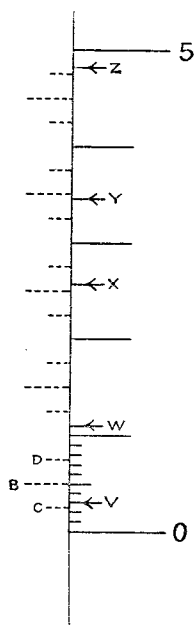


FIG. 12

and wet-bulb thermometers, the *difference* between the readings of these instruments must be known with accuracy, and hence the observer should estimate fractions of a degree to the nearest *tenth*. To do this he should imagine the degree divided into two equal parts as at B (Fig. 12), and each of these halves again subdivided into quarter degrees as at C and D. If the end of the mercury column falls within the first quarter the correct fraction will be $\cdot 1$ or $\cdot 2$, and the observer must use his discretion which value he enters in the register. Similarly the values $\cdot 3$ and $\cdot 4$ fall within the second quarter; $\cdot 5$ represents the half degree; $\cdot 6$, $\cdot 7$, and $\cdot 8$, $\cdot 9$ fall within the third and fourth quarters respectively. Thus, in Fig. 12 the points V, W, X, Y and Z read $0\cdot 3$, $1\cdot 1$, $2\cdot 6$, $3\cdot 4$ and $4\cdot 8$ respectively.

Maximum and minimum thermometer readings need only be entered to *whole* degrees. The readings should be estimated to tenths, the corrections for the errors of the thermometers should then be applied, and the values should be rounded off to the nearest whole degree before entry in the pocket register.

When a thermometer reading is entered to a whole degree it should be the nearest degree, *e.g.*, if the corrected reading be between 49° and 50° but nearer 50° than 49° , 50° should be entered. Where the corrected reading comes half way between two degrees, *i.e.*, at 0.5 , the *odd* degree should be entered in the return. For example, corrected readings of 48.5 and 49.5 would both be entered as 49° , while 50.5 and 51.5 would both be entered as 51° .

Rapidity.—The thermometers should be read as rapidly as is consistent with accuracy in order to avoid changes of temperature due to the presence of the observer. When observing with a lamp care must be taken not to heat the thermometers.

Reading.—When taking a complete observation proceed as follows :—

- (1) Enter the readings of the dry and wet bulbs and the maximum and minimum thermometers in the appropriate columns of the pocket register. In the cases of the first three instruments the position of the end of the mercury column is observed ; in that of the minimum thermometer the position of the end of the index *furthest from the bulb* must be noted.
- (2) Check these entries—
 - (a) By comparing them again with the instrumental readings, special attention being directed to making sure that no errors of 5° or 10° have been made.
 - (b) By ascertaining that the reading of the maximum thermometer is as high as or higher than the dry bulb reading taken at or since the previous setting, and similarly, that the reading of the minimum thermometer is as low as or lower than the dry bulb reading taken at or since the previous setting. The maximum reading should be at least as high as, and the minimum at least as low as those readings.

NOTE.—If, after checking the readings at the time of observation, the reading of either the maximum or the minimum thermometer is found to be inconsistent with the readings of the dry bulb, the cause of the discrepancy may be :—

- (a) an error in the reading of the dry bulb at one of the preceding times of observation during the period covered by the reading of the maximum or minimum thermometer ; or
- (b) an actual discrepancy between readings correctly taken, owing to some defect in one of the instruments.

The reading which, on examination, the observer considers to be erroneous, should be adjusted by him and the adjusted value should be entered in the records enclosed in brackets, thus (59). The actual reading of the instrument should also be inserted in the pocket register and in the permanent register, in both cases in the "Remarks" column.

Setting.—To set the maximum thermometer, it is necessary to cause mercury to flow from the stem past the constriction until the empty space between the bulb and the constriction is completely filled. The usual method is to grip the thermometer by the middle firmly in the right hand, the bulb being outward, and swing it from the shoulder. The swing should begin with the right arm raised about 45° above the horizontal and it should end about 30° beyond the vertically downward position. The swing must be vigorous but it should begin and end smoothly. Great care should be taken to prevent the thermometer striking anything, including the observer's own person or clothing. The coat should be held with the left hand; this not only avoids the danger of breaking the thermometer by its coming into contact with a swinging coat, but also assists in getting a good swing. Maximum thermometers with solid stems (not sheathed) are very liable to break immediately above the bulb. They should therefore be gripped near the bulb rather than in the middle when setting.

In the case of a sheathed maximum thermometer the following method of setting is also effective. Grip the end of the thermometer (*not* the bulb end) as if it were a tennis racket and hold the arm horizontal and forwards. Move the thermometer *rapidly* to and fro in a half circle by motion from the wrist, the knuckles being alternately upwards and downwards. Though the motion should be as rapid as possible, avoid an absolute jerk, which would tend to break the thermometer.

To set the minimum thermometer the instrument should be sloped gradually, bulb upwards, until the index touches the end of the column of spirit. Tap gently if necessary.

After setting, a maximum thermometer and the index of a minimum thermometer should read the same as the dry bulb within a fraction of a degree. This check should always be applied; if the minimum thermometer is then found to be reading low, examine the thermometer for bubbles in the stem and other defects (p. 28.)

When replacing the minimum thermometer in the screen, incline the thermometer *bulb upwards* and place the other end of the thermometer on its support first. When replacing the maximum incline the thermometer *bulb downwards* and place the bulb end of the thermometer on its support first.

TERRESTRIAL RADIATION THERMOMETER

(*Grass Minimum*)

As injury to the tissues of growing plants is not caused until the temperature has fallen appreciably below the freezing point of water (32° F.), a "ground frost" is regarded as having occurred when the thermometer on the grass has fallen to 30° F. or below. If the thermometer is read to tenths of a degree the limit is 30.4° F. A minimum thermometer exposed freely over a grass surface is used to enable the number of "ground frosts" at night to be determined. The minimum thermometer is a "sheathed" pattern instrument in

which the graduations on the stem are protected by an outer glass jacket, and is identical with the thermometer used for recording the minimum temperature in the screen (*see also* p. 27). The stem should be graduated from -30° F. to 100° F. The plot on which the thermometer is exposed should be covered with *short* grass, 1 in. to 2 in. in length. The thermometer should be supported on two Y-shaped pieces of wood with its bulb just touching the tips of the blades of grass. Care should be taken that the bulb does not touch the supports (*see* E, Fig. 10.)

The proximity of walls, trees, benches, etc., should be avoided, and it should be noted that the use of any protecting cage for the thermometer would invalidate the readings.

When the ground is covered with snow, the thermometer should be supported immediately above the surface of the **snow**, as near to it as possible without actually touching it.

If snow has fallen during the night in sufficient quantity to cover the thermometer, the snow should be carefully removed and the thermometer read at the morning hour of observation. The reading should be entered in the registers and marked "?". A note should be made in the remarks column "grass minimum buried in snow."

Hours of reading and setting.—The instrument should be read at the hour of the morning observation (0700 at telegraphic stations). After the reading is taken the thermometer should be placed in the shade, bulb downwards, until the evening, when it should be reset and replaced on its supports; but a thermometer having a black sheath over the end furthest from the bulb should be left in position during the daytime as the black sheath becomes hot in sunshine and this causes any condensed spirit to rejoin the main column. If for any reason, the practice of setting the thermometer in the evening cannot be followed, application should be made to the Meteorological Office for a black sheath to be supplied.

Bubbles in stem.—During great cold and also when exposed to strong sunshine, grass minimum thermometers are very liable to the development of bubbles in the bulb or stem or to the condensation of drops of spirit in the upper part of the stem. Great care must be taken to avoid errors due to either of these causes. In summer the instrument should be placed in the shade during the day-time in a vertical position, bulb downwards, while not in use. It is convenient to fix in the floor near a back corner of the Stevenson screen a small pill-box so that the bulb of the thermometer can rest in the box in the day time, the stem being supported in the corner of the screen. These difficulties can be largely overcome by covering the end of the thermometer stem furthest from the bulb with a black sheath about $2\frac{1}{2}$ in. in length. The heat absorbed by the sheath prevents condensation of spirit in this part of the stem and makes it unnecessary to take the thermometer indoors during the day-time, except in very hot weather. Directions for making the spirit

column join up again, should it become broken up, have been given on p. 28. If the spirit column is found to be broken at the time of observation the reading should not be entered and a note should be inserted in the "Remarks" column.

SOLAR RADIATION THERMOMETER

(Black bulb in vacuo)

For obtaining some indication of the maximum intensity of the sun's radiation which penetrates the atmosphere a maximum thermometer having the bulb and 1 in. of the stem coated with dull

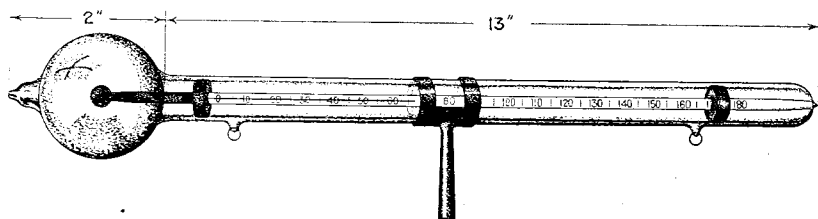


FIG. 13. SOLAR RADIATION THERMOMETER

lamp-black is sometimes used. The whole is enclosed in a glass jacket which is exhausted of air. The stem of the solar radiation thermometer should be graduated from 10° to 200° F.

The site for exposure may be near the thermometer screen. The proximity of trees, buildings, etc., must be avoided. The instrument is fixed on a wooden stand at the same height above the ground as the thermometers in the screen (4 ft.). The bulb must be most fully exposed to the sun at its highest, and hence the tube should be directed from east to west. Readings are taken once a day only, preferably just before sunset or in the late evening. The method of setting is similar to that used in the case of the maximum thermometer. (See p. 30.)

The difference between the maximum shown by the "black bulb" and the maximum reading in the thermometer screen is usually regarded as an index of the intensity of solar radiation, but owing to the difficulty of securing and maintaining uniformity in the essential features of the instrument it is not possible to obtain concordance between readings of different specimens, consequently the climatic significance of the readings is qualitative rather than strictly quantitative. The instrument is therefore no longer regarded as forming part of the equipment of a normal station.

EARTH THERMOMETERS

The temperature of the ground at depths of 1 ft. or more is measured by means of thermometers suspended in iron tubes sunk into the earth to the required depth. The depths most commonly adopted are 1 ft. and 4 ft. (See C, Fig. 10.) Consideration should be given to the selection of a site for the thermometers where the soil is representative of the locality.

The thermometers are enclosed in glass tubes and their bulbs are embedded in paraffin wax so as to render them insensible to sudden changes of temperature. This allows for their being drawn to the surface and read before the temperature has time to change appreciably. As underground changes of temperature are very slow, the loss of sensitiveness, resulting from the coating of wax, does not lead to inaccuracies in the determination of the temperature of the earth.

The stems of earth thermometers for use in the British Isles should be graduated from 20° F. to 100° F. and have open scales, say 12° F. to the inch, so as to facilitate reading to tenths.

Water must not collect in the iron tubes; to prevent this the tubes are fitted with small metal covers to which the chains holding the thermometers are fastened. If present, water may be removed by means of a sponge or other absorbent material tied to the end of a stick.

In reading take care to raise the thermometer to the same level as the eye so as to avoid errors of parallax (*see* p. 15) and read to a tenth of a degree as quickly as possible. The instrument should be screened from direct sunshine during the process.

At certain agricultural stations readings are taken with special thermometers at depths of 4 in. and 8 in. installed on a patch of bare soil. These thermometers have their stems bent at right angles, so that the bulbs can be sunk into the ground to the required depth and the scales read *in situ*. (*See* B, Fig. 10.)

SEA TEMPERATURE

An "ordinary" mercury thermometer having a porcelain scale but provided with a special metal protector is used for taking sea temperature, the procedure being as follows:—

(a) **At coast stations.**—Select a place where the water is not less than 6 ft. deep; plunge the thermometer, case and all, 1 ft. under water, and keep it there for three minutes, then take it out and promptly read off. If a canvas bucket and line are available throw the bucket into deep water (not less than 6 ft.). Haul in the full bucket. Put the thermometer into the water in the bucket, and after three minutes read the thermometer, holding it upright in the bucket with the bulb and the lower part of its stem in the water. Take care to avoid errors of parallax (*see* p. 15.)

(b) **At ship stations.**—Draw water from the sea surface in a canvas bucket, forward of ejection pipes. Place the thermometer and protector in the water for a minute or so, then throw away all the water and take a fresh sample. Hold the bulb immersed in this and read when the temperature becomes steady, keeping the bulb below the surface while reading.

THE WET-AND DRY-BULB HYGROMETER

The humidity of the atmosphere is usually determined from readings of dry and wet-bulb thermometers placed in a Stevenson screen. The combination of the two instruments is known as a "psychrometer."

A wet-bulb thermometer is made by coating the bulb of an ordinary thermometer with muslin kept moist with water. Its action depends on the fact that evaporation takes place from every free water surface as long as the air in contact with it is not saturated with aqueous vapour. The heat required to bring about this evaporation from the wet bulb is taken in part from the thermometer itself and hence a wet bulb generally reads lower than a dry bulb placed in the same screen. In a saturated atmosphere both instruments should read the same. In unsaturated air the amount of lowering depends on the rate of evaporation, and this in turn on the temperature and dryness of the air.

The relative humidity, dew point, pressure of aqueous vapour, etc., corresponding with various readings of dry and wet-bulb thermometers are obtained from tables.*

The stems of dry and wet-bulb thermometers should be graduated from -15° F. to 115° F. for use in temperate latitudes.

Mounting of the wet bulb.—The wet-bulb thermometer should be covered with a single thickness of thin clean muslin or cambric, which is kept moist by attaching to it a few threads of darning cotton (No. 8) dipping into a small reservoir of water placed near it. The muslin and thread must be entirely free from grease otherwise they will not keep moist. To remove grease they may be washed in water containing ammonia. Care must be taken that the muslin is stretched smoothly on the bulb, creases must be avoided as far as possible. The muslin may be tied on to the bulb with a cotton thread or it may be secured in position by looping two strands of the cotton used for supplying moisture to the bulb, in a clove hitch or in the manner shown in Fig. 14 at (a), so that four strands actually convey water to the wet bulb. In the case of thermometers with cylindrical bulbs a small “finger” of muslin should be sewn exactly to fit the bulb. After fixing the muslin it should be carefully trimmed with a pair of scissors; all superfluous material and all loose ends should be cut off.

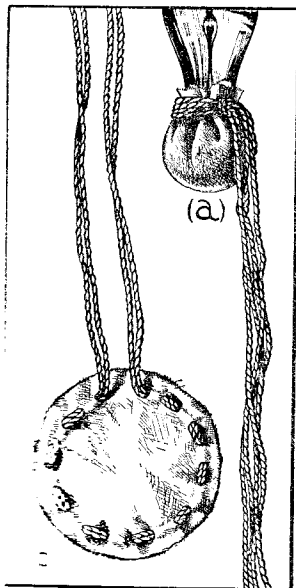


FIG. 14.
 (a) WET BULB
 (b) MUSLIN CAP

Muslin caps ready threaded with cotton are now available (see Fig. 14 (b)). These are slipped over the bulb and the thread is then pulled tight and tied.

The muslin must be clean and must, therefore, be changed before it becomes dirty. In country districts it will generally suffice to change it once a fortnight, but in towns this should be done oftener. At coast stations the muslin and wick and water should be changed immediately after

* *Hygrometric Tables* M.O. 265.

a storm with an on-shore wind, as salt carried by spray invalidates the readings of the wet bulb. The change should be made immediately after or some time before observing. At least 15 minutes should elapse between mounting and reading; if the clean water supplied is not at the temperature of the air a much longer time is required.

The water used for moistening the wet bulb must be soft; distilled water or rain water is to be preferred. If hard water is used the bulb and muslin become encrusted with a deposit and the readings become inaccurate. Sea-water must never be used. If distilled water is used it should be obtained from a chemist, not from a motor garage, where it is liable to be contaminated with acid.

The dates on which the muslin, wick and water are changed should be noted in the pocket register and transcribed to the monthly returns.

The vessel containing the water supply should be placed below and a little to one side of the bulb of the thermometer. In order to avoid breakage of the water vessel during frost, it should not be filled beyond the line of its widest part.

The part of the cotton thread exposed to the air should be between 3 in. and 6 in. in length, and must be kept as straight as possible. If it be allowed to hang in a loop, water will drip down from the lowest point of the curve and the reservoir will soon be emptied.

The value of the readings depends greatly on supplying moisture to the wet bulb at a sufficient rate. If the water reservoir is too far away from the thermometer, and in particular if it is too low, insufficient water may reach the muslin in warm dry weather and the thermometer will give a reading higher than the true temperature of evaporation. This defect will be accentuated if the wick is too thin, if the muslin is slack on the bulb, or if either the muslin or wick are dirty.

At places near the sea where the muslin on the wet bulb may rapidly become impregnated with salt from the air, the effect of the salt in raising the reading of the wet-bulb thermometer may be diminished :—

- (a) by arranging for the level of the water in the container vessel to be slightly above the level of the bulb of the thermometer, and fixing the wick in such a way that water drips very slowly from the bulb itself;
- (b) by raising the water vessel so that the water covers the bulb of the thermometer completely in the interval between observations. The vessel is lowered and the bulb exposed freely, but with the wick still dipping into the water, for at least 10 minutes before the time of observation.

These methods were tried experimentally at a number of stations in 1929-30, but the improvement over the ordinary method was not found to be sufficient to justify introducing the methods at the generality of stations.

Unless the vessel containing the water has a small neck it should have a cover (through which the cotton passes by a small hole) so that the air inside the screen may not be moistened by the evaporation from the vessel.

If the reading of the wet bulb is above that of the dry, make sure first that there is no error in reading, and that there is still an excess when the known corrections have been applied. The phenomenon usually occurs when the temperature is falling. The dry bulb follows the change of temperature with only a small time lag, but the wet bulb, being coated with muslin, has a greater lag; if the temperature is falling sufficiently quickly, this may produce the result mentioned*.

Management of wet bulb during frost.—The management of the wet bulb during frost or at times when the wet-bulb reading is below 32° is troublesome, as the freezing of the water on the conducting threads cuts off the supply of moisture to the muslin. In order to secure satisfactory results the bulb must be coated with a **thin** layer of ice from which evaporation takes place as from water. It is therefore necessary to wet the muslin slightly with **ice-cold** water by means of a camel hair brush or feather, **10 or 15 minutes** before observing. When there is likelihood of the wet-bulb temperature being below the freezing point, the observer should make a point of visiting the screen a quarter of an hour before the hour of observation in order to attend to the wet bulb. If he finds but little difference between the dry and wet bulbs the probable reason is that the ice covering has evaporated from the muslin. This will almost certainly be the case in dry windy weather. In such circumstances no reading should be taken until a new ice film has formed. After the moistening of the muslin the temperature generally remains steady at the freezing point, 32° , until all the water has been converted into ice, and it then commences to fall gradually to the true wet-bulb reading. No reading should be recorded until the temperature of the wet bulb has become steady.

The water used must be at the freezing point (it is best taken from under ice), otherwise a very much longer period is required for it to cool. As little water as is consistent with thorough moistening of the muslin should be used. If excess is put on not only is the time of waiting much increased, but a thick layer of ice forms on the thermometer which interferes with the accuracy of this and subsequent readings.

It often happens that after water has been applied the temperature of the wet bulb may fall considerably below the freezing point without the formation of ice, the water being supercooled. In such

* If the air temperature is below freezing point, it is possible for the ice-covered wet-bulb temperature to exceed the dry-bulb temperature. This occurs, normally in the presence of water-fog, when the vapour pressure exceeds that corresponding to saturation over ice at the air temperature. In recording such readings, which are of great interest, every precaution should be taken to eliminate errors due to lag and index errors.

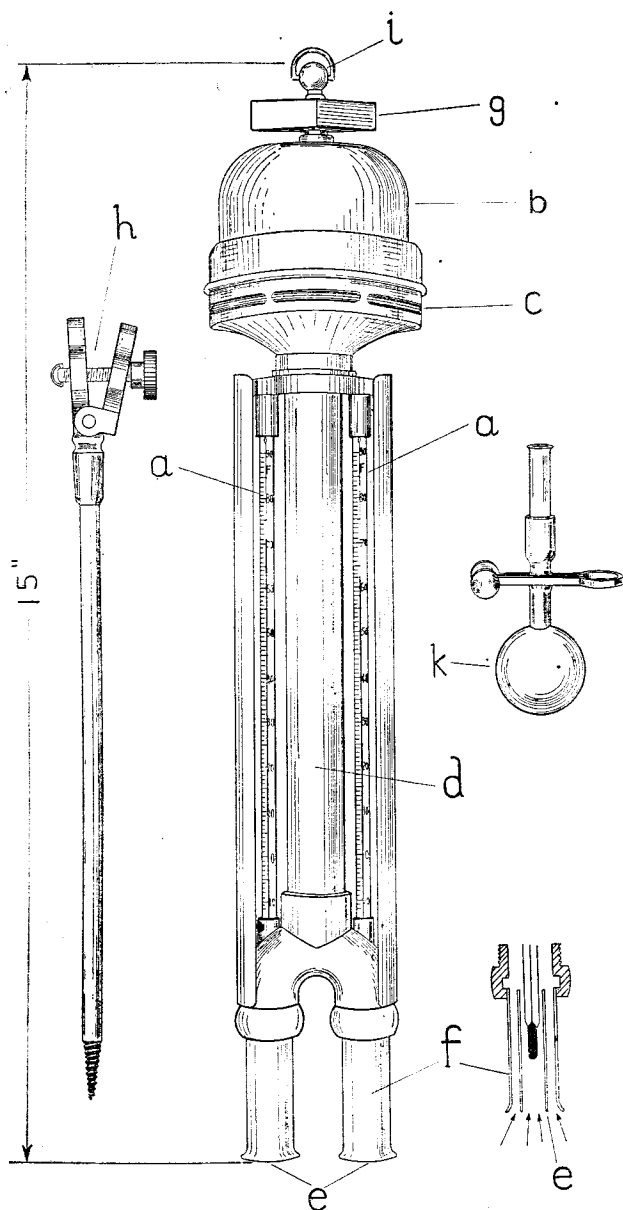


FIG. 15. ASSMANN PSYCHROMETER

a—the thermometers.
b—dome containing clockwork.
c—the fan and air outlets.
d—main air duct.
e—air inlets.
f—polished tubes protecting ther-
 mometers.

g—key for winding clockwork.
h—clamp for supporting the instrument.
i—the point of support of the instrument.
 The clamp holds the ball securely
 but allows the instrument to hang
 vertically.
k—injector for wetting muslin of wet bulb.

circumstances the water should be induced to freeze, *e.g.*, by touching the wet bulb with a fragment of ice (snow or hoar frost will do) on the end of a match stick. At the moment of solidification the temperature rises to 32° F. and then commences to fall again. The temperature finally reached should be entered as the correct wet-bulb reading.

ASSMANN PSYCHROMETER

The combination of the ordinary dry and wet-bulb thermometers, often known as Mason's psychrometer, is not a perfect instrument for the estimation of humidity, since the rate of evaporation from the wet bulb depends upon the rate at which the air is passing over it. A limit to the fall of temperature of the wet bulb is reached as soon as the loss of heat by evaporation is compensated by the gain of heat from the air moving past the bulb. The temperature of the wet bulb is practically independent of the speed of the air past the bulb when this exceeds 10 mi/hr. Moreover, readings of a dry-bulb thermometer in the Stevenson screen are not always unaffected by radiation and do not then indicate the true temperature of the air.

The Assmann psychrometer is designed to give precise measurements of temperature and humidity. By means of a clockwork fan air is drawn past the dry and wet thermometer bulbs. Hence the psychrometer is known also as the "aspirated psychrometer" and the thermometer bulbs are said to be "aspirated." Each bulb is protected from external radiation by two highly polished coaxial tubes (shown in Fig. 15). The instrument can be placed in strong sunshine without risk of solar radiation affecting the readings. A wind shield is provided for the purpose of preventing the aspiration being impaired by wind blowing in through the air outlets *c* (Fig. 15).

Special humidity tables* are required to obtain the relative humidity, dew point, and vapour pressure of the air from readings of the Assmann psychrometer. The psychrometer tables of the U.S. Weather Bureau are suitable for aspirated Fahrenheit thermometers because whirled thermometers are used by the Weather Bureau for humidity observations. Special tables for Centigrade thermometers were compiled by Professor Assmann and published by the Prussian Meteorological Institute.

Normally observations should be made with the instrument 4 ft. from the ground; the clamp may be screwed to a post or to the Stevenson screen at that height.

The muslin cover of the wet bulb must be kept clean and changed as often as necessary. The thermometers can be withdrawn by unscrewing the clockwork dome which holds them in position in the frame of the instrument.

The polished tubes should be kept bright by rubbing with clean leather. It is necessary to oil the bearings occasionally with a little good clock oil. The parts requiring attention will be easily reached if the dome cover to the clockwork be removed.

* The results may also be computed on the Bilham Humidity Slide Rule by means of the scales engraved in red (*see London, Met. Mag.*, 70, 1935, p. 254).

The following procedure should be followed when making an observation :—

- (a) Moisten the wet bulb. To do this the injector *k* (Fig. 15) is filled with distilled water and the bulb is pressed until water rises to the top of the glass tube. By means of the clip the rubber tube is closed so that water remains in the glass tube. The tube is then pushed up the right hand inlet of the psychrometer until the muslin surrounding the wet bulb is fully immersed in water and the injector is then withdrawn. *The wet bulb should never be moistened by using the injector as a squirt.*
- (b) Wind the clock.
- (c) Wait until the wet-bulb reading has become steady. (This usually takes about 2 minutes. Do not delay too long or the clock may slow down preparatory to stopping, thus reducing ventilation.)
- (d) Read the wet bulb.
- (e) Read the dry bulb.

Where access to electrical mains is available the clockwork motor may, with advantage, be replaced by an electric motor.

Whirling psychrometers.—In the whirling or “sling” psychrometer the aspiration is provided by whirling or rotating the thermometers which are mounted on a suitable frame for that purpose. The procedure is generally similar to that described in the preceding paragraph and similar humidity tables are appropriate. The readings must however be taken very rapidly in a place sheltered from direct radiation from the sun.

§ 9. WIND

For the complete specification of the wind at a given height above the ground it is necessary that we should know (1) the direction from which it is blowing and (2) its force or speed.

WIND DIRECTION

When recording wind direction, the point from which the wind comes should be stated. The methods of specifying directions, and for determining orientation have been described above, *see* pp. 9 and 11. All directions should be “true” and not “magnetic.”

When identifying wind direction the observer must be on his guard against mistaking local eddies due to buildings, trees, etc., for the general drift of air over the station. He may use as his guide the indications of a wind vane or those afforded by the direction of drift of smoke from elevated chimneys, the set of flags, etc.

If a wind vane be used care must be taken :—

- (1) That it is freely exposed on all sides and not affected by local eddies, etc.
- (2) That it moves freely. With most vanes it will frequently happen that the wind is too feeble to move them. In such circumstances the direction of drift of smoke, etc., must be used for determining wind direction.
- (3) That the cardinal points, if indicated on the vane, are correctly set, and that the vane is well balanced, *i.e.*, that it has no bias to set itself in a particular direction.

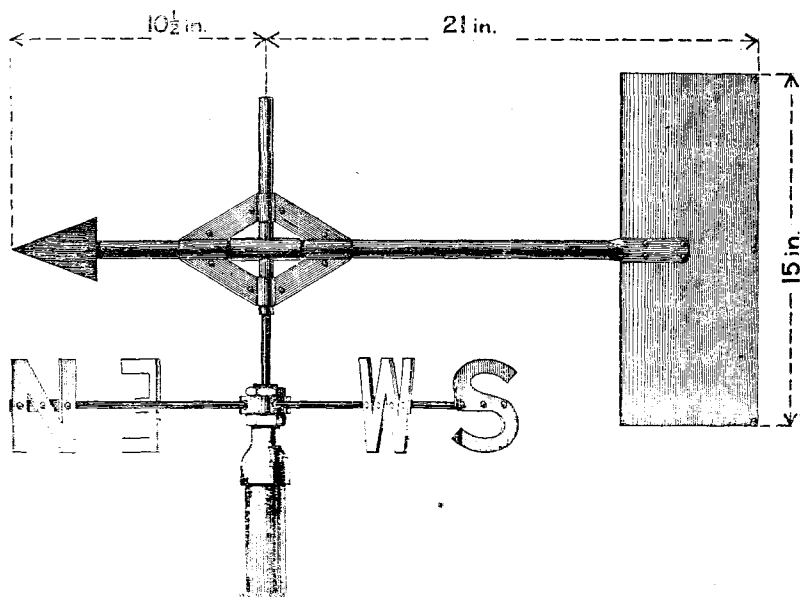


FIG. 16. WIND VANE

An excellent wind indicator is furnished by a streamer attached to a tall flagstaff in an open situation. A "drogue" or "wind sleeve" is even better as it is relatively insensitive to small eddies.

Whatever mode of observation is used, errors due to perspective are liable to be made unless the observer stands vertically below the indicator.

Wind Vanes.—The Meteorological Office wind vane Mk. I is illustrated in Fig. 16. The streamline fin is mounted on a long arm to provide a large turning moment about the axis, and thereby ensure an adequate sensitivity even in light winds. The arms carrying the direction letters N., S., E., W., are attached to a boss which can be clamped in the correct position below the vane spindle. The wind vane Mk. II differs in that its rotating part is carried on a revolving spindle; this is fitted at its lower end with a connecting sleeve, by means of which the vane can, if desired, be connected to a direction transmitting rod for the operation of a direct-reading dial some way below the vane. Such dials are usually improvised by their users, and are not normally supplied by the Meteorological Office.

For indication of wind direction at a distance the wind vane remote indicating, is available; this consists of a wind vane with electrical contact gear, connected by suitable multi-core cable to one or two indicators and a source of electric supply. The indicators have eight direction lamps, corresponding to the eight principal points of the compass, and indicate sixteen directions, two lamps lighting at the same time when the wind direction is intermediate between them. With this instrument, the vane can be set up at any distance from the indicators. Full instructions for installation are issued by the Meteorological Office. Provision is

made in these indicators for measuring wind speed in conjunction with a cup contact anemometer (*see* under anemometers); a lamp and buzzer in the indicator can be connected to the cup contact anemometer to take the place of the portable receiver otherwise used.

All Meteorological Office wind vanes have sockets for screwing to suitable steel pipe mounts; the sizes are:—

Wind Vane Mk. I 1¼ in. B.S.P.

Wind Vane Mk. II 1½ in. B.S.P.

Wind Vane, remote indicating 2 in. B.S.P.

The pipes should be firmly stayed in a vertical position.

WIND FORCE

Wind force is estimated on the numerical scale ranging from 0, calm, to 12, a hurricane, first adopted by Admiral Beaufort. The explanations originally given by Beaufort for guidance in estimating, had reference to a man-of-war of the period 1800–50. As vessels of this type have become obsolete these instructions now possess little more than historic interest.

The table on pp. 44 and 45 gives the specifications of the Beaufort Scale for use on land and at sea (provisional) agreed to at the meetings of the International Meteorological Committee. Those for use on land were agreed at the meeting at Warsaw in 1935 and those for use at sea were agreed provisionally at the meeting at Berlin in 1939. The table also includes specifications for coast use.

It will be noticed that the criteria referred to depend in many cases rather on the effects which the observer perceives on objects round about him than on his own physical sensations. By adopting this method an estimate of wind force may be obtained which is to some extent independent of the observer's actual position. The latter may be comparatively sheltered, but it should be such as to command a good view of a number of objects, by the behaviour of which wind force can be estimated.

Difficulties of exposure frequently render a good estimate of wind force preferable to a measurement with an anemometer. The latter can only record the speed of the sample of air which passes it, and unless the exposure is satisfactory this may differ greatly from the speed of the air at the same height in the open country.

VELOCITY EQUIVALENTS OF THE BEAUFORT NUMBERS

The equivalents of the Beaufort numbers given in the table on p. 45 are based on a large number of comparisons of estimates of wind force made by observers of long experience with the records of well-exposed anemometers. Actually the estimates made at the full hour were compared with the "run" of the wind recorded during the 60 minutes reckoned from 30 minutes before to 30 minutes after the hour. The final figures agreed very closely with the values given by the following formula

$$V = 1.87 \sqrt{B^3}.$$

when V is expressed in miles per hour, and B is the corresponding Beaufort number. This formula has therefore been adopted by the Meteorological Office for expressing the relation of force to velocity

and the figures given in the table are calculated from it, the first result being rounded off to the nearest whole number. The mean pressure exerted by the wind of given intensity depends on the shape and size of the object, but for circular or square plates from 1 sq. ft. to 100 sq. ft. in area, the relation between the velocity of the wind and the pressure it exerts may be represented approximately by the formula*

$$P = \cdot 003 V^2.$$

when P is expressed in lb. per square foot and V in miles per hour. From these two formulae we may deduce the following relation between pressure and Beaufort number :—

$$P = \cdot 0105 B^3.$$

For the metric system when the velocity v is expressed in metres per second, the pressure f in millibars, the corresponding formulae are

$$v = 0.836 \sqrt{B^3} \quad f = \cdot 0072 v^2.$$

$$\text{and } f = \cdot 005 B^3.$$

When considering all questions of wind velocity it must be borne in mind that the velocity in the strata near the ground is much influenced by the ground. The comparisons which led to the numerical relations quoted above were with anemometers exposed in open situations at a height of about 10 metres (33 ft.) above ground level. The equivalents specified in the table may, therefore, be regarded as applicable to such conditions.

They are also applicable when on account of neighbouring obstacles the height is increased by such an amount that the exposure is judged to be equivalent to that represented by a height of 10 metres in a perfectly open situation. For other heights scales of equivalents have been adopted at Meteorological Office stations, based on Hellmann's formula—

$$V_h = V_{10} [0.233 + 0.656 \log (h + 4.75)].$$

Where h is the "effective" height in metres, V_h the velocity at height h and V_{10} the velocity at 10 metres. From this formula the following values of the ratio of the velocity at height h to the velocity at 10 metres have been calculated* :—

Height in metres	...	2	3	4	5	10	15	20	25	30	35	40
Ratio of velocity to that at 10 metres.		.78	.82	.85	.89	1.00	1.08	1.15	1.20	1.24	1.28	1.32

The increase of wind with height is more rapid in proportion when the air is not much disturbed by convection, *e.g.*, in cold weather and at night. It is less rapid under the opposite conditions.

* For further details reference should be made to a report, entitled "Beaufort Scale of Wind Force" (official No. 180), published by H.M. Stationery Office, now out of print.

* For further details reference should be made to "The Velocity equivalents of the Beaufort Scale" by G. C. Simpson (*London, Prof. Notes.* 4, 1926, No. 44). Detailed instruction for the determination of Beaufort force from an anemometer record will be found in "Instructions for meteorological telegraphy," Supplement No. 1 to this book (M.O. 191/1).

Beaufort Wind Scale

SPECIFICATION OF THE BEAUFORT SCALE WITH STANDARD

Beaufort Number	Explanatory Titles	Specification of the Beaufort Scale for use at sea (provisional)	Specification of the Beaufort Scale for coast use
0	Calm	Sea like a mirror.	Calm.
1	Light air ...	Ripples with the appearance of scales are formed, but without foam crests.	Fishing smack* just has steerage way.
2	Light breeze ...	Small wavelets, still short but more pronounced. Crests have a glassy appearance and do not break.	Wind fills the sails of smacks which then travel at about 1-2 miles per hour.
3	Gentle breeze...	Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.	Smacks begin to careen and travel about 3-4 miles per hour.
4	Moderate breeze	Small waves, becoming longer; fairly frequent white horses.	Good working breeze, smacks carry all canvas with good list.
5	Fresh breeze ...	Moderate waves, taking a more pronounced long form; many white horses are formed. (Chance of some spray.)	Smacks shorten sail.
6	Strong breeze...	Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray.)	Smacks have double reef in mainsail. Care required when fishing.
7	Moderate gale†	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.	Smacks remain in harbour and those at sea lie-to.
8	Fresh gale ...	Moderately high waves of greater length; edges of crests begin to break into the spindrift. The foam is blown in well-marked streaks along the direction of the wind.	All smacks make for harbour, if near.
9	Strong gale ...	High waves. Dense streaks of foam along the direction of the wind. Sea begins to "roll." Spray may affect visibility.	—
10	Whole gale ...	Very high waves with long overhanging crests. The resulting foam, in great patches, is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shock-like. Visibility affected.	—
11	Storm	Exceptionally high waves (small and medium-sized ships might be for a time lost to view behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.	—
12	Hurricane ...	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	—

* The fishing smack in this table may be taken as representing a trawler of average type and trim. For larger or smaller boats and for special circumstances, allowance must be made.

† For the purpose of statistical summaries, winds of force 7 are not regarded as gales.

EQUIVALENTS OF THE NUMBERS OF THE SCALE

Beaufort Number	Specification of Beaufort Scale for use on land based on observations made at land stations	*Mean Pressure	Equivalent speed in miles per hour at 33 ft.	Limits of Speed in the Open				
		At 10 m. (33 ft.)			At 6 m. (20 ft.)			
		Lb. per sq. ft.		Knots	Miles per hour	Metres per second	Miles per hour	Metres per second
0	Calm ; smoke rises vertically.	0	0	Less than 1	Less than 1	Less than 0.3	0-1	0-0.5
1	Direction of wind shown by smoke drift, but not by wind vanes.	0.01	2	1-3	1-3	0.3-1.5	2-3	0.6-1.7
2	Wind felt on face ; leaves rustle ; ordinary vane moved by wind.	0.08	5	4-6	4-7	1.6-3.3	4-7	1.8-3.3
3	Leaves and small twigs in constant motion ; wind extends light flag.	0.28	10	7-10	8-12	3.4-5.4	8-11	3.4-5.2
4	Raises dust and loose paper ; small branches are moved.	0.67	15	11-16	13-18	5.5-7.9	12-16	5.3-7.4
5	Small trees in leaf begin to sway ; crested wavelets form on inland waters.	1.31	21	17-21	19-24	8.0-10.7	17-21	7.5-9.8
6	Large branches in motion ; whistling heard in telegraph wires ; umbrellas used with difficulty.	2.3	28	22-27	25-31	10.8-13.8	22-27	9.9-12.4
7	Whole trees in motion ; inconvenience felt when walking against wind.	3.6	35	28-33	32-38	13.9-17.1	28-33	12.5-15.2
8	Breaks twigs off trees ; generally impedes progress.	5.4	42	34-40	39-46	17.2-20.7	34-40	15.3-18.2
9	Slight structural damage occurs (chimney pots and slates removed).	7.7	50	41-47	47-54	20.8-24.4	41-48	18.3-21.5
10	Seldom experienced inland ; trees uprooted ; considerable structural damage occurs.	10.5	59	48-55	55-63	24.5-28.4	49-56	21.6-25.1
11	Very rarely experienced ; accompanied by wide-spread damage.	14.0	68	56-63	64-73	28.5-32.6	57-65	25.2-29.0
12	—	Above 17.0	78	64-71	74-82	32.7-36.7	>65	>29.0

For Beaufort numbers 13 to 17 see next page.

For Beaufort numbers 13 to 17 see next page.

* The pressure due to the wind on any object exposed to it arises from the impact of the air on the windward side and suction on the leeward side ; the mean pressure depends on the shape and size of the object. The values given are for standard air density and a disc of 1 sq. ft. in area, but they apply with fair approximation for circular or square plates from 1 sq. ft. to 100 sq. ft. in area.

The following limits for Beaufort numbers 13 to 17 were adopted in January, 1944.

Beaufort Number	Limits of Speed in the Open at 10m. (33 ft.)	
	Knots	Miles per Hour
13	72-80	83-92
14	81-89	93-103
15	90-99	104-114
16	100-108	115-125
17	109-118	126-136

ANEMOMETERS

The question of exposure enters into all matters connected with the measurement of wind to a very large extent ; so much so, that it is hardly an exaggeration to say that the exposure is of more importance than the actual instrument. At many stations the orographical features are such that the provision of an anemometer is not to be recommended, unless it be intended to investigate such special points as the effect of the configuration of the land on the wind.

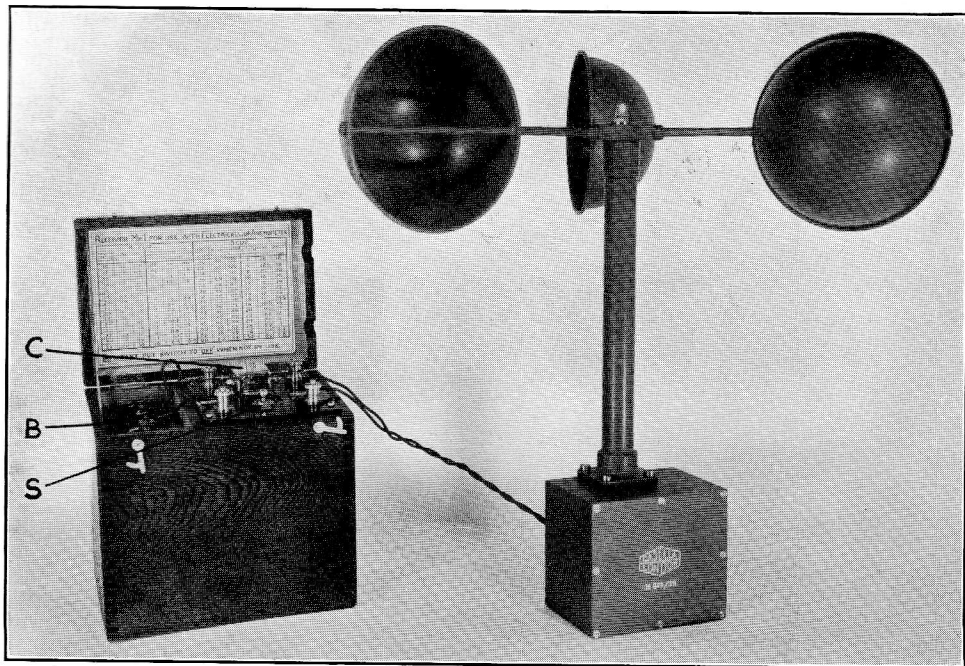
The site selected for the instrument should be such that it is not sheltered by trees or buildings, and it should be remembered that the eddies caused by such obstacles extend both vertically and horizontally to great distances. In a perfectly open and flat situation a lattice tower or mast some 30 to 40 ft. in height affords an excellent exposure.

Cup Anemometers.—Cup anemometers of the Meteorological Office pattern consist of a rotor with three hemispherical or conical beaded-edge cups mounted on a vertical spindle, which is carried in suitable bearings in a housing. The cups are 5 in. in diameter ; the radius of the path of the cup centres is 6.30 in. ; the "factor", or ratio of the distance travelled by the wind to the distance travelled by the cup centre, has a mean value of 2.76 for hemispherical cups and 2.98 for conical cups.

The types now in use are as follows :—

- (1) Anemometer, cup contact, Mk. I, for use with portable (buzzer) receiver ; this instrument is illustrated in Plate I and has a tall stem, hemispherical cups and mechanically operated contact gear in a rectangular housing.
- (2) Anemometer, cup contact, Mk. II, also for use with buzzer ; illustrated in Plate IA. It has a short stem, conical cups, tilting mercury switch contact gear and symmetrical circular housing.

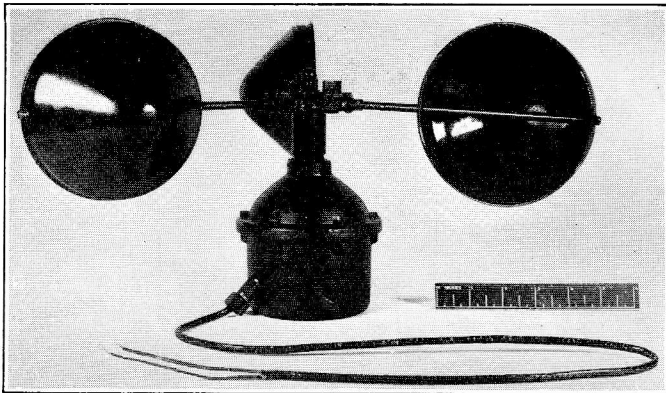
Both the above anemometers make one contact for 1/20 mile of wind, and the number of contacts made in 3 minutes is the wind speed in miles per hour.



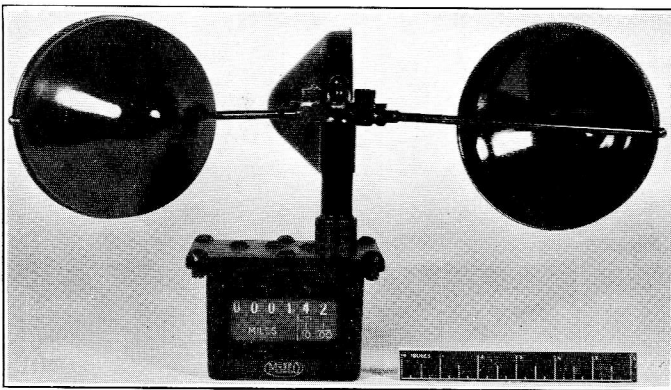
CUP CONTACT ANEMOMETER, MK. I, AND PORTABLE RECEIVER
(B = Battery, C = Buzzer, S = Switch.)



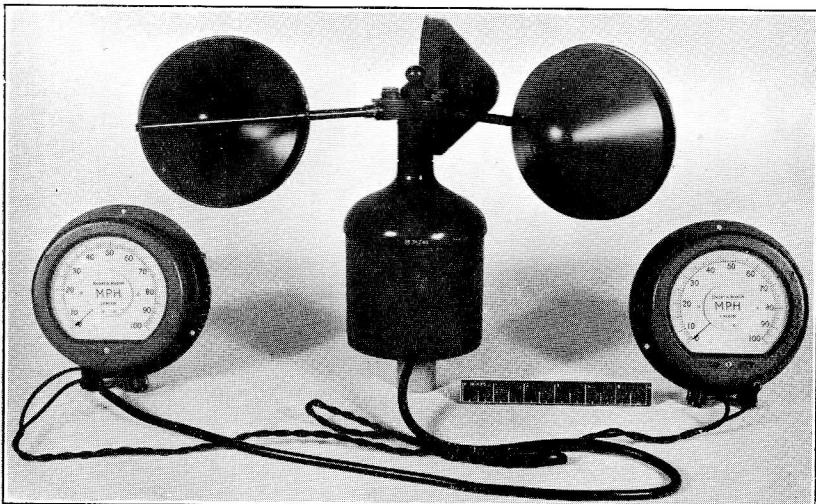
CUP COUNTER ANEMOMETER, MK. I



CUP CONTACT ANEMOMETER, MK. II



CUP COUNTER ANEMOMETER, MK. II



CUP GENERATOR ANEMOMETER, MK. IA

- (3) Anemometer, cup counter, Mk. I, illustrated in Plate I, has a counter giving the run of the wind in miles, reading to 1/100 miles. It has a tall stem and hemispherical cups.
- (4) Anemometer, cup counter, Mk. II, illustrated in Plate IA, has a similar counter gear to Mk. I, but has a short stem and conical cups.

Using the factors given above, the wind speed indicated by these instruments is within ± 1 m.p.h. of true wind speed throughout the range of the instruments, and no corrections are necessary.

- (5) Cup Anemometer, generator type, Mk. I. This has an electrical generator unit consisting of a small permanent magnet alternator driven by a three hemispherical cup rotor, and has one indicator dial which incorporates a metal rectifier and is, in effect, a voltmeter, but calibrated in miles per hour.
- (6) Cup Anemometer, generator type, Mk. IA. This is illustrated in Plate IA, and is similar to Mk. I, but has detachable conical cups and two indicators, one or both of which may be used without affecting the calibration.

To measure wind speed with the cup contact anemometer, the time is taken for a known number of buzzes (usually one or ten according to whether the wind speed is low or high), and the mean wind speed is read off from the table on the lid of the portable receiver. In the case of the cup counter anemometer, the time is taken for the observed difference between two consecutive readings of the counter dial; this difference gives the distance travelled by the wind, and its speed can be deduced. In the generator type anemometer, instantaneous wind speed in miles per hour is indicated on the dial or dials.

Periodical attention.—To obtain good results, cup anemometers of the contact or counter type should be taken down from their supports every three months and dismantled, cleaned, lubricated and reassembled. Instructions for carrying this out may be obtained from the Meteorological Office. No attempt should be made to dismantle the generator type anemometer.

Mounting of Cup Anemometer.—All Meteorological Office pattern cup anemometers have in their bases a socket carrying a screw thread, the size of which is $\frac{1}{2}$ in. B.S.P. for cup contact and cup counter anemometers, and 2 in. B.S.P. for cup generator anemometers. They may be conveniently mounted on a suitable length of the appropriate size of steel gas pipe, screwed at one end to enter the anemometer socket, and firmly stayed in a vertical position in exposed exposure. As $\frac{1}{2}$ in. pipe is not very rigid in large lengths, it is advisable to use only a short length of $\frac{1}{2}$ in. pipe, joined to a larger ($1\frac{1}{2}$ in. or 2 in.) pipe by means of a reducing socket.

If the anemometer is used in conjunction with a remote indicating wind vane, it may be conveniently mounted on a side bracket attached to the wind-vane support. A drawing of such a bracket is obtainable from the Meteorological Office.

To take a reading.—Close the switch. Time the interval from the end of one ring of the bell to the end of the next. If the wind is strong take the time for five or ten rings. Open the switch after the reading has been obtained. The corresponding speed is found by dividing the wind-run by the average interval between two successive rings. For convenience, a table giving the wind speeds corresponding to various times between contacts is pasted in the lid of the portable receiver.

NOTE.—Instructions for the care of recording anemometers are given in §§ 21, 22, pp. 118–31.

§ 10. WEATHER

Under the heading “Weather Observations” are classified the various appearances which for the most part indicate modifications in the condition of the aqueous vapour in the atmosphere, and which are therefore known in some countries under the generic term of “Hydrometeors.”

With a view to avoiding misunderstandings arising from the use of different languages the International Congress held in Vienna in 1873 agreed on a system of symbols for recording such phenomena which should be independent of any language. The system has been added to from time to time and is now extensively used in meteorological literature.

In this country a system of notation devised by Admiral Beaufort, consisting as a rule of the initial letter of the phenomenon to be indicated, has been in use for many years. It affords a simple and concise means of indicating by a group of letters either the actual state of the weather at the hour of observation, “present weather”; or a general summary of the conditions over the interval since the last observation was made, “past weather.” Columns with these headings are therefore provided in the registers issued by the Meteorological Office for the use of observers.

The system has been added to since Beaufort’s day, and during the last few years the ever-growing need for more precision has led to the introduction of a method of indicating intensity and duration which has proved itself very necessary in practice. Beaufort used small letters in his notation, but it has been the practice to use small or capital letters indifferently. Under the present convention capital letters are used to indicate occasions when the phenomenon to be noted is intense. At the other end of the scale, occasions of slight intensity are distinguished by adding a small suffix *o*. We thus arrive at the convention—

R ...	Heavy rain ...	●
r ...	(Moderate) rain ...	●
r _o ...	Slight rain ...	●°

and similarly with other phenomena. If the system of international symbols be used, intensity may be indicated by adding exponents 0 or 2 to the symbols, but the terminology is not usually carried beyond three degrees of intensity as indicated above.

Under the present convention, continuity is indicated by repeating the letter thus :—

RR ...	Continuous heavy rain.
rr ...	Continuous (moderate) rain.

The prefix “i” is used to indicate “occasional” or “intermittent” thus :—

if ...	occasional fog.
ir _o ...	intermittent slight rain.

There is a difference in the type of weather indicated by “ir” (intermittent rain) and “p” (passing showers); the latter is usually associated with relatively short periods of rain, occurring with intervals of clear blue sky, and is often found with a W. or NW. wind, a rising barometer and improving weather; the former is characteristic of days occurring more frequently in autumn and winter, when the sky remains dull and overcast throughout.

We proceed to give in tabular form a summary of the letters and symbols in general use for climatological purposes. Further explanations of the individual phenomena follow.

BEAUFORT LETTERS AND INTERNATIONAL SYMBOLS*

1. Appearance of Sky.

b	...	Blue sky whether with clear or hazy atmosphere.
c	...	Cloudy, <i>i.e.</i> , detached opening clouds.
o	...	Overcast, <i>i.e.</i> , the whole sky covered with one impervious cloud.
g	...	Gloom.
u	▽	Ugly, threatening sky.
—	⊙	Sunshine.

2. Wind.

—	↗	Gale (Force 8 or above).
q	∧	Squalls.
Q	⋈	Heavy squalls.
q _o	...	Light squalls.
KQ	...	Line squall.

*Certain additional symbols are used for plotting weather on synoptic charts; see “Instructions for the preparation of weather maps with tables of the specifications and symbols (Form 2459).”

3. Precipitation.

r	●	Rain.
R	● ²	Heavy rain.
r _o	● ^o	Light rain.
rr	●	Continuous rain.
RR	● ²	Continuous heavy rain.
r _o r _o	● ^o	Continuous light rain.
p	▽ [•]	Passing showers of rain.
P	▽ ^{•2}	Heavy passing showers of rain.
d	;	Drizzle.
D	; ²	Thick drizzle.
d _o	; ^o	Thin drizzle.
dd	;	Continuous drizzle.
DD	; ²	Continuous thick drizzle.
d _o d _o	; ^o	Continuous thin drizzle.
s	*	Snow.
S	* ²	Heavy snow.
s _o	* ^o	Light snow.
ss	*	Continuous snow.
SS	* ²	Heavy and continuous snow.
s _o s _o	* ^o	Light and continuous snow.
ps	* ▽	Showers of snow.
—	*†	Snowstorm.
rs	● *	Sleet. (Rain and snow together, or partially melted snow.)
RS	● ² *	Heavy sleet.
r _o s _o	● ^o *	Light sleet.
rs rs	● *	Continuous sleet.
RSRS	● ² *	Heavy and continuous sleet.
r _o s _o r _o s _o	● ^o *	Light and continuous sleet.
prs	* ▽	Showers of sleet.
h	▲	Hail.
—	△	Small hail.
—	×	Soft hail.
H	▲ ²	Heavy hail.
h _o	▲ ^o	Slight hail.
hh	▲	Continuous hail.
HH	▲ ²	Heavy and continuous hail.
h _o h _o	▲ ^o	Slight and continuous hail.

4. Electrical Phenomena.

l	<	Distant lightning.
tl	℞	Thunderstorm which passes over place of observation.
t or tl	(℞)	Thunder in the neighbourhood of station.
TL	℞ ²	Severe thunderstorm.
t _o l _o	℞ ^o	Slight thunderstorm.
tl tl	℞	Continuous thunder and lightning.

5. Atmospheric Obscurity, Suspensoids and Water Vapour.

*z	∞	Haze. Range of visibility 1,100 yards or more, but less than 2,200 yards.
*z _o	∞ ^o	Haze. Range of visibility more than 2,200 yards.
*m	== or ≡ ^o	Mist. Range of visibility 1,100 yards or more, but less than 2,200 yards.
*f	≡	Fog
fe	≡	Wet fog
*F	≡ ²	Thick fog. Range of visibility less than 220 yards.
—	≡	Shallow fog.
—	≡	Ground fog.
—	≡	Frost fog.
—		Waterspout.
—	→	Dust or sandstorm.
—	⊗	Dust devil.
—	→	Ice needles.
—	△	Grains of ice.
—	△	Granular snow.
—	→	Drifting snow (high up).
—	→	Drifting snow (near the ground).
v	○	Pure air, abnormal visibility.
e	...	Wet air, without rain falling.
y	...	Dry air (less than 60 per cent. humidity).

6. Ground Phenomena.

w	^	Dew.
x	⌈	Hoar-frost.
—	∨	Soft rime.
—	▼	Hard rime.
—	~	Glazed frost.
—	⊛	Snow lying.†

* The use of the symbols 8f-3f, Fm_o and z_o is explained in the table on p. 59.

† Half or more of the ground representative of the station covered with snow.

7. Optical Phenomena.

—	⊙	Solar corona.
—	⊕	Solar halo.
—	☾	Lunar corona.
—	☾	Lunar halo.
—	⌒	Rainbow.
—	↗	Aurora.
—	☾	Zodiacal light.
—	⌒	Mirage.

Caution.—Such errors as the use of “d” for “dew,” “f” for “fine” or “sh” for “showers” should be carefully avoided. “d” would be read as “drizzle,” “f” would be read as “fog” and “sh” as “snow and hail.”

APPEARANCE OF THE SKY.—b, c, o, g and u

The letters b, c, o, g and u are used to describe the general appearance of the sky.

The use of the letters g and u is sufficiently clear from the definitions given above. The following remarks apply to the use of the letters b, c and o.

o is used whenever the sky is completely overcast with a uniform layer of thick or heavy cloud. c is used to denote that there is some cloud present but o is not appropriate; b denotes blue sky.

In order to meet difficulties which occur when there are only small quantities of cloud or blue sky present, c should not be used unless the sky is more than a quarter covered and b unless there is more than a quarter of the sky free from cloud.

If cloud covers between one quarter and three quarters of the sky b and c will both be recorded.

PRECIPITATION

A distinction is drawn in the Beaufort notation between rain (r), drizzle (d) and passing showers (p). The international symbol ● is used in climatology for all three. Passing showers are characteristic of a special type of weather and it is most important that they should be differentiated by the use of the letter “p” from other types of precipitation. The letter “e” has been added to the Beaufort system to indicate a state in which the air deposits water copiously on exposed surfaces without rain falling.

CONTINUOUS AND OCCASIONAL PRECIPITATION—SHOWERS—DRIZZLE

Difficulties have arisen from time to time in regard to the meaning of certain words such as “continuous,” “occasional,” etc., in connexion with precipitation.

1. **Continuous precipitation (Beaufort letters rr, ss, etc.).**—In reports of past weather a break of only ten minutes’ duration in a period of continuous rainfall can be disregarded, but a break of half an hour must be taken into account. Thus a period of moderate continuous rain with a break of ten minutes in it would be described merely as rr, but a period of moderate

continuous rain with a break of half an hour in it would be described as rr, o, rr, if "o" were the appropriate letter for the interval. The duration of precipitation necessary to justify the use of the word "continuous" in reports of past weather cannot be rigidly fixed. If it rained without a break for two hours it should undoubtedly be described as "continuous rain." If it rained for only half an hour it would not be called continuous rain. If it rained for an hour *in the middle* of a period without rain, it would not be necessary to describe it as continuous, *e.g.*, the description in Beaufort letters, o, or, o, would be appropriate. If, however, the hour's rain came at the beginning of a period and was the continuation of continuous rain in the previous period, it would still be reported as continuous rain in the new report, *e.g.*, the weather would be described as rr, o. The same would apply to rain which began an hour or more before the report and of which there was no evidence of cessation at the time the report was made.

2. Occasional precipitation—showers.—In general, showers are of short duration, and the fair periods between the showers are usually characterised by definite clearances of the sky. The clouds which give the showers are isolated clouds. The precipitation does not usually last more than fifteen minutes, although it may sometimes last for half an hour or more. Typical showers occur in the cooler west and north-west current behind a depression which has passed eastwards.

Occasional precipitation, on the other hand, usually lasts for a longer time than showers and the weather in the periods between the precipitation is usually cloudy or overcast. It should, however, be realised that weather between showers may also be cloudy or overcast and the weather between periods of occasional precipitation may be clear. The experienced observer will usually decide from the type of cloud which description to use.

The international symbols distinguish between shower of rain ∇ , shower of snow ∇^* and shower of rain and snow (sleet) $\nabla^{\times}$.

3. Drizzle—slight rain.—Drizzle is not "rain in small amount" but "precipitation in which the drops are very small." Slight rain, on the other hand, is precipitation in which the drops are of appreciable size (they may even be large drops) but are relatively few in number. Observers should decide from the size of the drops whether the precipitation is drizzle or rain; and from the combined effect of the number and size of the drops whether the precipitation is slight, moderate or heavy.

There are some occasions when rain is observed to be falling through drizzle; both the drizzle and the rain should be noted in the register and in the case of telegraphic reports if both cannot be reported, the drizzle should be reported as a rule because the rain on such occasions is generally slight and of short duration.

HAIL

The international symbols distinguish between true hail $\blacktriangle$, small hail $\triangle$ and soft hail $\times$. In the first case the stones are hard and occasionally of considerable size, in the second case they are small semi-transparent grains covered with ice, and in the third case white opaque grains easily compressible. The German and French terms for soft hail are *graupel* and *grésil* respectively.

The following working definition of hail was adopted by the Congress of Vienna for the purpose of computing the number of days of hail. "Hail may be defined as a precipitation of frozen water in which the stones attain such a magnitude that they may be expected to do damage to agricultural products." In preparing statistics for British stations it has been customary to count all days on which hail

was observed as "days of hail" even though the stones were small and few. The days to which the international definition ▲ applies should be specially noted in the register.

ICE NEEDLES ←

On some occasions, usually in cold, clear weather, small ice crystals are observed in the air down to ground level, and they may under suitable conditions give rise to halo phenomena. The symbol ← should be entered on such occasions. The phenomenon is distinct from an ordinary fall of snow and may, indeed, occur when the sky is apparently free from cloud. The symbol should not be used merely to indicate that a regular crystalline structure is observed in flakes forming part of an ordinary snowfall, the proper symbol for which is ✱.

DRIFTING SNOW

The international symbols distinguish between drifting snow high up ↗ and drifting snow near the ground ↘.

Drifting snow is snow which travels with the wind without settling when it reaches the ground. It may occur with or without new snow falling. If drifting snow occurs without new snow falling the appropriate symbol is to be used alone. If drifting snow occurs whilst new snow is falling the two symbols for drifting snow and snow are to be used together.

SNOW LYING ☒

The symbol should only be used when one-half or more of the ground representative of the station is covered with snow at the hour of morning observation. The ground representative of the station is defined as the flat land easily visible from the station and not differing from it in altitude by more than 100 ft. In judging whether half the ground is covered, no account should be taken of bare patches under trees nor of areas occupied by the sea, rivers, ponds or lakes. The depth of the snow, determined by plunging a centimetre or inch measure vertically into the snow in a place where it is lying evenly, should be entered in the column headed "Remarks," care being taken that the unit of measurement is clearly stated. The mean of measurements made in several different places should be given (*see also* p. 95).

Fog, f ≡; MIST,* m = or ≡°; HAZE, z ∞

The terms fog, mist and haze are used to indicate a diminution in the transparency of the atmosphere due to suspension in the lower layers of small particles. The particles may be either solid or liquid. The terms fog and mist are generally regarded as applicable to occasions when the obscurity is due mainly to water particles, the word haze being applicable when dust particles are the chief cause of the lack of transparency. The observer has no definite criterion for determining whether he is observing dust or water particles, but the humidity of the lower atmosphere as indicated by the readings of the dry and wet-bulb thermometers will afford some guide. If the depression of the wet bulb is slight it may be assumed that water

*The former of the two symbols for mist is normally used only on synoptic charts.

droplets predominate so that the terms mist or fog are appropriate ; on the other hand when there is a large difference between the wet and the dry bulbs, the term haze is appropriate. The distinction between fog and mist adopted at stations associated with the Meteorological Office is one of degree, the term fog being reserved for occasions of more marked diminution of transparency.

In preparing statistics of fog and mist in the Meteorological Office it has been found necessary to use only observations in which visibility has been recorded according to the scale given on p. 59. A fog is counted only when the visibility is reported to be less than 1 kilometre (1,100 yards) and mist or haze when the visibility is greater than this but less than 2 kilometres (2,200 yards).

This does not prevent the use of such expressions as "slight haze," "slight mist" when the visibility is 2 kilometres or more, but the unqualified words "mist" or "haze" should not be used in such circumstances.

High fog.—It occasionally happens near industrial centres that heavy, smoke-laden clouds overhead cut off practically all daylight, though the visibility in the surface layers of the atmosphere, as judged by the appearance of distant lights is but little influenced. Such conditions may be described as "*high fog*," and should be carefully noted in the remarks column, but they do not comply with the conventional definition of fog given above. In such circumstances the observations of visibility should be made according to the standards adopted for work at night. In statistical summaries occasions of high fog are not included. If the Beaufort notation be used the combination of letters "og" is more appropriate than either F or f. The international symbol $\equiv$ should not be used. The duration and times of occurrence of high fogs should be noted as accurately as circumstances permit.

Pure Air (abnormal visibility) $\vee \emptyset$. On some occasions the atmosphere has an abnormal clearness and transparency ; distant objects stand out in full relief from the background with great hardness and distinctness. Outlines and details which appear softened or even indistinct under ordinary conditions, are sharply defined on these occasions. The term "visibility" is used to indicate this abnormal clearness and is denoted by the Beaufort letter " $\vee$ ".*

Wet fog. $\equiv$ A fog in which water is deposited copiously on exposed surfaces should be noted by means of the letters "fe" or by the symbol given above, which is a combination of the symbol for fog with $\vdots$ formerly used to indicate rainfall.

Ground fog. $\equiv$ The use of this symbol to indicate a ground fog, *i.e.*, a fog which does not exceed the height of a man, has received international sanction. Fog in a valley seen from a station on a higher level should not be entered as a "ground fog."

* It should be noted that "visibility" ($\vee$) defined in this way is unrelated to the ordinary scale of visibility (p. 59). The Beaufort letter " $\vee$ " if used should come in "weather" and should not be used as a contraction for "visibility 9" on the visibility scale.

DEW ☽

Dew is moisture condensed from the atmosphere on exposed surfaces. It is caused by the loss of heat from blades of grass, shrubs, roofs, etc., by nocturnal radiation and consequent cooling below the temperature at which the water vapour present in the atmosphere is sufficient to saturate it. Wetness of grass caused by dew must not be confused with wetness of grass caused by precipitation during the night.

HOAR-FROST —

(German *Reif*, French *rosée blanche*.) Hoar-frost resembles dew in the manner of its formation. When the temperature falls sufficiently low the water vapour may be deposited in the solid state or the dew originally deposited in the liquid state may become frozen. The deposit thus formed is hoar-frost. It presents a white crystalline appearance but the particles have been shown to be amorphous in structure in most cases.

RIME

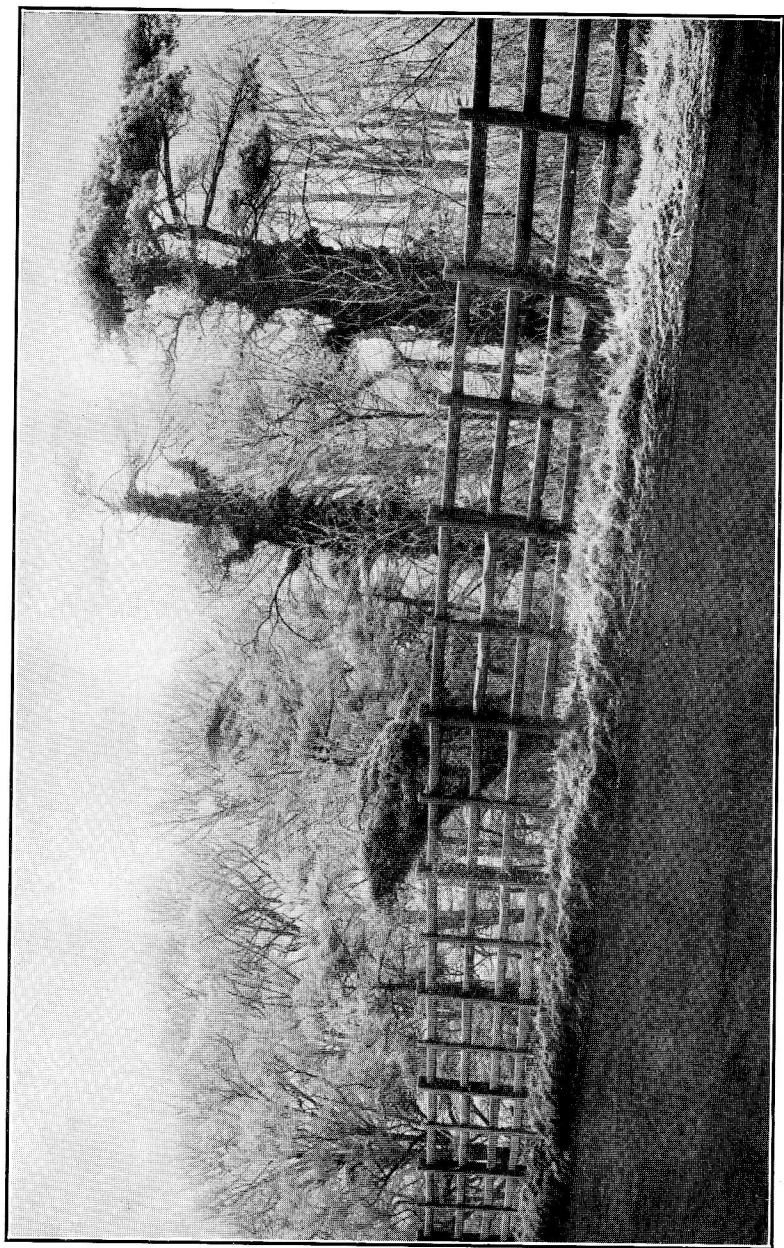
(German *Rauhreif*, *Rauhrost*, *Anreim*, *Duft*, French *Givre*.) (Plate II.) Rime is an accumulation of frozen moisture on trees, etc., which presents a silvery white and **rough** surface, bearing some resemblance to hoar-frost. The international symbols distinguish between soft rime √ and hard rime ▼. Soft rime consists of ice crystals which are deposited on vertical surfaces—especially on points and edges of all objects at hand—in supercooled fog or mist. Hard rime consists of masses of ice which are deposited analogously to the soft rime but are formed in “wet air” or supercooled drizzle.

In our climate rime is of comparatively rare occurrence, for the white deposit on grass, etc., observed on foggy mornings, consists in most cases of hoar-frost which had formed before fog developed. On Ben Nevis the depositions, however, were frequently so thick that they greatly interfered with the work of observing by clogging up the louvres of the thermometer screen, etc. The phenomenon was noted in the record under the name “fog crystals.”

The particles in a fog, even at temperatures far below the freezing point, consist of droplets of super-cooled water and when these come in contact with bodies they solidify immediately, and form rime. Hoar-frost and rime may be distinguished, to a certain extent, by the fact that the former is not readily formed on good conductors of heat in thermal contact with relatively warm bodies on which they can draw for a supply of heat to replace that lost by radiation, whereas rime is deposited on all with equal facility.

GLAZED FROST ~

(German *Glatteis*, French *verglas*.) (Plate III.) A transparent **smooth** coating of ice covering trees, buildings, etc. The phenomenon is usually caused by rain which freezes as it reaches the ground



RIME AT SEALAND, NEAR CHESTER 10H. 30M., DECEMBER 15, 1928



GLAZED FROST AT FONTAINEBLEAU, JANUARY 22-24, 1879

and thus covers all objects with a coating of smooth transparent ice. It is somewhat rare in our climate, but on the Continent and in America it is more common. The weight of the ice which collects is frequently sufficient to cause damage to telegraph wires, trees, etc. It is probable that the rain in these cases consists of super-cooled drops of water.

Glazed frost can also occur when a warm moist air current sets in suddenly after intense cold. The moisture of the air may then be condensed on cold surfaces and cover them with a thin layer of ice.

The illustration reproduced in Plate III (*see* Tissandier, "l'Océan aérien") shows a typical case of glazed frost.

The term "silver thaw" has been used by some writers as the equivalent of *verglas* and *glatteis*, but others use it to indicate what we have called "rime." The confusion has no doubt been considerably aided by the comparative rarity of both phenomena in our climate. It may, however, be pointed out that as both rime and glazed frost are probably caused by supercooled water drops, which differ only in size or in degree of supercooling, they may merge gradually one into the other. In many of the descriptions given by continental writers, it is expressly stated that the two phenomena occur side by side.

Some of the appearances of a glazed frost may be produced when frost sets in suddenly after a partial thaw of snow. This is, however, a combination of circumstances which does not call for a special meteorological symbol.

THUNDERSTORM ☌ ; LIGHTNING <

The symbol ☌ should be used to indicate a thunderstorm which passes directly over the place of observation and (☌) when a thunderstorm occurs in the neighbourhood of the station, even if, owing, for example, to daylight, thunder is heard without lightning being visible.

The times at which thunderstorms occur should be given in the "remarks" column; it is desirable to note the time of commencement of a thunderstorm, as given by the first thunder, and the time of the more prominent flashes to the nearest minute. The direction from which the thunderclouds approach should also be noted.

GALE ☌

The occurrence of winds of force 8 or above, should be noted in the "remarks" column by means of this symbol. The times of commencement, abatement and greatest violence of the gale should be stated.*

* For details in regard to the specification of "days of gale" at stations with anemometers *see* Supplement No. 1.

SQUALLS q ; LINE-SQUALL KQ

The letter q (squalls) is used to indicate the occurrence of strong winds blowing for brief periods. The squall is usually accompanied by a change of wind direction (most frequently a veer), a fall of temperature and a darkening of the sky by clouds of cumulus or cumulonimbus type, from which showers of rain, hail or snow may fall. The appropriate entry in such cases is a combination of letters such as "phq" (squall with hail shower).

When all these features are well marked and the front of the cloud mass is in the form of an advancing line or arch, the occurrence is known as a "line-squall" (KQ). During the passage of such a disturbance the barometer often rises abruptly by perhaps 2 millibars. Notes should be made of the time of the squall, the maximum wind force, the change of wind direction and of temperature and pressure. Such notes are often useful in tracing the course of the squall.*

§ 11. VISIBILITY

The importance for navigation and especially for air navigation of the degree of transparency of the atmosphere has given rise to a demand for observations of this element of greater precision than made in the past under the rather vague headings fog and mist. The most direct manner of specifying the degree of transparency is to give the extreme distance at which objects are visible to an observer under normal conditions of illumination. This method presupposes an accurate knowledge on the part of the observer of the distance of all objects within his range of vision, and therefore is hardly practicable; and moreover it would result in reports of numerous distances varying from a few yards to many miles which would be difficult to summarise and compare. In practice observations are therefore restricted to a number of selected objects at fixed distances, the distances increasing roughly in such a way that each distance is nearly double the next smaller distance. All the selected objects can be seen under normal conditions of illumination when the air is clear; and the determination of the most distant object of the series which is visible on any given occasion constitutes the observation of visibility†.

No observer should attempt observations of visibility whose eyesight is defective to the extent that, for example, he cannot identify a church spire six or seven miles distant when the spire is viewed against a sky background on a clear day in good daylight (with the aid of his ordinary outdoor spectacles or eyeglasses if he wears them, but without the aid of field-glasses or telescopes.)

* A line-squall occurs when a mass of cold air, usually in the form of a current of wind from some point north of west, advances upon a mass of warmer air in which the wind direction is from a southerly point. The phenomena occur at the "cold front" or line of demarcation of the two air masses.

† More detailed observations are now made at synoptic stations, see "Instructions for meteorological telegraphy," Supplement No. 1 to this book (M.O. 191/1).

SELECTION OF OBJECTS

For convenience of reference indication letters are assigned to the various objects. These are given in the following table :—

Indication Letter of Object	Standard Distance of Object		Permissible Standard Distances of Object	To be used when the object given in column 1 is the furthest visible			Beaufort Letters		
	Metres	Yards	Yards	Tele-graphic Code Figure	Description*	Full Scale for Registers	For Registers	Contracted Scale	For Telegrams
X	(See p. 61)								
A	25	27	— 25-30	0	Dense fog.	8f	F	a	
B	50	55	50-60	1	Thick fog.	7f			
C	100	110	100-120			6f			
D	200	220	200-240	2	Fog.	5f			
E	500	550	500-600	3	Moderate fog.	4f	f	f	
F	1,000	1,100	1,000-1,200	4	Mist, haze, or very poor visibility.	3f			
G	2,000	2,200	miles. 1½-1¾	5	Poor visibility.	m or z	m or z	m or z	m or z
H	4,000	4,400	2½-2¾	6	Moderate visibility.	m. or %	m. or %	m. or %	n m or n z
I	7,000	7,700	4-4¾						
J	10,000	11,000	5½-6½	7	Good visibility.				
K	20,000	22,000	11¼-13¼	8	Very good visibility.				
L	30,000	33,000	16¾-20¼						
M	50,000	55,000	28-34	9	Excellent visibility.				

* If it is necessary to refer to the sub-divisions of the scale for which no descriptions are given, the actual visibility should be used. Thus, if object B is visible but not C, the description might be "thick fog with visibility more than 50 metres but less than 100 metres."

† A capital letter is used if object lies within these distances. The objects should be at the distances given in column 3 if possible.

The following notes will guide the observer in selecting suitable objects.

For the nearer distances the objects should be relatively small (a lamp-post, a bush, a gate, a large stone are suitable for A, B and C). Those for greater distances should increase progressively in actual size in such a way that the apparent size of the part above the horizon remains about constant. The ideal object for the longer distances beyond D is one which stands above the horizon so that it is seen against the sky.

Thus a house or tall tree would be suitable for object F ; a church spire or a clump of trees would serve for objects H and I ; while objects J and K require natural features of the landscape of considerable size. For L and M an island, mountain summit or crest of hills may be used.

It is not always possible to find objects at the exact distances specified at any rate throughout the whole scale. A variation of 10 per cent. from the standard distances is therefore allowed. It is not necessary to have exactly the same standpoint for near as for distant objects. For example, an object which could only be seen by walking 100 yards from the instrument enclosure or climbing a tower would be quite suitable for G or more distant objects.

The visibility of object F is the standard criterion for fog ; if F is invisible the state of obscurity should be called " fog " but if F is visible the expression " fog " should not be used in the " Remarks " or elsewhere.

Objects A to F at least should be determined at all stations in order that the important climatic condition " occasions of fog " may be determined.

The distances of the nearer objects should be determined by direct measurement ; those of the intermediate objects up to about H or I should be measured from an Ordnance map, scale 1 in. to the mile, while the farther objects can usually be obtained from a good atlas.

Difficulties may arise in connexion with the choice of objects where the visibility at the station varies in different directions owing to permanent local conditions, for example, where the station lies to one side of a smoky area. In such a case if there is a choice of objects at a given standard distance the one likely to be most clearly seen is to be adopted. Accuracy of distance is, however, not to be sacrificed for this purpose.

It is hoped that the observers at stations of exceptional situation having a wide range of vision or a considerable number of suitable objects will take additional observations for their own use ; for example, interesting comparisons might be made between the visibilities of objects at the same distance in different directions. A special case of such comparison is the relative visibility in a landward and seaward direction.

At stations contributing telegraphic reports in connexion with the Forecast Service special provision is made for observing and entering landward and seaward visibility separately.

It is a frequent occurrence at coast stations that there is a fog or mist on the sea and none on the land or *vice versa*. These conditions occur in very different meteorological situations, but it is obviously important that an observer should not rest content with recording the land visibility, by noting one of the more distant objects, when it is clear to him that there is fog on the sea. In such circumstances he should make use of the "Remarks" column for indicating the visibility measured, or arrange for two regular and independent sets of observations, one to seaward and the other to landward.

It is not always possible to get a complete set of objects seawards, and in such cases the observer must use the experience which he acquires from the observation of his objects to estimate to the best of his ability the visibility in the seaward direction.

METHOD OF OBSERVATION

The visibility is to be determined by noting the most distant of the objects A, B, C, D, etc., which is visible, *e.g.*, suppose D is visible and E is not visible then the visibility letter to be entered in the register is D. If object A is not visible the fact is denoted by entering the letter X.

It is necessary to have a criterion of what is meant by an object being visible. It is often possible to see that there is "something" without being able to see what it is, unless one knows beforehand what it is; in such a case the object is not visible according to the Meteorological Office convention. An object is therefore to be regarded as "visible" if it can be distinguished by eye; if the object is a tree and it can be distinguished as a tree, it is to be noted as visible. In many cases a complete scale of objects is not available owing to lack of suitable objects. In such cases of "gaps" in the scale, small letters corresponding with the capital letters of the normal scale are used where it is estimated that one of the missing objects would be visible if it existed. The method of estimation is as follows:—Assuming there are objects for I and K but no object for J, the entry of "j" should be made if I is clear but K is invisible. Again if the available scale ended at J and this object was visible with extreme clearness on a given occasion, the observer would enter "k" if he judged that an object about 12 miles away would be visible or "m" if he judged that one about 30 miles away would be visible. Care should be taken in such a case not to enter "J" on every occasion that "J" is visible. The use of the small letter clearly differentiates estimates based on the visibility of other objects in the scale from actual observations based on the standard object at the specified distance.

For the purpose of routine, observations should be confined to one and the same series of standard objects. Where the returns provide

separate columns for land and sea visibility, two series of objects should be used, one for land and one for sea. Observations of duplicate objects in different directions, or of objects not complying with the standards of distance, may be entered in the remarks column if of special interest. In the case of missing objects, observations of objects not in the standard scale may be utilised in making a small-letter estimate; thus, assuming the scale ends at J ($6\frac{1}{4}$ miles) but there is also an available object at, say, 24 miles (coming between L and M), the latter object would obviously be utilised together with the appearance of J in making the small-letter estimates "k," "l" or "m."

It may occasionally happen that a more distant object of the series is visible while a nearer one is not. In this case the usual rule of entering the most distant standard object visible should be followed, but a note should be made in the "Remarks" column that the nearer object or objects of the scale were obscured. In such circumstances the entry of remarks on the visibility or invisibility of other nearer objects not in the scale would obviously be of interest.

The observer is recommended to draw up a table for himself showing (i) the list of objects chosen; (ii) their actual distances and bearings; (iii) the letter by which each is to be known. When no object exists at some particular distance the small letter will be inserted in the table instead of the capital and the ideal distance inserted against it.

Provision for the insertion of these particulars is made in Meteorological Office registers.

OBSERVATIONS MADE AT NIGHT

In the case of observations made at night the letters will be used to denote as nearly as possible the same degree of atmospheric obscurity as in daylight observations. This part of the subject presents difficulties and a good deal must be left to the observer, as the aids available for indicating atmospheric obscurity at night vary so much from one place to another. Stationary lights at known distances will in general provide the basis of estimation, but it is usually difficult to get a selection of fixed lights at the appropriate distances. Care must also be used to avoid the difficulty raised by the fact that a very bright light, such as that of a powerful lighthouse, may cause an appearance of brightness in its direction, or show light on the sky, in a state of atmospheric obscurity which would not permit the observer to see the actual source of the light in the same sense that he can see one of his daylight objects. The International Meteorological Conference at Warsaw in 1935 accordingly adopted a provisional table, based on experiments, indicating the distances at which lights of known intensity (expressed in candle power) would become invisible at night, if the conditions of atmospheric transparency were the same as those in which the corresponding objects would become invisible by day. This table is reproduced.

Code Figure.	Daylight Observations.	Night Observations (provisional)			
		If lights at the same distances as objects are to be used they must be of the candle power shown below.		If lights of fixed in- tensity of 100 candle power are used they must be at the following distances.	
				Object distance.	Distance for 100 candle power light.
0	Objects not visible at 50 m. (or $\frac{1}{4}$ cable).	c.p.	m.	m.	m.
		0·13 at	50	50	100
1	Objects visible at 50 m. but not at 200 m. (1 cable).	0·9 „	200	200	330
2	Objects visible at 200 m. but not at 500 m. (or 2 cables).	3·5 „	500	500	740
3	Objects visible at 500 m. but not at 1,000 m. (or 4 cables).	10 „	1,000	1,000	1,340
4	Objects visible at 1,000 m. but not at 2,000 m. (or 1 nautical mile).	35 „	2,000	2,000	2,300
5	Objects visible at 2,000 m. but not at 4,000 m. (or 2 nautical miles).	100 „	4,000	4,000	4,000
6	Objects visible at 4,000 m. but not at 10 Km. (or 5 nautical miles).	420 „	Km. 10	Km. 10	Km. $7\frac{1}{2}$
7	Objects visible at 10 Km. but not at 20 Km. (or 10 nautical miles).	1,250 „	20	20	12
8	Objects visible at 20 Km. but not at 50 Km. (or 30 nautical miles).	4,500 „	50	At greater distances 100 candle power is not suitable.	
9	Objects visible at 50 Km. or more but not at 150 Km. (or 80 nauti- cal miles).	From 20,000 „	150		

The candle powers and distances specified for night observations are to be regarded as provisional.

Lights of the requisite brightness are not often available at suitable distances. To meet this difficulty Mr. E. Gold, C.B., D.S.O., F.R.S., has designed the "Gold Visibility Meter", which utilises the fact that the brightness of a fixed light at a fixed distance depends upon the transparency of the atmosphere, and can be measured by the density of an obscuring screen or filter which just suffices to reduce it to the limit of visibility. This density is found by means of a neutral filter or screen and a slider, to which is attached a pointer reading on a graduated scale. The scale reading can be converted to visibility by means of tables which must be constructed separately for each light source employed. A description of the instrument and full instructions for its use are available at the Meteorological Office (*see also London, Quart. J. R. met. Soc.*, **65**, 1939, p. 139); an early form of the instrument is illustrated in Plate IV.

INTERNATIONAL SCALE

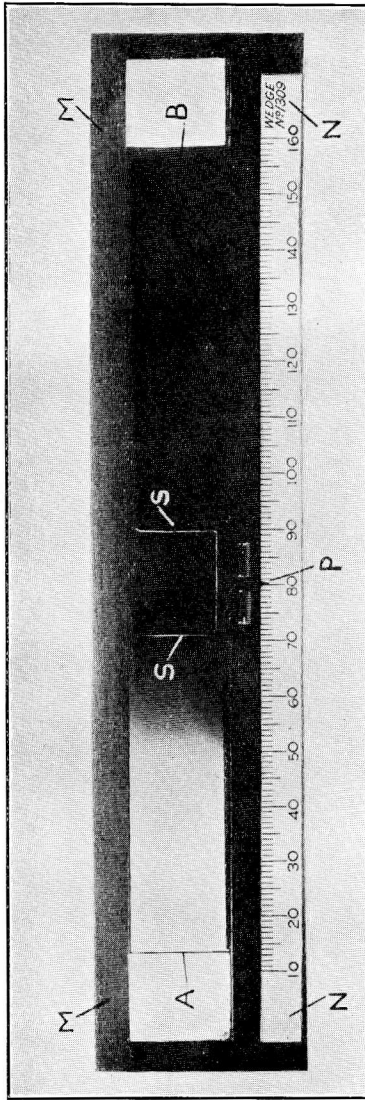
In 1921 the International Meteorological Committee adopted a scale of visibility for use in telegraphic weather reports exchanged between meteorological services. The exigencies of the telegraphic code make it necessary to limit this scale to one of 10 steps, and it is therefore necessary to group together some of the observations of the standard objects indicated by the letters A to M. The method of this grouping is shown in the fourth column of the table on p. 59. The same grouping is adopted in the summaries of visibility given in the *Monthly Weather Report*. For the purpose of this summary an entry of a small letter in the register is regarded as equivalent to that of the corresponding capital letter.

VERBAL DESCRIPTION

It has been found convenient to assign verbal descriptions to the various degrees of atmospheric transparency indicated by observations of the standard objects A to M, but there is some risk of inconsistency and therefore of confusion in any such attempt to assign specialised meanings to words such as fog, or mist, which are in general use. The descriptions given in the fifth column of the table on p. 59 should therefore be used as purely technical expressions defined in terms of horizontal visibility. It has been customary in the statistical summaries published by meteorological offices to include particulars of the number of occasions of fog, but the lack of precision in the definition of fog has rendered such summaries of doubtful value for comparative purposes. It is hoped that the adoption of the more definite standards of the visibility scale will overcome this difficulty and ultimately give a homogeneous body of statistics.

In all statistics issued by the Meteorological Office it has been decided to count as occasions of fog only occasions when an observation of visibility has produced an entry of one of the objects A to E. If object F is visible the occasion is not counted as one of fog. In other words an occasion of fog is one on which the range of vision is less than 1,100 yards.

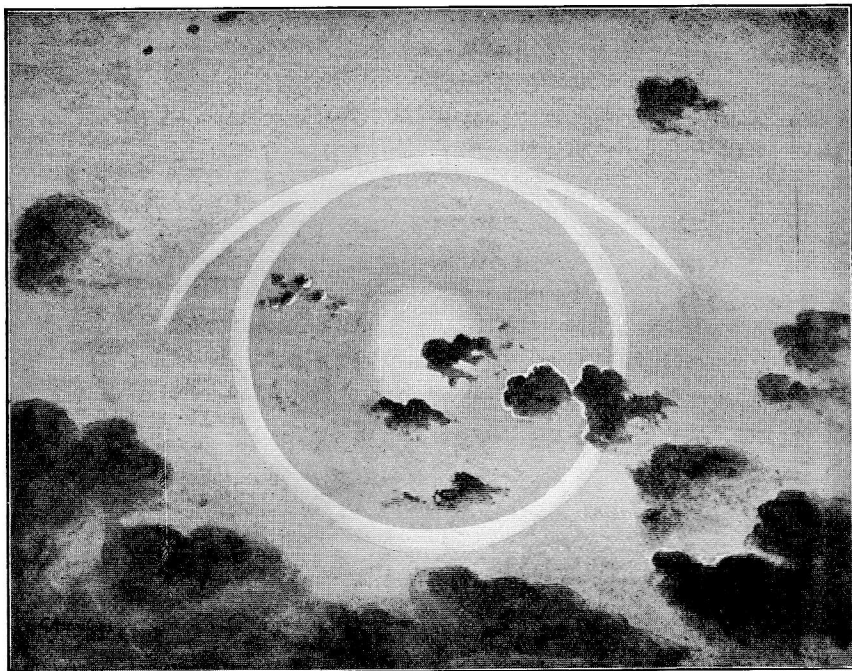
GOLD VISIBILITY METER.



A.B.—NEUTRAL LIGHT FILTER.
M.M.—FRAME ($12\frac{3}{4}'' \times 2\frac{3}{4}'' \times \frac{1}{2}''$).
N.N.—GRADUATED SCALE.
S.S.—SLIDE.
P.—POINTER.

SOLAR HALOS, OBSERVED AT ABERDEEN

Reproduced from sketches by G. A. Clarke, Aberdeen Observatory.



Solar Halo of 22° radius, May 27, 1912. Complete circular halo, with arc of contact. Semi-major axis of the ellipse of which the arc of contact forms a part was about 29° .



Solar Halo of 22° radius, March 5, 1908, with arc of contact, mock sun ring, and mock suns (parhelia).

In order to prevent confusion observers are particularly requested not to use the Beaufort letter for fog in the weather groups or the international symbol $\equiv$ in the "Remarks" column of their registers in connexion with occasions when the visibility reaches or exceeds this limit.

For a "thick fog" the limit is taken at 220 yards and the capital Beaufort letter F (see p. 59) should therefore be restricted to occasions when only objects A to C are visible and should not be used when the range of vision extends to object D or beyond.

§ 12. OPTICAL ATMOSPHERIC PHENOMENA

There are a large number of optical phenomena which not only arrest the attention of observers on account of their beauty, but also are more or less closely connected with the weather; they are of importance for both reasons, and observers are recommended to note them carefully.

For exact measurements of optical phenomena suitable instruments are required. For rough estimates a graduated rod held at arm's length may serve. The position of such phenomena as a "mock sun" may be determined by noting its relation to fixed objects in the landscape. The diameter of a corona may be estimated by taking the diameter of the sun or moon (approximately $30'$) as unit.

The following instructions for observing optical atmospheric phenomena are based on the instructions which were drawn up by the late Professor J. M. Pernter and incorporated in the handbook issued by the Austrian Meteorological Department. They received the approval of the International Conference of Directors of Meteorological Institutions which met at Innsbruck in 1905.

HALO. SOLAR HALO $\oplus$; LUNAR HALO $\ominus$

Many different kinds of halo have been observed (see Fig. 17*). The most common is the halo of 22° —a large ring, CIBG, round the sun or moon, having a radius of very nearly 22° (of a great circle).† When of no great intensity the ring appears white, but when it is more strongly developed we may easily recognise the fact that the edge nearest the sun is red—a very pure red—and that orange, yellow and, under very favourable circumstances, green, follow on, as we go outwards. The latter colour is always rather faint and whitish, and the blue is almost always so faint that it is not recognised as blue. Violet is never recognisable. The ring thus appears white on its outer edge.

* Fig. 17 is a representation of the so-called Danzig phenomenon, as seen, drawn, and described by the well-known astronomer Hevel. The date of the observation is shown at the head of the figure. This figure is a reproduction of the original in Hevel's Publication (see Hellmann, "*Neudrucke, Meteorologische Optik*," p. 57).

† 90° is the measurement of the arc extending from the zenith to the horizon.

It should be mentioned that the rings are frequently incomplete in the cases of the three first-mentioned halos also ; at times only small portions of them can be seen.

There is a number of other halo phenomena which, from their method of formation, can only be seen as arcs. Among these are the so-called *arcs of contact*, of which two are shown in the figure. Both of them are arcs of upper contact, RGQ belonging to the halo of 22° , THS to that of 46° . Arcs of lower contact may occur in connexion with both these rings, but they are very rare. The arcs of upper contact appear with their convex sides turned towards the sun, as shown in the figure, when the sun is low, but when the sun is high the arcs of upper and lower contact may appear concave to the sun (see Plate V). Very rarely the ends join to form a complete ellipse. Contact arcs appear occasionally at the sides of the halos of 22° and 46° , but they are as rare as the arcs of lower contact. The arcs of upper contact are very luminous at the points of contact, which have occasionally been described as "mock suns." The colour effects are often brilliant, red being turned towards the sun, *i.e.*, on the convex edge of the halo. The coloration of the arc of upper contact of the halo of 46° is frequently exceedingly brilliant.

A large number of other rings and arcs have been observed on rare occasions, and are generally described as "irregular"; observers who are fortunate enough to see such irregular bows are requested to sketch and describe them carefully, and, if possible, to **measure their angular distance from the sun.**

Of all halo phenomena, mock suns (parhelia) and mock moons (paraselenae) are probably the most admired. These terms are used to describe luminous, or even brilliant, images of the sun which are seen most frequently at or near the intersection of the halo of 22° with the white mock sun ring (B and C, Fig. 17). Very rarely mock suns are seen at or near the intersection of this ring with the halo of 46° . The mock suns of this halo are always very faint, and their colouring is indistinct; mock suns belonging to the halo of 22° are, on the other hand, both frequent and very luminous, and their colours are brilliant. Red is on the side nearest the sun, with yellow, green, and blue following in order. Blue is generally indistinct and violet is usually too faint to be distinguished. As a rule a long and pointed white tail, occasionally attaining a length of 20° , extends from the mock suns along the mock sun ring (see Fig. 17). The mock suns of the ring of 90° (D and E, Fig. 17) have been observed on a few occasions only since Hevel's day. Not infrequently mock suns are seen without any of the rings being observed.

A white brilliant image of the sun is occasionally observed immediately opposite to it, *i.e.*, 180° away from the luminary along the mock sun ring (F, Fig. 17). This is known as the counter sun or parheliion. Mock counter suns, at about 60° along the mock sun ring from the counter sun, have been repeatedly observed, and their distances from the sun have been measured.

Other mock suns, besides those which have been mentioned, are occasionally seen. Observers are requested to sketch and describe what they see carefully, should they happen to observe one of these. If possible they should determine its position by measurement.

Other very beautiful halo phenomena are afforded by *sun pillars*, which are most easily observed at sunrise or sunset. These frequently extend about 20° above the sun and generally end in a point. At sunset they may be entirely red, but as a rule they are of a blinding white and show a marked glittering. If the sun is high in the heavens, white bands may appear vertically above and below it, but these are not very brilliant and often they are very short. Occasionally these white columns appear simultaneously with a portion of the white mock sun ring, and so form another very remarkable phenomenon, viz., the cross.

Frequently parts only of the rings and arcs are visible, having apparently no connexion with one another, thus lending a very peculiar appearance to the sky; not infrequently these arcs intersect obliquely, which increases the strangeness of the appearance.

Many other halo phenomena are known to occur, but the space which can be devoted to the subject in a book of instructions to observers is limited, and they cannot all be described here. All halo phenomena should be carefully sketched and described.

Halos only occur in presence of cirrus clouds or of light ice fog; they are produced by refraction and reflection of the rays of the sun or moon by ice crystals. The sun has been assumed as the source of light in all the phenomena described. This has been done solely for the sake of brevity; precisely similar though less brilliant appearances may be produced by moonlight.

CORONA. SOLAR CORONA ☉; LUNAR CORONA ☾

Coronae are seen most frequently round the moon. As their diameter is generally considerably smaller than that of the halo of 22° they are very near the luminary and can thus only be seen around the sun under favourable circumstances. No doubt they occur round the sun as frequently as round the moon; they may be observed by making use of a reflector such as a pool of water or of a smoked glass to reduce the intensity of the light.

Coronae are very different from halos. The latter are produced by refraction, whereas the former are diffraction phenomena. The positions and orders of the colours serve to distinguish the two sets of phenomena. Coronae invariably show a brownish red inner ring, which, together with the bluish-white inner field between the ring and the luminary, forms the so-called *aureole*. Frequently, indeed very frequently, the aureole alone is visible. The brownish red ring is characteristically different from the red ring of a halo; the former is distinctly brownish, especially when the aureole alone is visible, and of considerable width, whereas the latter is beautifully red and

much narrower. If other colours are distinguishable, they follow the brownish-red of the aureole in the order from violet to red, whereas the red in a halo is followed by orange, yellow and green. The order of the colours is thus reversed.

The size of the diameter of the ring has been erroneously suggested as a criterion for distinguishing between halos and coronae, but a corona may be quite as big as a halo. The diameter of a corona is inversely proportional to the diameter of the particles in the atmosphere by the agency of which it is formed. Bishop's ring* has furnished a well-known example of such a corona. The criteria which the observer should apply to distinguish the two sets of phenomena are not the diameters of the rings, but the sequence of colour and the presence of the brown-red of the aureole.

As coronae are diffraction phenomena they occasionally show the sequence of colour two or three or even four times over. This can never be the case with a halo. Observers are requested to note carefully the colours which they can identify and also the order in which they follow one another from the inside to the outside of the ring.

BROCKEN SPECTRE

It happens frequently on mountains that there is mist on one side of a ridge and not on the other. In such circumstances an observer standing with his back to the sun will sometimes see coloured rings of light round the shadow of his own head on the mist. Similar observations may be made from aircraft. The whole appearance has been called the "Brocken Spectre," and the rings are usually known as a "Glory." The colours are not caused by the shadow, they are due to light diffracted backwards in the same way as the corona is due to light diffracted forwards. A large outer ring, known as Ulloa's Ring, which is essentially a white rainbow, is sometimes seen at the same time.

IRIDESCENT CLOUDS

Green and red colours are occasionally seen on the edges of cirrus and cirrocumulus clouds, at a distance from the sun or moon up to 25° or more. They are also seen at times on the edges of fractocumulus or stratocumulus clouds. Frequently a number of them may be seen along a line passing through the sun. These patches are perhaps portions of coronae, in which case they are probably due to the local occurrence of exceedingly small drops of water. The most important point to note is the (angular) distance between the sun (or moon) and the patches showing irisation.

* In the year following the eruption of Krakatoa, 1883, and again in 1903 after the eruption of Mount Pelée, a brownish red ring of over 20° radius was frequently seen with a clear sky. It was proved to be an unusually large corona.

RAINBOW

Rainbows are due to refraction and reflection of sunlight (occasionally moonlight) in falling drops of rain. They are circular arcs of coloured light centred at the anti-solar point (or point of the celestial sphere diametrically opposite to the sun).

The normal appearance of a bright well-developed rainbow is as follows :—The chief or primary bow shows the sequence of colours, violet, blue, green, yellow, orange and red, the red being on the outside or top of the bow.* Closely inside this bow are one or two supernumerary bows with the colours in the same order, the first inner bow being much fainter than the primary bow and the second fainter still. In cases of exceptionally brilliant rainbows more than two supernumerary bows may be seen. Outside the primary bow and entirely detached from it is the secondary rainbow in which the colours appear in the reverse order, red inside and violet at the top or outside. The primary bow is formed by means of one internal reflection in each raindrop, the secondary bow by two such reflections. In very exceptional cases more than one secondary bow has been seen. The sun, the observer's eye and the centre of the circle of which the primary rainbow forms an arc are always in a straight line, so that the azimuth of the highest part of the bow is 180° from the sun's azimuth. The normal radius of the arc of red light of the primary rainbow is 42° , of the violet arc $40\frac{1}{4}^\circ$; in the secondary bow the radii are: for red light 51° and for violet light 54° , all the values given being approximate ones. Hence it follows that the normal breadth of the primary bow is about $1\frac{3}{4}^\circ$ and that of the secondary bow about 3° . It also follows that with the sun at an altitude of 42° the uppermost point of the primary bow is on the horizon and hence no primary bow can be formed if the sun's altitude exceeds 42° . Consequently rainbows are mainly morning and evening phenomena; nearer mid-day if seen at all the arc of the bow is shorter and the altitude small.

Lunar rainbows are formed in precisely the same circumstances as solar bows, but are considerably rarer having regard to the comparatively short periods that a bright moon is above the horizon. In favourable circumstances a lunar rainbow is so much fainter than a solar one that colour is difficult to distinguish and the normal appearance of a lunar rainbow is whitish. In exceptional cases, however, the same sequence of colours may be observed as in a solar rainbow. On rare occasions white rainbows are formed by the sun; for this to occur the raindrops composing the cloud must be very small and the observer must be near the cloud. Such a rainbow is called a "fog-bow" or "Ulloa's Ring" and may form a complete circle.

"Reflection rainbows" are occasionally seen on calm days when a sheet of water lies in front of an observer standing with his back to the sun. Such bows are formed by rays of light illuminating the falling raindrops after reflection at the surface of the sheet of water. The centre of a reflection bow is as high above the horizon as the centre of the direct bow is below the horizon, consequently the arc, when complete, exceeds a semi-circle. The direct and reflection bows intersect on the horizon and the colours have the same sequence.

* Mnemonic V-I, violet inside.

COLORATION OF THE SKY

A cloudless sky appears to be blue, but it may show all possible gradations between a deep blue and a whitish-blue shade. It is desirable to note the gradations of colour according to the scheme: deep blue, light blue, and pale blue. Such observations give information regarding the purity of the air. For more exact observations the scale devised by Ostwald and Linke* may be used.

The most beautiful colours are seen at dusk. When the sky is cloudless, the colour and form of the first† “purple light” is worth attention. It is approximately parabolic in shape and appears at a considerable elevation above the point where the sun disappeared soon after sunset.‡ It varies in colour between pink and violet. Observers are also invited to note the colouring of the western sky and the appearance of the “second purple light” which develops after the disappearance of the first. The time of disappearance of the second light is also of importance. If “Alpenglühen” and “afterglow” are associated with the sunset, the phenomena should be noted.

The coloration of the clouds at sunset is often very beautiful and very striking and is therefore frequently noted although the phenomena observed when the sky is clear are more important.

THE GREEN RAY

When the sun sets under favourable conditions the last glimpse of it is coloured a brilliant green. The phenomenon and the corresponding one at sunrise are explained by the unequal refraction of light of different colours.

MIRAGE ∞

The position and appearance of distant objects are always altered to some extent by refraction when the light, which passes from the object to the observer, traverses obliquely layers of air of different density, and sometimes the displacement of position or distortion of appearance is so great as to produce an illusion of apparent water, trees, or buildings. Such phenomena are conspicuous when the variations of temperature close to the ground are very marked, as in desert countries when the ground is very strongly heated by the sun. Corresponding phenomena are often to be noted in this country.

As an International symbol for mirage a combination of two crossing arcs ∞ was recommended at an International Conference in Paris in 1919.

AURORA ∩

The aurora usually appears as a bright arch beneath which the sky seems to be darker than in the surrounding regions. Frequently

* *Met. Z., Braunschweig*, 45, 1928, pp. 367-70.

† Like Bishop's Ring, the first and second “purple lights” and also the “afterglow” on snow-peaks are associated with the presence of volcanic dust in the upper atmosphere.

‡ All these remarks apply also to sunrise but in the reverse order.

streamers of light shoot out radially from the arch and sometimes extend beyond the zenith. Occasionally the arch resembles a swaying sheet or curtain of light, and at times several arches can be seen simultaneously.

Observers should note such points as, the direction in which the phenomenon appears most intense, the direction of the arches and their angular height above the horizon, the length and position of the most prominent streamers, etc. Attention should also be directed to the colour effects visible.

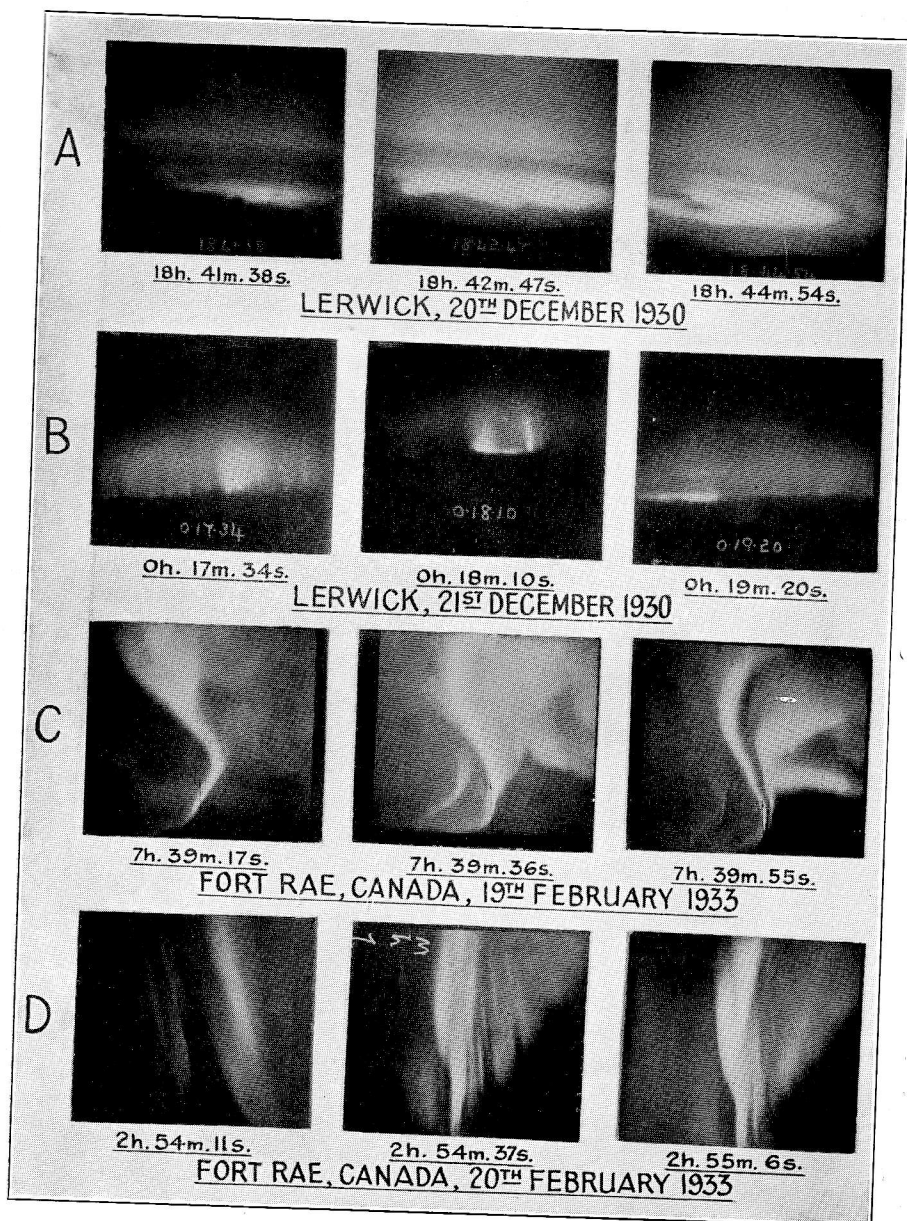
It is possible, by the use of very sensitive plates, to photograph the aurora and Professor Stormer has designed a special camera by means of which six photographs can be taken in rapid succession on one plate. Examples of auroral photographs made in this way are shown in Plate VI. The following descriptive notes will assist the observer in identifying typical auroral forms :—

- A. *Lerwick*, December 20, 1930.—Development of a low, quiet, homogeneous band from a diffuse luminous surface along the horizon with a feeble homogeneous arc above, into a system of bright ellipsoidal bands.
- B. *Lerwick*, December 21, 1930.—A strong arc with ray structure disintegrates into ray bundles which gradually re-merge to form a continuous arc. The brightest ray patches appear to travel from west to east along the arc. As is usual the lower edge of the arc is sharp.
- C. *Fort Rae, Canada*, February 19, 1933.—From an extensive arc, mainly of ray and curtain formation, long-rayed bands trail irregularly away to the east horizon, appearing by perspective to converge there. The whole system is bright and quickly changing.
- D. *Fort Rae, Canada*, February 20, 1933.—A long-rayed curtain developing from a broken band of rays strengthens into intense heavy draperies moving rapidly across the sky and extending to the zenith. The next stage is usually the formation of a corona near the magnetic zenith, a perspective effect arising from the convergence of the constituent rays of the drapery.

The aurora is an electrical phenomenon and is usually associated with magnetic storms.

ZODIACAL LIGHT

This is observed as the extremity of an elongated ellipse of soft whitish light, which extends from the sun as centre, appearing above the westerly horizon after sunset or above the easterly horizon before sunrise. The best time for observation is just after the last traces of twilight have disappeared in the evening or just before the first traces appear in the morning, the greatest extent of the light being then visible. The Light retains its apparent place among the stars as it gradually sets in the evening or rises in the morning. It is



PHOTOGRAPHS OF THE AURORA
(For description see p. 72.)



ZODIACAL LIGHT. NORTHERN FRANCE, 19h., JANUARY 29, 1918

sufficiently bright even in temperate latitudes not to be rendered invisible by faint twilight or partial moonlight.

The axis of the Light lies nearly in the plane of the Ecliptic, approximating more closely to the plane of the sun's equator. The whole phenomenon is confined to the zodiacal constellations. In tropical latitudes, where the Ecliptic makes a large angle with the horizon at all times of the year, the Light may be well seen on any clear night or morning in all months. In temperate latitudes the Ecliptic is often inclined at a small angle to the horizon and the Light is then rendered invisible by the additional extent of the atmosphere it has to traverse. In the latitudes of the British Isles it is best seen in the evenings of January to March and in the mornings of September to November; only about the time of the winter solstice is it possible to observe it on the morning and evening of the same day. In February the Light lies between the constellations of *Pegasus* and *Cetus*, the apex being near the *Pleiades*. Just after dark in the latitude of the British Isles the altitude of the apex of the Light is therefore about 50° , the cone lying obliquely with regard to the horizon. At this season the breadth near the horizon is 25° – 30° , the altitude of the part of greatest luminosity being 20° – 30° .

The Light is pearly and homogeneous and differs markedly in quality from that of the *Milky Way*, the brightest part of which it may considerably exceed in luminosity. It is more brilliantly and readily seen in the tropics, but it is very conspicuous even in the latitude of the British Isles if observed away from large towns. The nature of the Zodiacal Light is unknown. It is generally believed to be a cosmic phenomenon, due to the reflection of the sun's light from innumerable minute bodies or dust which revolve about the sun, the mass extending outwards somewhat beyond the earth's orbit. The meteorological origin of the Light as the final stages of twilight in the earth's atmosphere is, however, still upheld.

The accompanying plate is from a painting by Mr. G. A. Clarke based on a sketch made by Sergeant L. G. H. Lee in France in 1918.

NOTES ON SKETCHES, ETC.

(Communicated by Mr. G. A. Clarke, of Aberdeen Observatory.)—Whenever unusual optical or other meteorological phenomena present themselves, they should, if possible, be photographed. But it very frequently happens that from some cause, such as inherent colour, excessive faintness, want of definition, and in the case of aurora, want of sufficient light, these phenomena cannot be easily photographed.

In such cases, a simple, carefully made sketch may afford valuable amplification of any written description. Such sketches may be made either in water-colours, chalk, or pencil. Perhaps the better method, unless the observer is accustomed to water-colour painting, is to make sketches either in ordinary black pencil, or with the coloured chalk pencils which may be obtained from any artist's colourman. For scientific purposes, it is preferable at all times to

have an accurate even though simple sketch, so that elaboration should be quite a secondary consideration.

On the appearance of any phenomenon the best method of procedure is to note down rapidly in a few pencil lines the general appearance thereof, and also to indicate on the horizon line (which should always be included in the sketch if possible), a few landmarks, the bearings of which are known. This will give the position of the phenomenon and rough angular measurements can be made from these notes later on. Notes should also be made of the colours seen, especially if the rough sketch is intended to form the basis of a more finished coloured sketch.

Halos and other optical phenomena are very easily noted and sketched by observing their images reflected in a black mirror (a piece of ordinary glass about 8 in. square, coated on the back with black varnish, makes an excellent mirror for the purpose). Rough angular measurements of the image can also be made with a scale by using the halo of 22° as a reference.

Sketches of aurora should be made using a light no brighter than is absolutely necessary to illuminate the paper upon which notes and sketches are made. The bearing of the auroral arch should always be noted and the ends of the arch should be referred to some known point on the horizon. The angular altitude of the arch or arches can also be determined by noting any known star that may be situated near the top of the arch, and by finding the altitude of the star afterwards.

The times of the appearance of phenomena should be noted, particularly if a series of sketches is made.

For cloud phenomena it will be found advantageous to use pale blue-tinted cartridge paper for the finished drawings, working upon it with white and coloured pencils.

For aurorae a dark-blue or indigo tinted paper will give very good results with the chalk pencils.

§ 13. CLOUDS

Cloud observations may be considered under four headings, viz.:—
(1) height, (2) amount, (3) form, (4) direction and velocity of motion.

HEIGHT OF CLOUD

Some part of our knowledge of the height of clouds has been obtained from simultaneous measurements of the elevation and azimuth of a given cloud made at the two ends of a base line a quarter of a mile or more. The length of the base line being known, and the angles having been obtained by measurement, the height of the cloud selected for observation can be accurately calculated by the application of simple trigonometry. Rather elaborate apparatus is required and it is necessary that the observers at the two ends of the base should be in telephonic communication with one another. The method is therefore not described here in detail.

Measurement with balloons.—A simple method of determining cloud height is by the observation of a small balloon such as a pilot balloon rising at a known rate. All that is necessary is to note the time that elapses between the release of the balloon and its disappearance in the lower surface of a cloud. When, however, the cloud is tenuous or the base ragged, the balloon may be visible for some time after it reaches the cloud; the time of entering the cloud is then to be taken as the time at which cloud or mist is first seen between the observer and the balloon. A theodolite, binoculars or a telescope should be used as the unaided eye may be unable to follow the balloon to a sufficient height. Care must be taken to distinguish between cases when the balloon is seen to enter a cloud and those in which the balloon is obscured by a cloud at some lower level drifting across the field of view.

At night a small paper lantern containing a lighted candle can be attached to the balloon by means of about 12 ft. of fine thread. In strong winds, in order to avoid extinguishing the light by jerking the lantern, 2 or 3 ft. of *bare* elastic (cross section $\frac{3}{4}$ mm. square) should be inserted in the thread. When obstacles such as wires or buildings prevent a successful release with a suspension of the usual length, the elastic alone may be used. Small candles, such as Price's Christmas candles, are suitable. A lantern may be simply made as follows :—

Cut from thin card two circular discs $3\frac{1}{2}$ in. in diameter, to form the ends. Take a sheet of tissue paper 6 in. wide by 12 in. long to form the cylindrical side of the lantern. Cut a hole in the top end 2 in. in diameter and provide it with a handle of thin wire. Now attach the ends by means of paste lapping the tissue paper over about half an inch all round.

The free lift necessary to give balloons of standard sizes an ascensional velocity of 400 ft./min. or 500 ft./min. (a) without attachments and (b) with a lantern or weight w gm. is as follows :—

48-in. balloon, 400 ft./min., (a) 20 gm., (b) 30 gm. + w .

70-in. balloon, 500 ft./min., (a) 61.5 gm., (b) 71.5 gm. + w .

90-in. balloon, 500 ft./min., (a) 71.5 gm., (b) 80.5 gm. + w .

Thus if the lantern is not attached to the balloon while the latter is being filled, an equivalent weight w must be added to the filler weight. The weight w , which includes the lantern, thread and elastic, must be arranged to be approximately 10 gm.

The ascensional rates quoted are the mean values obtained from the various sizes of balloon. As the rates vary considerably for individual balloons and further variations occur when convection currents are present, this method of determining cloud height is not regarded as being very accurate.

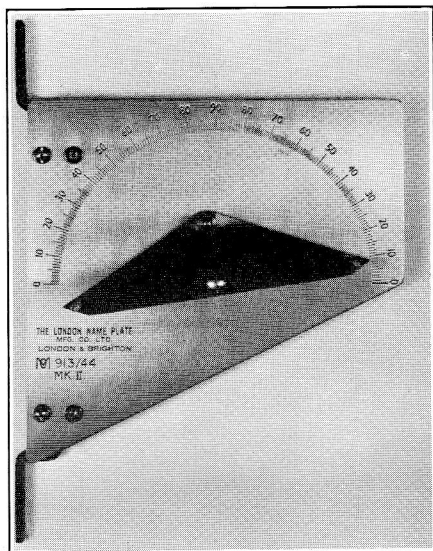
Measurement at night by means of a vertically directed beam of light.—Measurements of cloud heights are easily and rapidly obtained by means of a vertically directed beam of light.

The principle underlying the method used is simple. At one end of a measured base line is placed a searchlight of special design, the light of which is directed vertically upwards in a well-defined parallel or even slightly converging beam. This beam on striking the underside of cloud produces a well-defined illuminated spot, or, in some cases of very low cloud, the beam produces diffuse illumination over a part of its course. From the other end of the base line the altitude of the light spot or the altitude of the lowest point of the diffuse illumination is measured by means of an alidade. This is a simple instrument for determining the angular altitude and consists of a sighting system rotating about a horizontal axis over a quadrant of a circle graduated in degrees. The base line, the line of sight of the observer and the beam of light, then constitute the three sides of a right-angled triangle, the base of which is known and of which one angle is measurable. If h be the height of the cloud and b is the length of the base line we have $h=b \tan A$ where A is the angular elevation of the illuminated spot, from which h can be obtained for varying values of A . If the base line is fixed this formula may be used to construct a scale from which the height of the cloud may be read off directly.

Observations made by this method sometimes disclose the presence of thin cloud layers which are invisible from the ground, the existence of which is not discernible by other means such as a pilot-balloon ascent.

Standard cloud searchlight.—The standard cloud searchlight used in the Meteorological Office (*see* Plate VIIIA.) consists of a 16-in. diameter parabolic silvered glass reflector mounted in a strong cylindrical case, the base of which has three adjustable feet for levelling purposes. The top of the case is inclined to the horizontal and is covered by a piece of glass pressed tight between two rubber packing rings. The metal ring which clamps the glass in position is provided with a small hole at the lowest point to allow rainwater collected on the glass to run away. The lamp, which is generally 24 volt 250 or 500 watt, works at a very high efficiency and consequently has a rather short life. There is adequate provision for focussing the lamp. Full instructions for setting up the instrument, adjusting the verticality of the beam and general maintenance are issued with each instrument.

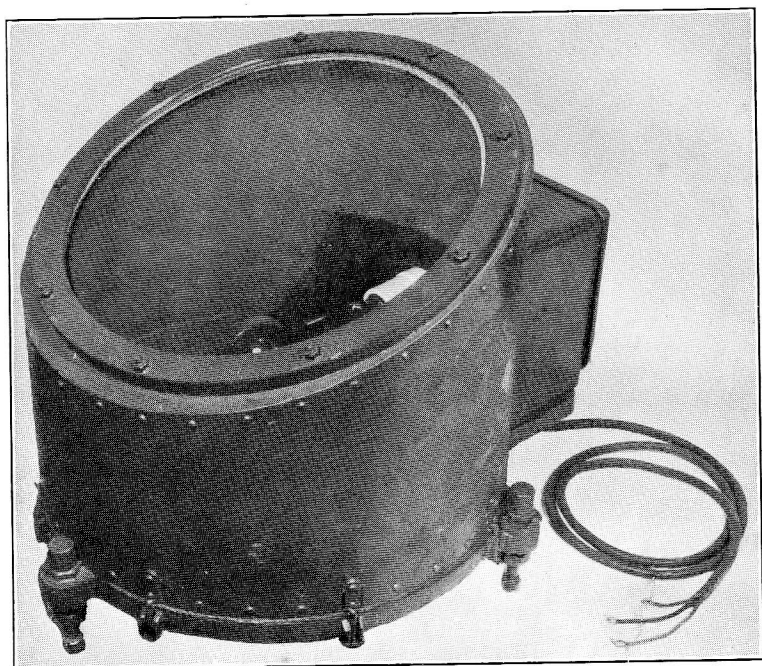
Portable cloud searchlight.—A smaller searchlight, designed primarily for mobile meteorological units, was introduced into the Meteorological Office in 1944; it is illustrated in Plate VIIIA. The lamp is a standard 8 in. motor-car headlamp with a 12 volt 36 watt bulb which can be run off a car battery. The lamp base is fitted with levelling screws and a small relay switch, by means of which the lamp may be switched on by the observer standing at the other



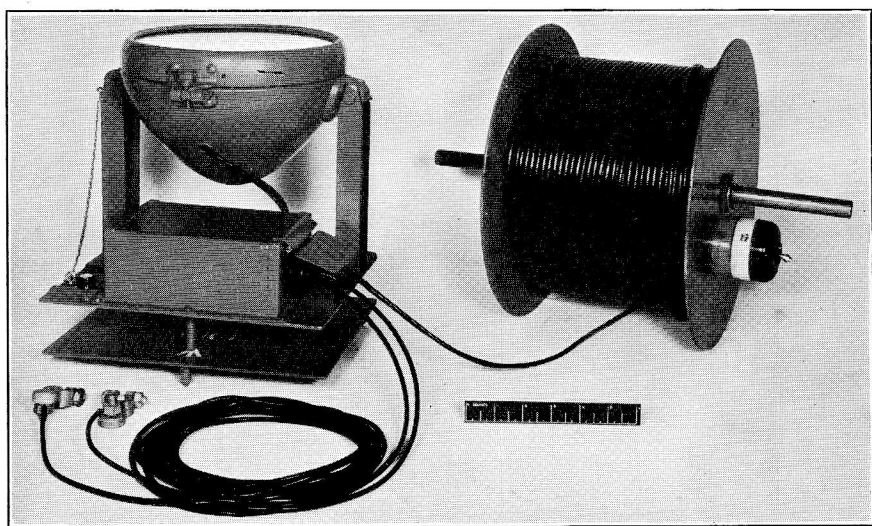
METEOROLOGICAL OFFICE ALIDADE, MK. II



METEOROLOGICAL OFFICE PORTABLE ALIDADE



METEOROLOGICAL OFFICE CLOUD SEARCHLIGHT



METEOROLOGICAL OFFICE PORTABLE CLOUD SEARCHLIGHT

end of a 1,000 ft. length of light cable. A portable alidade is used with this searchlight. The indicating arm is free to swing about a horizontal axis and is maintained in a vertical position by the force of gravity as the observer points the main body of the alidade at the light spot on the cloud. The scale is, for convenience, graduated direct in terms of cloud height for a 1,000 ft. base line. The portable searchlight gives satisfactory light spots on clouds up to at least 3,000 ft. when the bulb is adjusted in accordance with instructions issued by the Meteorological Office.

Estimating cloud heights.—In hilly and mountainous districts the heights of the bases of clouds which are lower than the tops of the visible hills can be determined with some accuracy by inspection, when the clouds are banked-up against the hills, provided the heights of the different features of the hillside are known. These heights can be obtained from an Ordnance Survey map of the district. The cloud height over high ground, hills or mountains is frequently, and in moist winds with a general cloud layer is usually, less than it is over areas near sea level.

At stations in level country where pilot-balloon observations are not made and direct measurements are not possible, we have to fall back on estimates. In view of the great practical importance of a knowledge of the height of the low clouds in aerial navigation, estimates of the height of the lowest cloud are now included in the meteorological reports sent from telegraphic reporting stations in order that this information may be made promptly available to pilots of machines. Some guidance in forming such estimates can be obtained from the following table, giving the levels between which the bases of the different forms of clouds are usually observed.

Observers who have the necessary experience or information to enable them to form satisfactory estimates of cloud height in thousands of feet should note the information in the monthly returns.

Heights of the Base of Clouds

<i>Form of Cloud</i>	<i>Usual Heights in Britain</i>			<i>Remarks</i>
<i>Low cloud—</i>				
Stratus	...	500–2,000 ft.	...	Sometimes practically down to the surface; sometimes as high as 4,000 ft.
Stratocumulus		1,500–4,500 ft.	...	Sometimes as low as 500 ft.; or as high as 8,000 ft.
Cumulus	...	2,000–5,000 ft.	...	Sometimes as low as 1,000 ft.; or as high as 8,000 ft.
Cumulonimbus		2,000–5,000 ft.	...	Sometimes as low as 1,000 ft.; or as high as 8,000 ft. (The top of Cb frequently extends to heights of over 10,000 ft. and may reach 25,000 ft.)
Nimbostratus		300–2,000 ft.	...	Sometimes practically down to the surface; occasionally as high as 8,000 ft.

Heights of the Base of Clouds—contd.

<i>Form of Cloud</i>	<i>Usual Heights in Britain</i>	<i>Remarks</i>
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Middle cloud—

Altostratus	}	Heights usually between 6,500 and 20,000 ft.
Altostratus		

High cloud—

Cirrus	}	Heights usually between 20,000 and 40,000 ft.*
Cirrocumulus		
Cirrostratus		

Observers should miss no opportunity of comparing notes with pilots of aircraft for the purpose of checking their estimates.

The heights of the base of low cloud given in the preceding table are heights above ground level, but they refer to places in Great Britain in level country not more than 500 ft. above the sea. For stations at substantially greater heights, or stations on mountains, the height of the base of low cloud will be less; for instance, for a station in Great Britain between 1,000 and 1,500 ft., the heights in the table would be reduced by about 1,000 ft. Thus, the base of stratus or nimbostratus would sometimes be below the level of the station.

AMOUNT OF CLOUD

The degree of cloudiness is to be given by the figures 0–10, in which 0 represents a sky **quite free from cloud**, and 10 an entirely overcast sky **in which no patches of blue sky are visible**. We are required to estimate the number of tenths of the area of the sky which are obscured from view by cloud. The entry “trace” should be made when there are small amounts of cloud present and these small amounts do not obscure as much as one-twentieth of the sky; and the entry “9+” when there are small breaks in an otherwise overcast sky, though the breaks do not actually amount to one-twentieth of the sky’s area. The numbers given are to refer solely to the amount of the sky obscured and not to the density, height or other quality of the cloud.

If desired the density of the cloud may be indicated by the following scale:—

- | | |
|-----------------------------|-------------------------------------|
| 0. Very thin and irregular. | 3. Thick. |
| 1. Thin but regular. | 4. Very thick and of a dark colour. |
| 2. Moderately thick. | |

In estimating the observer will do well mentally to sub-divide the sky into quadrants by means of diameters at right angles to each other. An estimate (on the scale 0–10) is then formed for each quadrant separately, and the figure finally entered in the register

* In the tropics the upper level may be 50,000 ft. or more.

is the mean of the four numbers so obtained. The direction of the dividing diameters should be selected to give convenient sub-divisions of the prevailing cloud canopy.

It was the general custom until recently to note only the total amount of cloud of all forms and to leave out of consideration questions of height or form of the cloud when making the observation. The information regarding amount of cloud published in the *Monthly Weather Report* of the Meteorological Office is still prepared on that understanding.

Sometimes the amount of cloud of a specified form or type is required. This is found by imagining that every other visible form or type of cloud is replaced by blue sky, and by determining the amount of the specified form or type in the manner already described.

On occasions of fog or mist, if the vertical thickness of the fog is so great that it is impossible to tell whether there is cloud above it, the cloud amount should be entered as 10. This applies, for example, to all cases of fog in the day time in which the sun is *quite* invisible.

If cloud can be seen through the fog then the amount should be estimated as well as possible and entered in the ordinary way. The form can also be recognised under these conditions more or less correctly and should be noted.

If the sun or stars can be seen through the fog, and there is no evidence of cloud above the fog, the amount of cloud should be entered as 0 irrespective of the *horizontal* thickness of the fog.

CLOUD FORMS. INTERNATIONAL DEFINITIONS

The international classification of cloud forms is based upon the four fundamental types of the classification proposed by Luke Howard at the beginning of the 19th century, namely, **cirrus**, the thread-cloud ; **cumulus**, the heap-cloud ; **stratus**, the flat cloud or level sheet ; and **nimbus**, the rain-cloud. The details of a more precise classification occupied the attention of meteorologists in many countries during the latter part of the century, among whom were specially prominent our own countrymen, the Rev. Clement Ley and the Hon. Ralph Abercromby. A book by Mr. Clement Ley entitled "Cloudland" is well known to meteorologists. Mr. Abercromby contributed a number of papers on the subject, laying stress upon the most important fact that cloud forms are not peculiar to special localities or latitudes, but are the same for all parts of the world. Both these gentlemen unfortunately died before the classification was settled. The other meteorologists who were specially active in this work were Professor H. H. Hildebrandsson, of Uppsala, Sweden ; M. Léon Teisserenc de Bort, of Paris ; and M. A. Riggenbach, of Zürich, Switzerland.

A classification was agreed on at the International Conference at Munich in 1891, and as a sequel the first edition of the "International Cloud Atlas" appeared in 1895. It has run through several editions since that date; the last appeared in 1910 and is now out of print.

After the Great War the need for a new Atlas was acutely felt and an International Commission for the Study of Clouds was set up in 1922, under the presidency of General E. Delcambre, the Director of the Office Nationale Météorologique de France, to undertake this work. An "Abridged edition for the use of observers" was produced in 1930, and the complete Atlas with separate editions having the text in French, English and German was published in 1932. The method of classification and the definitions of forms of cloud adopted therein differ in certain respects from those of the Atlas of 1895. The following summary is based on Part I of the English edition :—

I.—TABLE OF CLOUD CLASSIFICATION

At nearly all levels clouds may appear under the following forms :—

- (a) *Isolated*, heap clouds with vertical development during their formation, and a spreading out when they are dissolving.
- (b) *Sheet clouds which are divided up into filaments, scales, or rounded masses* and which are often stable or in process of disintegration.
- (c) *More or less* continuous cloud sheets, often in process of formation or growth.

Classification into families and genera

Family A : High clouds (mean lower level 6,000 m. (20,000 ft.)).*

Form b $\left\{ \begin{array}{l} 1. \text{ Genus Cirrus.} \\ 2. \text{ Genus Cirrocumulus.} \end{array} \right.$

Form c 3. Genus Cirrostratus.

* It should be noted that the heights given are for temperate latitudes, and refer, not to sea level, but to the general level of the land in the region. In certain cases there may be large departures from the given mean heights, especially as regards cirrus, which may be found as low as 3,000 metres in temperate latitudes, and in polar regions even almost as low as the surface.

Family B : Middle clouds (mean upper level 6,000 m. (20,000 ft.), mean lower level 2,000 m. (6,500 ft.)).

Form a } 4. Genus *Alto*cumulus.†
 Form b }
 Form c } 5. Genus *Alto*stratus.

Family C : Low clouds (mean upper level 2,000 m. (6,500 ft.), mean lower level close to the ground).

Form a } 6. Genus *Strato*cumulus.†
 Form b }
 Form c { 7. Genus *Stratus*.
 8. Genus *Nimbo*stratus.

Family D : Clouds with vertical development (mean upper level that of the cirrus, mean lower level 500 m. (1,600 ft.)).

Form a { 9. Genus *Cumulus*.
 10. Genus *Cumulo*nimbus.

II.—DEFINITIONS AND DESCRIPTIONS OF THE FORMS OF CLOUDS ‡

1. **Cirrus (Ci).**—Detached clouds of delicate and fibrous appearance, without shading, generally white in colour, often of a silky appearance.

Cirrus appears in the most varied forms such as isolated tufts, lines drawn across a blue sky, branching feather-like plumes, curved lines ending in tufts, etc. ; they are often arranged in bands which cross the sky like meridian lines, and which, owing to the effect of perspective, converge to a point on the horizon, or to two opposite points (*cirro*stratus and *cirro*cumulus often take part in the formation of these bands).

2. **Cirrocumulus (Cc).**—A cirriform layer or patch composed of small white flakes or of very small globular masses, without shadows, which are arranged in groups or lines, or more often in ripples resembling those of the sand on the sea shore.

In general cirrocumulus represents a degraded state of cirrus and *cirro*stratus both of which may change into it. In this case the changing patches often retain some fibrous structure in places.

Real cirrocumulus is uncommon. It must not be confused with small *altocumulus* on the edges of *altocumulus* sheets.

† Most *altocumulus* and *stratocumulus* clouds come under category b but the varieties *cumuliformis* and particularly *castellatus* belong to category a.

‡ Cloud formed by aircraft (condensation trails) should not be reported as "natural" cloud.

3. **Cirrostratus (Cs).**—A thin whitish veil, which does not blur the outlines of the sun or moon, but gives rise to halos. Sometimes it is quite diffuse and merely gives the sky a milky look ; sometimes it more or less distinctly shows a fibrous structure with disordered filaments.

4. **Alto cumulus (Ac).**—A layer (or patches) composed of laminae or rather flattened globular masses, the smallest elements of the regularly arranged layer being fairly small and thin, with or without shading. These elements are arranged in groups, in lines or waves, following one or two directions and are sometimes so close together that their edges join.

The thin and translucent edges of the elements often show *irisations* which are rather characteristic of this class of cloud.

5. **Altostratus (As).**—Striated or fibrous veil, more or less grey or bluish in colour. This cloud is like thick cirrostratus but without halo phenomena ; the sun or moon shows vaguely, with a faint gleam, as though through ground glass. Sometimes the sheet is thin with forms intermediate with cirrostratus (*altostratus translucidus*). Sometimes it is very thick and dark (*altostratus opacus*), sometimes even completely hiding the sun or moon. In this case differences of thickness may cause relatively light patches between very dark parts ; but the surface never shows real relief, and the striated or fibrous structure is always seen in places in the body of the cloud.

6. **Stratocumulus (Sc).**—A layer (or patches) composed of globular masses or rolls ; the smallest of the regularly arranged elements are fairly large ; they are soft and grey, with darker parts. These elements are arranged in groups, in lines, or in waves, aligned in one or in two directions. Very often the rolls are so close that their edges join together ; when they cover the whole sky—on the continent, especially in winter—they have a wavy appearance.

7. **Stratus (St).**—A uniform layer of cloud, resembling fog, but not resting on the ground. When this very low layer is broken up into irregular shreds it is designated *fractostratus* (Fs).

8. **Nimbostratus (Ns).**—A low, amorphous and rainy layer, of a dark grey colour and nearly uniform ; feebly illuminated seemingly from inside. When it gives precipitation it is in the form of continuous rain or snow.

But precipitation alone is not a sufficient criterion to distinguish the cloud which should be called *nimbostratus* even when no rain or snow falls from it.

There is often precipitation which does not reach the ground ; in this case the base of the cloud is always diffuse and looks " wet " on account of the general trailing precipitation, *virga*, so that it is not possible to determine the limit of its lower surface.

9. Cumulus (Cu).—Thick clouds with vertical development ; the upper surface is dome shaped and exhibits rounded protuberances, while the base is nearly horizontal.

When the cloud is opposite to the sun the surfaces normal to the observer are brighter than the edges of the protuberances. When the light comes from the side the clouds exhibit strong contrasts of light and shade ; against the sun, on the other hand, they look dark with a bright edge.

True cumulus is definitely limited above and below ; its surface often appears hard and clear cut. But one may also observe a cloud resembling ragged cumulus in which the different parts show constant change. This cloud is designated fractocumulus (Fc).

10. Cumulonimbus (Cb).—Heavy masses of cloud, with great vertical development, whose cumuliform summits rise in the form of mountains or towers, the upper parts having a fibrous texture and often spreading out in the shape of an anvil.

The base resembles nimbostratus and one generally notices *virga*. This base has often a layer of very low ragged clouds below it (fractostratus, fractocumulus).

Cumulonimbus clouds generally produce showers of rain or snow and sometimes of hail or soft hail and often thunderstorms as well.

If the whole of the cloud cannot be seen the fall of a real shower is enough to characterise the cloud as a cumulonimbus.

As compared with the specifications set out in the first International Cloud Atlas (reprinted in former editions of this handbook) the most important new features are the omission of " nimbus " and the inclusion of the new type " nimbostratus."

In addition to *families* and *genera* which suffice for the broad classification of cloud forms, the new International Atlas also recognises *sub-genera*, *species*, *varieties* and *casual details* to which distinguishing latin adjectives are applied for purposes of more precise differentiation.

For details of these sub-classifications reference should be made to the Atlas. It is proposed, in this handbook, to refer only to the varieties which are already so well known that their names have come into general use. These are distinguished by the adjectives " cumuliformis," " lenticularis," " castellatus " and " mammatus."

Cumuliformis.—Various types of clouds, particularly cirrus, altocumulus and stratus, may in certain circumstances assume a rounded appearance resembling cumulus. The adjective “cumuliformis” is added to the name of the cloud to indicate this condition (*e.g.*, stratus cumuliformis).

Lenticularis.—Groups of cirrocumulus, altocumulus and stratocumulus, sometimes show an ovoid form with sharp edges, resembling the cross-section of a lens. The adjective “lenticularis” is added to the name of the cloud to indicate this structure (*e.g.*, altocumulus lenticularis).

Castellatus.—Added to the name altocumulus to indicate the turreted or crenellated appearance sometimes assumed by individual cloudlets of middle height, usually in summer.

Mammatus.—The lower surface of certain cloud sheets sometimes forms pouches or breasts. This structure is distinguished by the adjective “mammatus” or the prefix “mammato,” *e.g.*, “cumulonimbus mammatus.”

Remarks on the classification of clouds.—The problem presented to those who classify clouds is of a dual character. There are first the forms of individual clouds, stratus, cumulus and cirrus, while the other forms are really aggregates, or groups of clouds or cloudlets, arranged sometimes in a continuous mass, sometimes in rows or waves, not infrequently in double or even triple sets of waves. There are all sorts of gradations, from the dappled mackerel sky of cirrocumulus to the altocumulus, often with a dense central portion and separate clouds on the margins, the irregular masses of stratocumulus, and finally the continuous strata which are to be found at various different levels—low, intermediate, and high. We can hardly exclude the continuous stratus itself from consideration as a group or aggregate, because when it thins it breaks up into detached clouds.

Lenticular, lentil-shaped or almond-shaped clouds have attracted some attention in recent times. They have a peculiar outline. In many cases they are very suggestive of an airship, and are perhaps the clouds in “Hamlet” which are “very like a whale” In others the inner part of the cloud becomes very thin, or disappears, so that the shape looks like a large horse-shoe as seen from beneath at a great distance. Photographs and eye observations show that the bank of clouds which keeps its position with little apparent change is really composed of a mass of cloudlets, forming and drifting into the cloud bank with the wind at one side and drifting away from it and dissolving at the other. Thus the stationary appearance of the cloud bank is illusory as regards the wind. The wind blows through the cloud bank, which is formed by the massing of the drifting cloudlets. The cloudlets belong apparently to the type of altocumulus or cirrocumulus.

The term "mammatus" was formerly associated exclusively with cumulus but mammatus structure is frequently observed on the under surface of an anvil of so-called "false cirrus" (now called cirrus nothus) projecting from a mass of cumulonimbus. A structure to which the name mammatus is appropriate, though differing somewhat from the typical form, is also sometimes seen beneath sheets of stratus and altostratus. Characteristic "cumulonimbus mammatus" has a peculiar heavy and ominous appearance.

A word must be added about cirrus. It is generally understood to be not only a cloud of thread-like structure, as its name implies, but at the same time a very high cloud, its normal height being about 9 Km., or nearly 30,000 ft. No doubt the best and most durable examples are to be found at those great heights, but thread-like clouds, indistinguishable in appearance from wisps of true cirrus, may be found at much lower levels just as the cirrus nothus is formed at various heights. C. K. M. Douglas, from close observation in an aeroplane, expresses the opinion that marked thread-like structure is always attributable to clouds formed of ice crystals, and if that be the properly distinctive characteristic of the thread-like structure, it only hampers our conception of the atmospheric processes if we assume all clouds which show that structure to be at a very high level. The form resembles trails of falling precipitation, and it is possible that the fall of the particles relative to the air (itself often rising) tends to produce a fibrous structure in the cloud. Ice crystals are much larger than most water particles (other than raindrops) and tend to fall faster and further without evaporating. Clouds which are definitely fibrous have a considerable vertical extension, but in cold weather they may exist entirely below 4 Km. Very thin delicate layers of cloud (often high) may sometimes appear wisp-like, especially under the influence of perspective, but this structure is different from the true fibrous type. These delicate layers often show iridescence when near the sun or moon, indicating that they are almost certainly not composed of crystals.

DIRECTION AND VELOCITY. NEPHOSCOPES

The direction of motion of clouds is always stated as the direction from which the cloud is coming. It is best observed by sighting the cloud against a fixed point. At night time and when the cloud canopy is broken, stars near the zenith form very suitable fixed points. At other times the top of a flagstaff, gable of a house, etc., may be used. If the cloud motion is slow the observer will find it advantageous to rest his head against some fixed support while taking the observation; otherwise the apparent cloud motion which he observes may be due to motion on his own part. To avoid errors due to perspective he should stand as near as may be vertically below the fixed point and confine his attention to clouds near the

zenith. A little experience will enable the observer to give a qualitative statement of the apparent velocity of clouds by means of such designations as slow, moderate, fast, etc.

For the accurate determination of the direction of motion of clouds, some form of nephoscope should be used. This instrument can also be used to determine the angular velocity of a cloud, but the linear velocity cannot be determined with it unless the height of the cloud is known from other considerations.

It is convenient in practice to adopt a measure for the apparent velocity which can be determined easily by observation and which will give the linear velocity directly when the height is known. A quantity which fulfils both these conditions is the ratio of the horizontal velocity of the cloud to its height. In what follows this will be called the velocity-height ratio. It is equal to the angular velocity of the cloud about the point of the earth's surface vertically beneath it. This is greater than the angular velocity of the cloud as seen by the observer except when the cloud is in the observer's zenith, when the two quantities are identical.

The two instruments about to be described are so arranged that the velocity-height ratio is determined directly by an observation which is independent of the distance of the observer from the point vertically beneath the cloud.

Two main types of instrument may be distinguished—

- (1) reflecting nephoscopes,
- (2) direct vision nephoscopes.

Fineman's nephoscope.—As an example of the first type, Fineman's nephoscope will be considered. The modified form known as Mark II which has been designed at the Meteorological Office consists of a disc of black glass mounted on a tripod stand which allows of accurate levelling. A vertical pointer which can be raised or lowered by a rack and pinion motion is attached to a collar which can be rotated independently of the mirror. A scale of millimetres engraved on the edge of the pointer gives the height of its tip above the glass surface.

The method of observing is as follows :—The mirror is levelled and then orientated by means of the scale of degrees engraved on the circular frame and a compass needle mounted below the mirror and then clamped. The observer must bear in mind that in this country the compass needle points about 12° west of true north (see p. 10) so that when the mirror is orientated, the south pole of the compass needle will point to about 166° . After orientating, the observer stations himself in such a position that the image of the cloud in the glass and the central point of the mirror are seen in the same straight line. He

then rotates the pointer and adjusts its length until the image of its tip is also brought into this straight line. This done he moves his head so as to keep the images of the cloud and of the tip of the pointer in coincidence. The point on the circumference at which the image of the cloud appears to leave the dial gives the direction from which the cloud is coming.

The velocity-height ratio of the cloud may be determined by noting the number of seconds required for the image to travel from one circle to the next. If a be the difference between the radii of the circles, b be the height of the tip of the pointer above the reflecting surface and t be the time required for the cloud image to traverse the distance a (both a and b being measured in the same units, *e.g.*, millimetres), the value of the velocity-height ratio is given by the formula a/bt .

←-----5 in.-----→

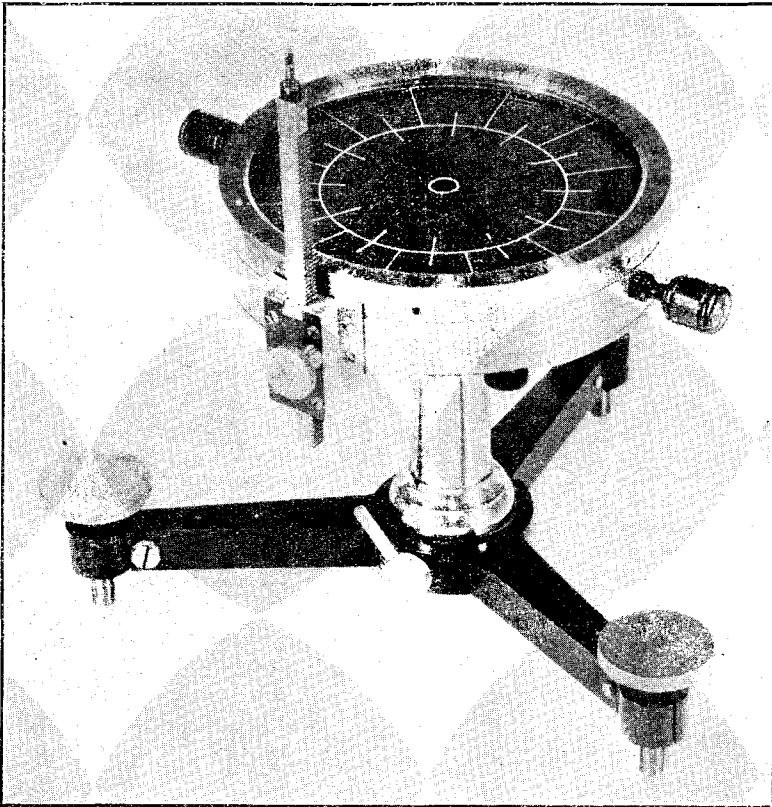
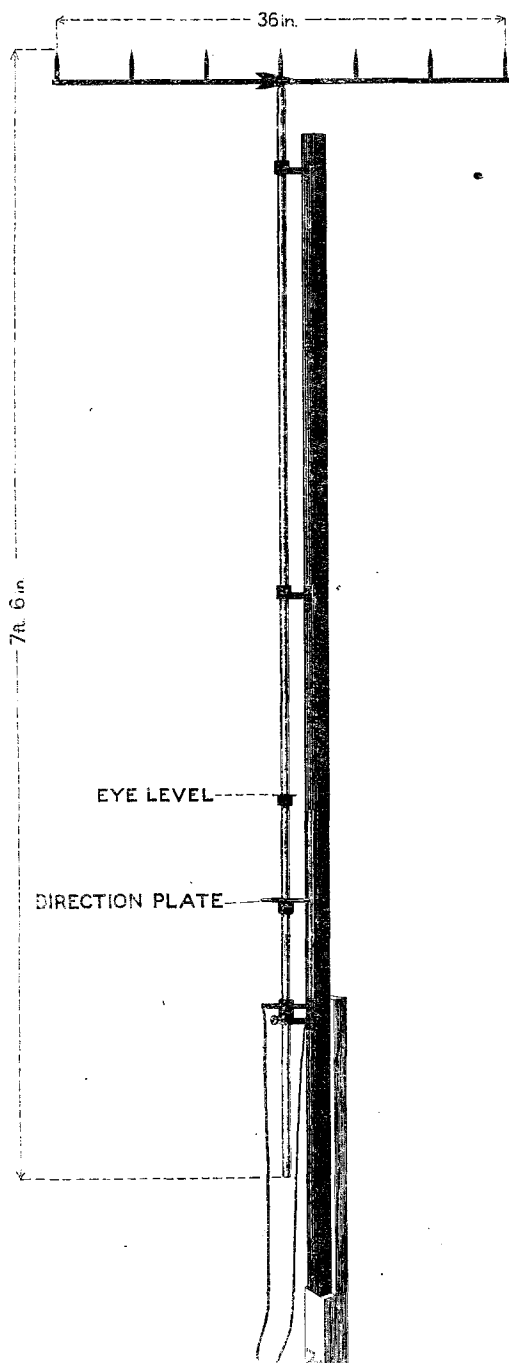


FIG. 18. FINEMAN'S NEPHOSCOPE

In the Mark II instrument the difference between the radii of the circles engraved on the glass is 25 mm. A table for computing the velocity-height ratio by means of this instrument is given on p. 151.

Besson's comb nephoscope



Besson's comb nephoscope (Fig. 19) will serve as an example of a direct vision nephoscope. It consists of a vertical brass rod bearing at its upper end a cross piece 3 or $3\frac{1}{2}$ ft. long, to which a number of equidistant vertical spikes are attached. The rod is mounted in a vertical position by means of a number of rings and clamps screwed into a tall post in such a manner that it can rotate freely. Its height should be adjusted so that a fixed mark on the rod is at the level of the observer's eye.

When using the apparatus the observer stations himself in such a position that the cloud selected for observation is seen in the same straight line as the **central spike**. He then turns the cross piece until the cloud appears to travel along the line of spikes in the direction of the arrow **while he himself remains motionless**. The cross piece will then be parallel to the line of motion of the cloud and the direction in which it points can be read off on a graduated circle which is provided for the purpose. The rod may be turned by an observer standing at some distance away from it by means of two cords tied to a second shorter cross piece attached to its lower extremity.

FIG. 19. BESSON'S COMB NEPHOSCOPE

The velocity-height ratio is determined by noting the time taken for the cloud to pass from spike to spike. If a be the distance between the spikes, and b the distance from the top of the central spike to the marked point on the rod which has been adjusted to the level of the observer's eye, and t the observed time, we have as before

$$\text{velocity-height ratio} = \frac{a}{bt}$$

Both a and b must be measured in the same units. The difference in level between the cross piece and the observer's eye should be the same in all measurements and hence the instrument must be set up on a level site. Smoked glass spectacles should be worn by the observer to protect his eyes.

Instructions for making observations with a Besson comb nephoscope

1. In observations with a Besson comb nephoscope, it is essential that the cloud observed should be in line with the **centre** spike of the nephoscope either initially or in the course of motion. If the cloud is moving slowly the sighting on the middle spike should usually be done in the first instance. If the cloud is moving rapidly it may be more convenient to watch it cross the centre spike in the course of its motion.

2. In some instruments the distance from the centre spike to the next spike is only half the standard distance between the spikes. If the time is taken for the cloud to move from the centre spike to the next spike, this time should be doubled before it is used to compute the velocity-height ratio. As a general rule this half-distance should not be used but the time should be taken over at least one full distance, unless the cloud is moving extremely slowly.

3. It is of the highest importance that the observer's head should be kept still during the observation. Some form of eye-steadier is necessary and observers should use the best means locally available to enable them to avoid any errors in observations due to movement of the observer's eyes.

NOTE.—The reason for insisting on the use of the centre spike (para. 1 above) is that if the cloud is sighted first on the centre spike and the nephoscope is then moved so that the cloud can be sighted on any other spike, the reading on the graduated circle gives the direction of motion of the cloud correctly. But if the cloud is first sighted on a spike other than the central spike and the nephoscope is then moved so that the cloud is sighted on another spike, the reading on the graduated circle does *not* give the direction of motion of the cloud correctly. If the centre spike is not used the direction on the graduated circle is correct only when the *nephoscope* as well as the *observer* remains still between the sighting on one spike and the next. The importance of using the centre spike is that after sighting the cloud on this spike the nephoscope can be moved so that the cloud moves along the other spikes without invalidating the observation either of direction or speed. It should be noted that even if the observer does not succeed in turning the nephoscope so that the cloud is sighted on the first or second spike from the centre, the observation will still be accurate if he sights it on the third spike provided he sighted it accurately in the first place on the centre spike. *This process, however, cannot be reversed*; if the observer sights the cloud on an end spike and then moves the nephoscope so that he sights it on the second spike he will not obtain the direction correctly.

Method of stating the results of nephoscope observations.—The velocity-height ratio has the dimensions of an angular velocity for which the usual unit is one radian per second. As this unit is too

large for the purpose, the radian per hour is used. The formula is then

$$\Omega = 3600 \frac{a}{bt}$$

where Ω is the velocity-height ratio in radians per hour and t is measured in seconds.

The actual velocity of the cloud is the product of the velocity-height ratio and the height of the cloud. If the height of the cloud is expressed in kilometres the resulting velocity will be in kilometres per hour, if the height is in miles the resulting velocity will be in miles per hour.

§ 14. THE RAIN-GAUGE

A great variety of rain-gauges exists, but only five types are officially approved by the Meteorological Office; these are illustrated in Fig. 20. The essential features of the standard gauges are (1) the accurately machined stout brass bevelled ring forming the aperture and (2) the cylindrical or slightly sprayed section between the ring and the funnel. The ring should be truly circular with a diameter of 5 in., and the cylindrical section should be at least 4 in. in length in order to prevent rain from being blown out by the wind as it enters the gauge and to retain a reasonable quantity of hail or snow. Fuller information about the various gauges is given in Air Ministry Form 1111 "Rules for Rainfall Observers". The Meteorological Office gauge is recommended for daily observations and the Octapent gauge for weekly or monthly observations. The splayed base of these two gauges is advantageous as it enables them to be fixed firmly in the ground. Most gauges are made of copper because of its durability.

EXPOSURE AND FIXING

The amount of precipitation collected by a rain-gauge depends to some extent on its exposure and great care must be exercised in selecting a suitable site. Full instructions regarding the exposure of a rain-gauge have already been given on p. 3. In most cases the gauge can be placed on the same plot of ground as the thermometer screen at a distance of 10 ft. from the latter.

The gauge should be fixed on level ground. Care must be taken that it is firmly secured so that it cannot be blown over in a gale or displaced when the funnel is removed for measuring the rainfall.

The gauge should be sunk into the ground so that its rim is 1 ft. above the surface, which should be covered with short grass.* This height is necessary to prevent more than a negligible amount

*The ground immediately surrounding the gauge may, if desired, be replaced by a narrow belt of gravel or the like.

of water splashing into the gauge, but if it be exceeded it is found that the amount of rain collected decreases owing to wind eddies set up by the gauge itself. The amount of loss depends on the wind force as well as the height above the ground, and no general rules can be given for rendering the records of gauges fixed at different heights above the ground strictly comparable. Wind eddies also render roof exposures inadmissible.

In very open situations the catch of the gauge may be seriously reduced on account of eddies set up by the gauge itself when the wind is strong. In such situations it is necessary to set up a "turf wall" round the gauge. This consists of a sloping circular embankment, the crest of which is horizontal and in the same plane as the rim of the gauge. To construct a turf wall the first step is to erect a low circular palisade 10 ft. in diameter with the gauge at the centre. The top of the palisade forms a horizontal circle level with the rim of the gauge. Drainage must be provided to prevent water accumulating and forming a pool inside the palisade. Outside the palisade earth is placed, made firm and finished off with turves, the surface sloping downwards with a gradient of 1 in 4.

A turf wall is particularly necessary in cases where the best available site has a downward slope in the direction of the prevailing wind, but such sites should be avoided whenever possible.

Anything which decreases the effective area of the collecting funnel reduces the amount of rain collected. Hence it is necessary

- (1) that the top of the gauge be level ;
- (2) that the mean of two diameters of the rim at right angles be accurately the same as the nominal diameter of the gauge, the value of which is engraved on the measuring glass.

MEASURING RAINFALL

The rain should be collected in the glass bottle, if provided for the purpose, which should be placed inside the copper receiver. The quart bottle used for the 8-in. gauge holds only about 35 mm. (1.4 in.) of rain, while the pint bottle used for the 5-in. gauge holds only about 45 mm. (1.75 in.) of rain, so that on occasion the collected rain will overflow from the bottle into the copper receiver. The object of the bottle is primarily to facilitate accurate measurement, especially in windy weather, since it is easier to pour water from the bottle into the measure without spilling it, than from the copper receiver. Another advantage of the bottle is that any crack in it is obvious to the observer. If the bottle cracks it should be replaced immediately by another one. Cracked bottles should never be used owing to the risk of leakage.

Great care is needed, nevertheless, to ensure by actual tests made periodically that both the copper receiver and the outer case of the rain-gauge are watertight. Water may be expected to overflow into the receiver one or two or more times a year according to the locality, while at rare intervals the receiver itself may overflow into the outer case. In the latter event the gauge must be dug out and the water very carefully poured from it into a suitably sized vessel for transfer to the glass measure.

If water is found in the outer case when the bottle is not full, the outer case should be dug out and carefully tested for leaks. If water appears in the outer case only when the bottle overflows into the copper receiver, it is probable that the receiver is leaking. All leaks should be carefully repaired without delay.

The glass bottles must be kept clean, they should therefore be washed out (and thoroughly dried afterwards) at intervals depending on the locality.

The gauge should be examined **every day even in dry weather** as a fall of dew may give rise to appreciable precipitation. Daily examination also acts as a safeguard against errors due to the accidental or even mischievous addition of water.

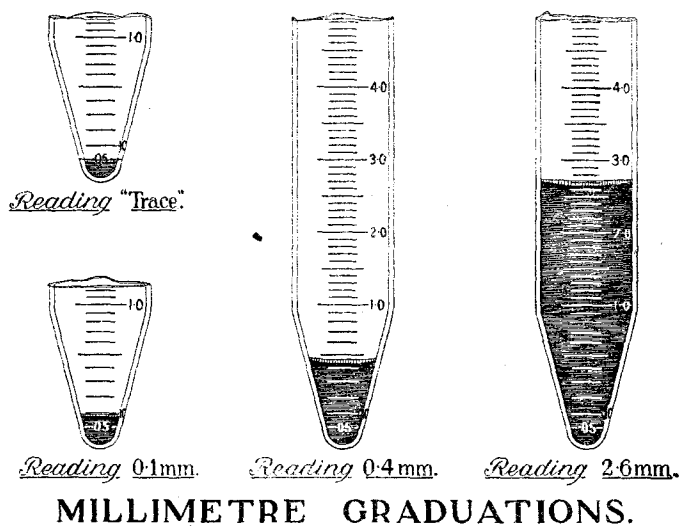
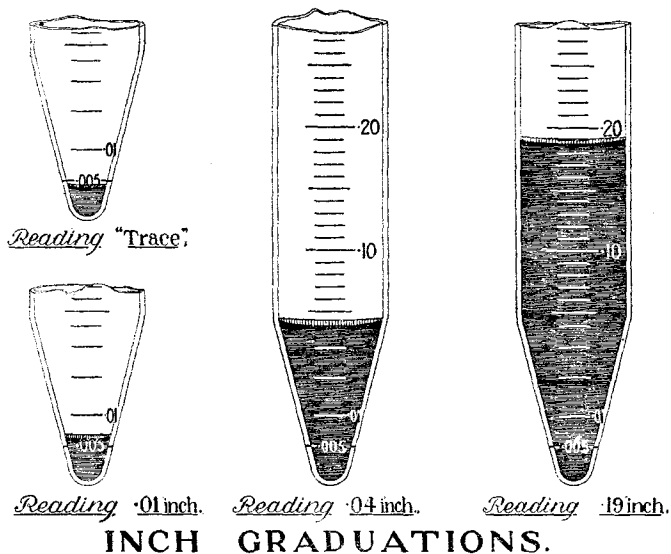
The water collected, including any found in the copper receiver, and very exceptionally, the outer case, should be carefully poured into the graduated glass measuring vessel, which must be kept clean. In reading the amount the vessel should be held upright between the thumb and first finger, or placed on a table or other horizontal surface. The eye must be brought to the level of the water in the glass so as to avoid errors of parallax. The reading should be taken **at the bottom** of the meniscus or curved surface of the water. When there has been no precipitation the entry in the register should be a dash — (not 0·0).

Measuring in millimetres.—The measuring glass when filled to the topmost graduation contains 10 millimetres (mm.) of rainfall. The graduation of the glass is carried to tenths (0·1) of a millimetre and the measurement should be made and entered in the pocket register and in the monthly return to the *nearest tenth* of a millimetre. The figuring on the glass represents *whole millimetres*; the decimal point *follows* the whole millimetre.

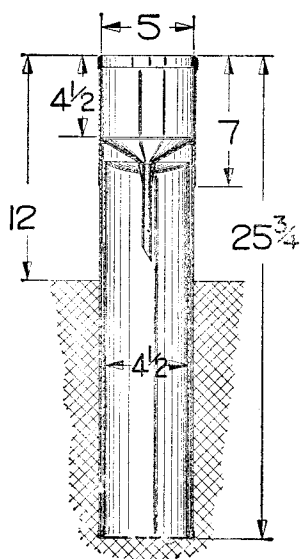
The entry "trace" or "tr." is to be made in the two following cases :—

- (a) When there is less than 0·05 mm. of water in the gauge and the observer knows that this is not the result of a drop or two draining from the sides of the can after emptying the rain-water out of it at a previous time of observation; *i.e.*, the observer is reasonably certain that there has actually been precipitation since the preceding measurement. If the observer knows that the precipitation has been in the form of dew or wet fog this may be noted in the return.

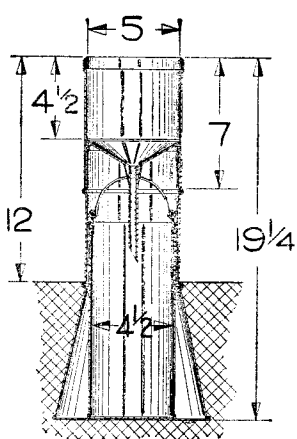
EXAMPLES IN READING RAINGAUGE GLASSES GRADUATED
IN INCHES AND MILLIMETRES.



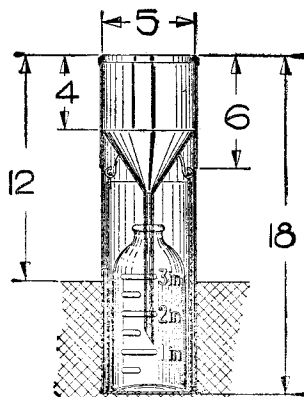
NOTE.—The reading "trace" is also applicable when rain is known to have fallen, even if the gauge is dry (see p. 91).



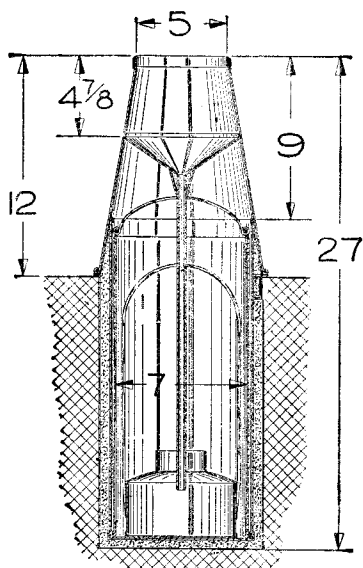
BRADFORD RAIN-GAUGE



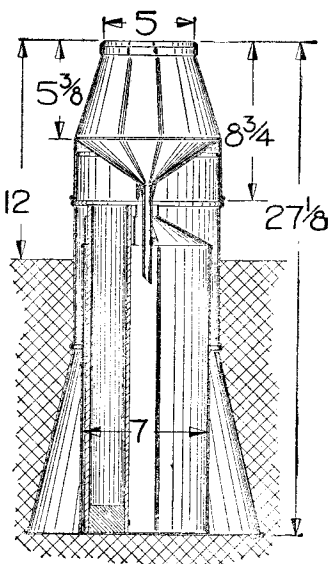
METEOROLOGICAL OFFICE
RAIN-GAUGE, Mk. II



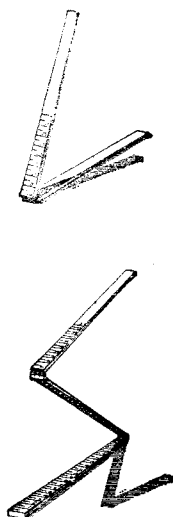
SNOWDON RAIN-GAUGE



SEATHWAITE RAIN-GAUGE



OCTAPENT RAIN-GAUGE



DIP-RODS

FIG. 20. APPROVED TYPES OF RAIN-GAUGES AND DIP-RODS

Dimensions are given in inches

- (b) When the observer knows definitely *from his own observation* that some rain (or other form of precipitation such as snow, hail, sleet or drizzle) has fallen since the preceding observation and yet finds no water in the gauge. This happens sometimes especially in dry warm weather, without the gauge being even damp, the small amount of rain having evaporated before it got into the bottle. In such a case the observer may enter in his return an appropriate note such as "slight shower of rain" or "slight drizzle."

The graduation 0.05 mm. is marked on the newer form of measuring glass.

As the measuring glass only holds 10 millimetres of rainfall,* heavy falls will have to be measured by instalments. To avoid mistakes in counting the number of tens, it is advisable to pour the water into a jug and to check the amount by re-measuring it. If difficulty is experienced in accurately filling the measuring vessel to the graduation 10 it is preferable approximately to fill the glass with each instalment and finally add the readings thus, $9.6 + 9.7 + 9.8 + 3.5 = 32.6$ millimetres.

Measuring in inches.—The measuring glass will hold $\frac{1}{2}$ in. of rainfall; the measure is graduated to indicate hundredths (.01) of an inch of rainfall and the reading should be given to the nearest hundredth. If the amount be less than one-tenth of an inch, the decimal point and the first "0" should always be entered in the register. Thus, seven-hundredths should be written .07.

The entry "trace" should be made in the same circumstances as those described under "Measurement in millimetres," the criterion in case (a) being .005 in. instead of .05 mm.

As the number of rain days depends on uniformity in this particular the .005 mark is placed on the newer pattern of measuring glasses. If the amount is exactly .005 or above .005 the entry is .01; if below, the entry is "trace."

SNOW AND FROZEN RAINWATER

On days of snowfall or when the water collected in the gauge has frozen, three courses are open to the observer :—

- (1) If snow is not falling at the hour of observation, the gauge (funnel and receiver) may be brought indoors, its contents melted and measured in the ordinary way. The top of the funnel should be covered by a flat plate to prevent loss by evaporation. Excessive heat should not be applied as some loss due to evaporation would occur. Carelessness in warming the gauge before a hot fire has in some cases resulted in melting the solder.

* Further information on the measurement of rainfall is contained in "Rules for Rainfall Observers" (Form 1111), which can be obtained from the Meteorological Office on application.

- (2) A cloth dipped in hot water may be applied to the outside of the funnel or receiver, or both, as necessary, so as to melt the snow or ice, and collect it as water in the receiver. The water is then measured in the ordinary way as if it had fallen as rain. Care is required to avoid allowing any hot water to enter the gauge.
- (3) A definite amount of very warm water may be accurately measured into the measuring glass (taking care not to break it) and then poured into the gauge. The amount of water added must of course be subtracted from the total amount measured. If snow is falling at the hour of observation this method or that numbered (2) should be adopted.

Only sufficient warm water to melt the snow or ice should be used ; a large excess increases the error arising from the decrease in the volume of water with fall of temperature.

The measurement may be checked by inverting the funnel of the gauge over the snow in a place where its depth seems to be uniform and of about the average amount and collecting the cylinder of snow thus cut out and melting it. This course can only be adopted on occasions when all precipitation has occurred in the solid form. Care must also be taken to collect only the snow which has fallen during the interval since the gauge was last read. At some stations a small wooden or stone floor is provided for the purpose of measuring the amount of snow. As a rough approximation 1 ft. of freshly fallen snow may be taken as equivalent to 25 millimetres (1 in.) of rainfall.

The **depth of snow**, determined by plunging a scale vertically into the snow where it lies evenly, should be noted.

Heavy falls of snow demand special treatment, which is justified by their rarity in the British Isles and by their exceptional meteorological interest. On such occasions the gauge may be entirely buried in snow, or on the other hand the measurement may be rendered inaccurate by snow having been blown out of the gauge by wind eddies. The observer should endeavour, each morning during periods of heavy snowfall, to make separate measurements of the following quantities :—

- (1) the amount of water (*i.e.*, actual rain or thawed snow) in the gauge ;
- (2) the amount of unmelted snow (as explained above) converted into water, including any snow immediately above the funnel, which should be separated and pressed into the funnel ;
- (3) the depth of fresh undrifted snow.

The sum of (1) and (2) gives the amount of precipitation for entry in the appropriate column of the register ; (3) should be determined as the mean of several measurements made in different places. Details of the measurements should be entered in the remarks column.

It is desirable in the case of a recording gauge to burn a nightlight in the gauge, so that the snow is melted as it falls.

§ 15. STATE OF THE GROUND

Provision for this observation is now made in the pocket register. The observation consists in noting the figure, taken from the following code,* which denotes the state of the ground at the time of observation :—

- 0 = Dry.
- 1 = Wet.
- 2 = Flooded.
- 3 = Frozen hard and dry.
- 4 = Partly covered by snow or hail.
- 5 = Covered with ice or glazed frost.
- 6 = Covered with thawing snow.
- 7 = Covered with snow less than 15 cm. (6 in.) deep but ground not frozen.
- 8 = Covered with snow less than 15 cm. (6 in.) deep and ground frozen.
- 9 = Covered with snow more than 15 cm. (6 in.) deep.

Supplementary code symbol, to be logged when appropriate, in addition to one of the code figures 0 to 9 :

—(hyphen) = Fresh snow has fallen on the mountains.

In order to decide which of the figures 0, 1 or 3 shall be used it is advisable to set aside a bare plot of ground, the surface of which is approximately level with its surroundings and about 2 yards square. At least the top 6 inches of the soil on this plot should be representative of the soil in the neighbourhood. A special exposure, such as the top of a mound, a steep slope, the bottom of a depression or near a spring should be avoided. The plot should be kept free from weeds but the soil should not otherwise be disturbed.

* The code as set out here was approved for general use by the International Conference of Directors which met at Warsaw in September, 1935. This code came into use on January 1, 1937, when it superseded the code given in the 1934 edition of this Handbook. The difference between the two codes is one of order only, the code numbers being different in the following cases :—

	New Code Number.	Old Code Number.
Ground frozen hard and dry	3	4
Ground partly covered by snow or hail ...	4	6
Ground covered with thawing snow	6	3

Code figure 0 should be used when the surface of the bare ground in the selected plot is dry (and when the soil is not frozen).

Code figure 1 should be used when the surface of the bare ground in the selected plot is wet, except in circumstances when figures 2 or 6 are applicable. There is usually a difference in the colour of wet soil and dry soil which renders the decision, as to whether code figure 0 or 1 is to be used, comparatively easy. It should be noted that code figures 0 and 1 refer solely to surface conditions; the condition of the soil below the surface is to be left entirely out of account.

Code figure 2 (and also figures 4 to 9; *see* below) should refer to the state of the ground representative of the station; that is to say, the flat land easily visible from the station and not differing from it in altitude by more than 100 ft.; it should be used when water is standing in pools over a considerable area, although the selected plot may not be under water.

Code figure 3 is used when the ground in the selected plot is rendered hard by the freezing of moisture in the pore-spaces; this condition is easily recognizable. Code figure 3 should not be entered when the surface is rendered slippery by the presence of a layer of ice on the surface; the appropriate entry in the latter circumstances is code figure 5.

Code figure 4 is used when the ground representative of the station is covered in part by snow or hail, even though considerable patches may be free from snow or hail.

Code figure 5 is used when the ground representative of the station is covered, wholly or for the greater part, with a layer of ice but *without* snow. The ground may or may not be frozen at the same time and the surface of the ice may be covered by water. The layer of ice may be produced in the following ways, and differs in character according to the means of its production:—

- (a) By the freezing of flood water.
- (b) By the alternate thawing and freezing of fallen snow.
- (c) By the formation of “glazed frost” (*see* pp. 56, 57).

Code figure 6 is used only when the ground representative of the station is covered with thawing snow (“slush”) and not when dry, or nearly dry, snow is present. Figure 6 should also be used when the “slush” is produced by a fall of sleet or by the mixing of snow with flood water.

Code figures 7 to 9 are used when the ground representative of the station is entirely covered by snow which is not thawing at all or is only thawing slightly.

The depth of snow denotes the total thickness of the snow down to the ground, including any old or icy layers, and not only the freshly fallen snow. It is measured on the selected plot, provided that the covering there is uniform and representative of the locality.

It should not be measured in places where drifting has brought about unrepresentative conditions. If the depth varies considerably within short distances, measurements should be made at a number of points and the mean value determined.

During the occurrence of hoar frost or dew, the state of the ground should be determined as though these were absent. There is no provision in the "state of ground" code for reporting such conditions, but they can be included in registers and returns as "present weather" and "past weather" by means of Beaufort letters.

Supplementary Code Symbol "—" (hyphen) has been added to the code from January 1, 1939. At stations from which mountains are visible the entry "—" should be made, when appropriate, in the column headed "state of ground" in registers and monthly returns in addition to one of the code figures 0 to 9 denoting the state of ground at the station. For the purpose of this symbol a mountain has been defined for the present in this country as ground exceeding 2,000 ft. above M.S.L.

§ 16. THE SUNSHINE RECORDER

The Campbell-Stokes sunshine recorder consists of a glass sphere which brings the sun's rays to a focus on a card mounted in a metal bowl which is approximately spherical in shape. The movement of the burn is opposite to that of the sun.

Both the recorder and the card must be made to a standard specification, otherwise records from different instruments will not be comparable with one another. Records are not accepted for publication unless the glass sphere bears the mark of approval of the Meteorological Office in the form of the letters M.O. followed by a serial number.

EXPOSURE

The conditions which the exposure should satisfy have already been described on p. 4. We may briefly recapitulate them here. A free horizon is required between north-east and south-east on the east side, and between north-west and south-west on the west side, these being the approximate limits of the position of the rising and setting sun in our latitude. An obstruction to the south should not be higher than from one-eighth to one-third of its distance from the instrument, according to the latitude of the station. Obstruction to the northward between north-east and north-west is of no consequence.

The support on which the instrument is placed should be perfectly rigid and be made of a material which is not liable to warp or to become otherwise deformed. The base of the recorder has three lugs drilled to take wood screws, which can be of any size between 8 and 12 (they should be brass). The screws form a triangle ABC

where AB is about $7\frac{1}{2}$ in. and lies east-west, while C is about $7\frac{1}{2}$ in. north of the centre of AB. A support for the base can be prepared without waiting for the receipt of the recorder, one method being to lay down a 1 ft. square of cement, not less than 2 in. deep, three wooden plugs being embedded in it to take the three screws. If the plugs are tapered (broad end downwards) and well painted on the top, they should be unaffected by weather.

Where a satisfactory exposure is available near ground level a brick or concrete pillar forms a suitable support. To avoid obstruction, however, it is often necessary to install the recorder on the roof of a building.

It is not in all cases possible to secure a site for the instrument where it will have an absolutely uninterrupted exposure. In such circumstances it is desirable to estimate how much of the "possible" sunshine may be cut off by the surrounding obstacles in each month of the year.

From the diagrams (Plate XI) showing the altitude and azimuth of the sun, the duration of sunshine cut off by any obstacle can be found for any time of the year at any latitude between 50° and 60° . The different curves in each diagram refer to the dates shown below. For intermediate dates interpolate an imaginary curve for the corresponding noon altitude. The latter is equal to the co-latitude ($90^\circ - \text{latitude}$) + the sun's declination. The declination at different dates can be found from Whitaker's Almanack. In order to estimate the amount of sunshine cut off by an obstacle, find the altitude and azimuth of its salient points when viewed from the sunshine recorder. Plot these on the diagram for the latitude nearest to that of the station and find the length of curve cut off by the object. Thus the house shown in the diagram cuts off on October 25, or February 18, 1 hour 40 min., 1 hour 50 min., 1 hour 55 min. for latitudes 50° , 55° , 60° N. respectively. At the winter solstice it cuts off nearly an hour in lat. 50° , less than $\frac{1}{2}$ an hour in lat. 55° , and nothing at all in lat. 60° .

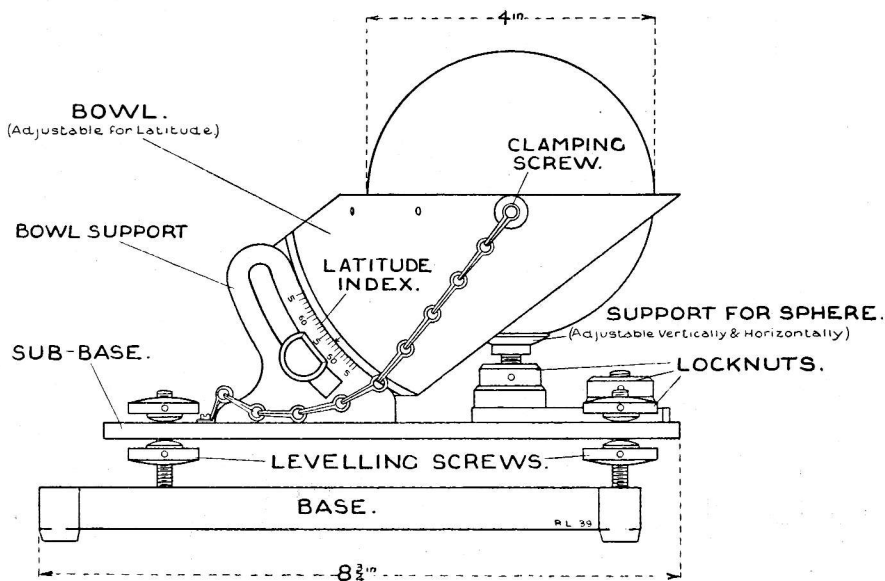
Sunshine is rarely bright enough to be recorded when the sun's altitude is below 3° . Obstacles subtending less than this angle may therefore be regarded as immaterial.

Key to the different curves shown under each latitude :—

				Sun's declina- tion.	Northern Hemi- sphere.	Southern Hemi- sphere.
June 22, solstice	...	...	...	$23\frac{1}{2}^\circ$ N.	A	E
April 21, August 23	...	...	...	$11\frac{3}{4}^\circ$ N.	B	D
March 21, September 23, equinoxes	...	...	...	0	C	C
February 18, October 25	...	...	...	$11\frac{3}{4}^\circ$ S.	D	B
December 22, solstice	...	..	...	$23\frac{1}{2}^\circ$ S	E	A

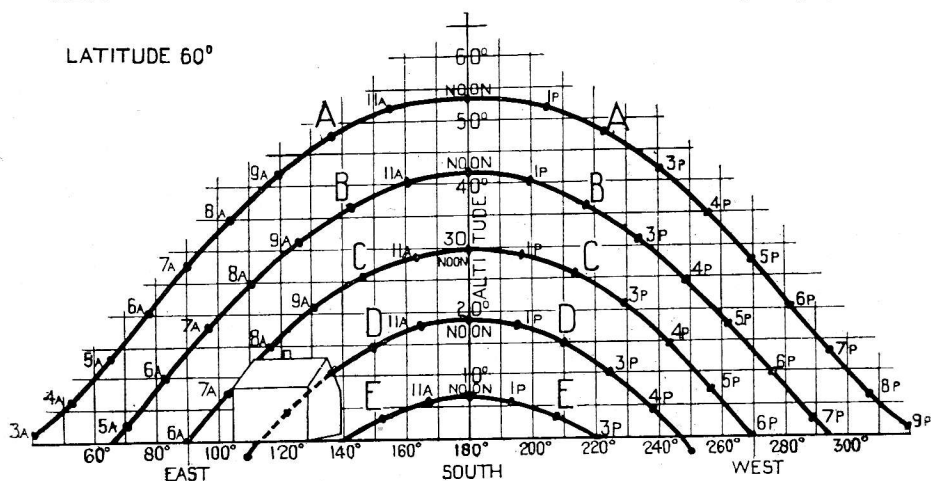


CAMPBELL-STOKES SUNSHINE RECORDER.
(Meteorological Office Pattern, Mark II.)

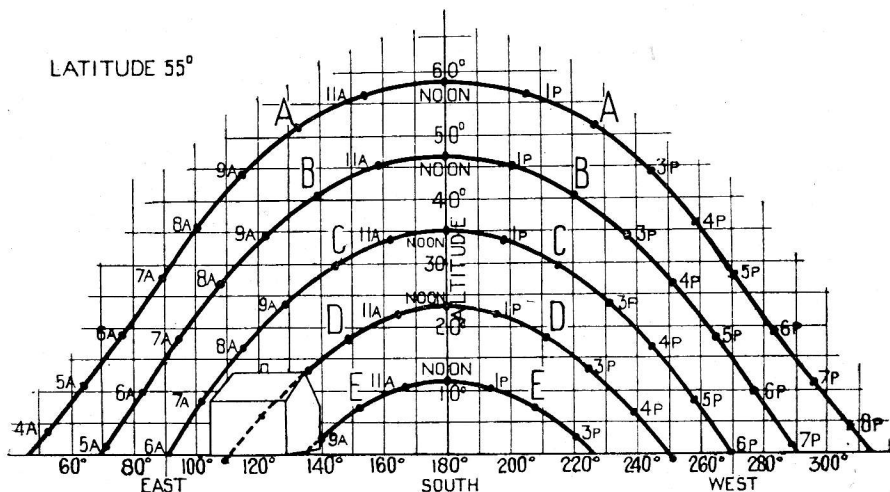


CAMPBELL-STOKES SUNSHINE RECORDER, SIDE VIEW, SHOWING THE
ADJUSTMENTS FOR LATITUDE, CONCENTRICITY AND LEVEL.

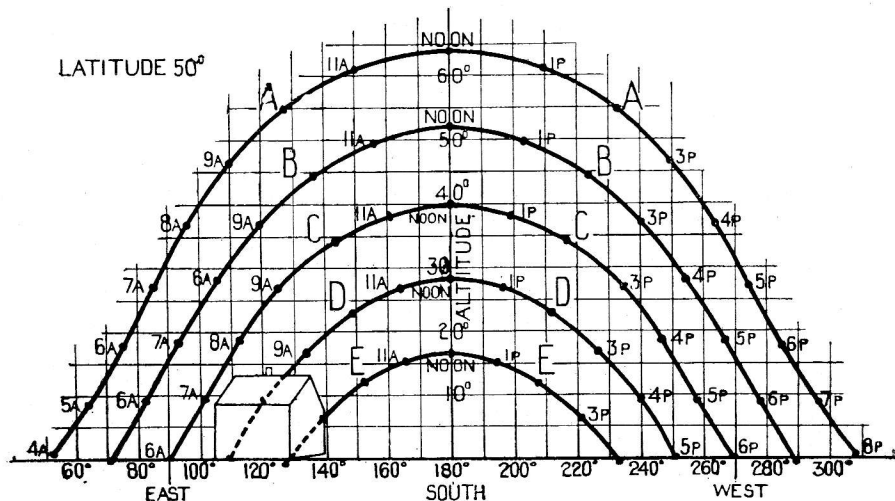
LATITUDE 60°



LATITUDE 55°



LATITUDE 50°



DIAGRAMS SHOWING THE ALTITUDE AND AZIMUTH OF THE SUN AT EACH HOUR (LOCAL APPARENT TIME) FOR PLACES IN LATITUDES 50°, 55°, 60°. (For explanation, see p. 98.)

ADJUSTMENTS OF A SUNSHINE RECORDER

When setting up a sunshine recorder the following adjustments must be accurately made :—

- (1) the centre of the glass sphere must coincide with the centre of the bowl ;
- (2) the plane cutting an equinoctial (straight) card mounted under the central flanges on the bowl along its central line must be inclined to the vertical at an angle equal to the latitude of the place ;
- (3) the instrument must be level as regards east and west, *i.e.*, the line joining the middle points of the six o'clock lines on the equinoctial card must be horizontal ;
- (4) the plane passing through the centre of the sphere and the "noon marks" on the bowl must be in the plane of the meridian.

Modern instruments are provided with an easy means of making the adjustment for latitude within certain limits. By loosening a screw at the back of the bowl, the latter can be slid through an arc of about 15° . If the arrow head on the bowl be set to the point on the graduated scale (Plate X), corresponding with the latitude of the place, it will be found that the instrument is in adjustment for latitude when its base is horizontal.

Adjustment for concentricity.—This adjustment should be made by the maker before the instrument reaches the observer. Instruments obtained through the Meteorological Office are tested and if necessary adjusted in the Office. The adjustment can only be made satisfactorily by the use of a special "centering gauge" and should not be attempted by the observer unless he receives special instructions from the Office.

Adjustment for level.—After placing the recorder approximately in the required position the adjustment for level in the east and west direction may be made with a spirit level placed on the top of the metal bowl, care being taken that the level is parallel to the front edge of the recorder. The base should not be used for levelling as the bowl may not be attached to it quite symmetrically. It is not necessary to level the instrument very accurately in the north and south directions for reasons which will appear when considering the adjustment for latitude.

Instruments of the Meteorological Office Mark II pattern are provided with a sub-base supported on three levelling screws, by means of which the level adjustment can be made after the main base has been screwed down. The holes through which the screws pass are slotted so that the adjustment for meridian can also be made without disturbing the main base.

The adjustment for meridian.—When in correct adjustment the sunshine recorder may be regarded as a sun-dial or solar chronometer in which "sun time," that is to say *local apparent time*, is

indicated by the position of the sun's image with reference to the time scale printed on the cards. The instrument will satisfy this condition when, and only when, a vertical plane passing through the common centre of the ball and the bowl, and the central "noon line" on the frame, is in the plane of the meridian. Having placed the recorder so that the opening in the frame is facing approximately south, the adjustment may be checked by ascertaining whether the sun's image crosses a given hour line on the card at the correct time. Local apparent time differs from Greenwich mean time by an amount which depends on the longitude of the place and on the time of year. The first step therefore is to determine the difference between local apparent time and Greenwich mean time.

What we require, in practice, is the time by G.M.T. at which the burn should be on a given hour mark on the card. This is obtained as follows :—

Add four minutes to the given hour for every 1 degree longitude *west* of Greenwich (subtract for east longitude).

Add the figure taken from the "equation of time" table given below when the sign is positive (subtract if sign is negative).

TABLE giving for every Third Day the mean value of the *Equation of Time* to the nearest half minute.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1 ...	+ 3	+13½	+12½	+4	-3	-2½	+3½	+6	0	-10½	-16½	-11
4 ...	+ 4½	+14	+12	+3	-3½	-2	+4	+6	-1	-11	-16½	- 9½
7 ...	+ 6	+14	+11	+2	-3½	-1½	+4½	+5½	-2	-12	-16	- 8½
10 ...	+ 7½	+14½	+10½	+1½	-3½	-1	+5	+5	-3	-13	-16	- 7
13 ...	+ 8½	+14½	+ 9½	+ ½	-4	0	+5½	+4½	-4	-13½	-15½	- 6
16 ...	+ 9½	+14½	+ 9	0	-4	+ ½	+6	+4	-5	-14½	-15	- 4½
19 ...	+10½	+14	+ 8	-1	-3½	+1	+6	+3½	-6	-15	-14½	- 3
22 ...	+11½	+14	+ 7	-1½	-3½	+1½	+6	+3	-7½	-15½	-14	- 1½
25 ...	+12	+13½	+ 6	-2	-3½	+2½	+6½	+2	-8½	-16	-13	0
28 ...	+13	+13	+ 5	-2½	-3	+3	+6½	+1	-9½	-16	-12	+ 1½
31 ...	+13½	...	+ 4½	...	-2½	...	+6	+ ½	...	-16½	...	+ 3

For example, at Pendennis (5° W.) on February 19, the burn should be on the noon mark at 12h. + 20m. + 14m. = 1234 G.M.T. At Dungeness (1° E.) on May 28, the burn should be on the noon mark at 12h. - 4m. - 3m. = 1153 G.M.T. = 1253 B.S.T.

It is desirable to make the adjustment as near the hour of noon as may be convenient, as defects in the adjustment for level are of least importance at this hour.

The adjustment for latitude.—In the case of instruments in which the position of the bowl with regard to the base can be altered, this adjustment is made by sliding the bowl in its socket until the arrow head, Plate X, is opposite the point on the graduated arc along which it moves, corresponding with the latitude of the place. The base must then be levelled in the north and south direction.

The adjustment may be roughly tested with the help of the diagram in Fig. 22 which shows the position on the bowl which the trace should occupy on each day of the year. As the positions of the flanges are found to vary slightly in different bowls this diagram can only be regarded as approximate.

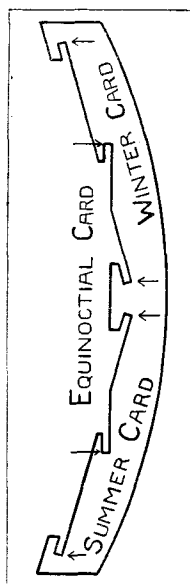


FIG. 21

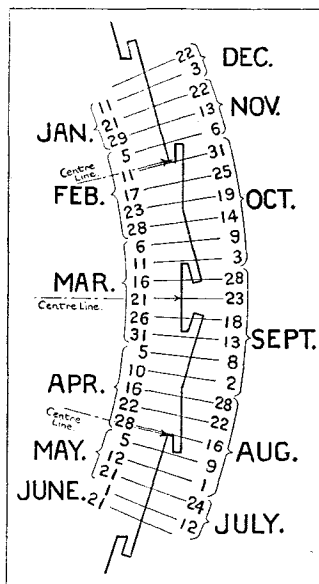


FIG. 22

Attention may be drawn to the fact that at the time of the solstices the rate of change of the sun's declination is very slow, and hence the position of the trace on the cards at these times will differ very little from day to day. For a period of nearly two months, about the time of midsummer or mid-winter, it varies through no more than one-tenth of an inch.

If all the adjustments have been made satisfactorily, the trace should be parallel to the central lines on the cards. Defects of adjustment are shown as follows :—

- | | |
|---------------------------|--|
| Trace sloping upwards ... | Bowl facing west of south or east side higher than west side. |
| Trace sloping downwards | Bowl facing east of south or west side higher than east side. |
| Trace lowest around noon | Bowl set for too low latitude or base tilted down from north to south. |
| Trace highest around noon | Bowl set for too high latitude or base tilted up from north to south. |

It should be noted that correct adjustment is not secured simply by having the burn parallel with the centre line of the card, local apparent time must also be indicated correctly and the burn must be at the correct height on the card for the date as shown in Fig. 22. If the adjustment is faulty the burn may fall on one of the flanges instead of on the card at certain times of the year.

If the lens is in good focus, *i.e.*, if the adjustment for concentricity is satisfactory, the trace should be narrow and well defined at its edges and the card should be scorched whenever the sun shines brightly even if it be only for a few seconds.

When the observer has satisfied himself that the recorder is accurately set he should fix it firmly in position to prevent its being accidentally displaced when changing the cards. At many stations the base is fixed in a bed of cement.

MANAGEMENT OF THE INSTRUMENT

When once the recorder has been set up, it requires little attention beyond that involved in changing the cards each day. The glass ball should be regularly cleaned with a wash-leather. It should not be cleaned with any cloth that will abrade the surface. If snow or hoar-frost settles on the recorder the deposit should be removed at once.

A card should be inserted every day even if no sunshine has been recorded. A blank card affords surer evidence that the day has been overcast than a card on which the statement "no record" is written, but which actually has a burn on the next day over the place where any record of the day in question would have been.

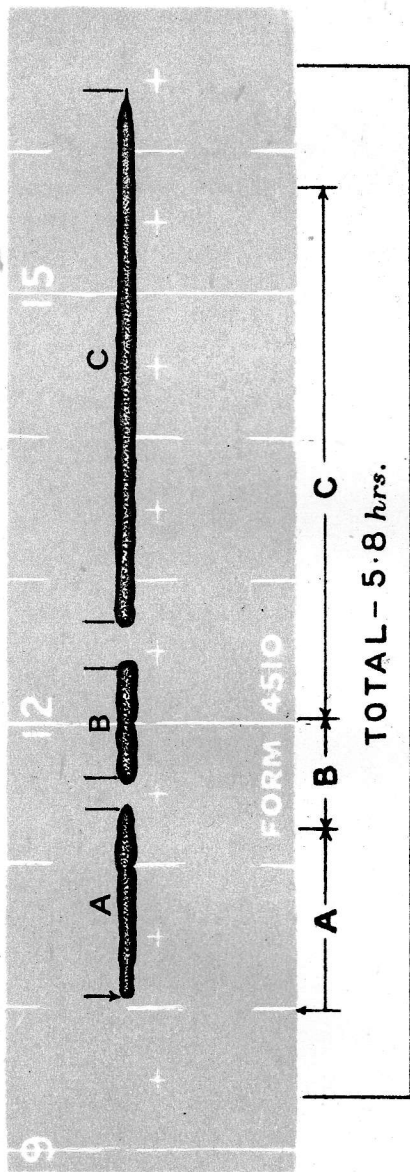
If possible the cards should be changed after sunset* each day. If this be impracticable any other hour may be selected, but an hour having been once fixed upon it should be adhered to as far as possible. If the cards are changed before sunset there is danger of two traces overlapping and to prevent confusion the exact local apparent time of insertion, as indicated by the burn, should be indicated by a pencil line passing transversely across the card. If the sun is shining at the time when a fresh card is being inserted, the observer should shade the ball in order to prevent a false scorch being made.

When inserting a card care must be taken that the 12-hour line on it coincides with the "noon" mark on the bowl.

If after rain a card cannot be withdrawn without tearing it, it should be cut out carefully by drawing a sharp knife along the edge of one of the flanges.

Every card should have written clearly on it the name of the station, the date (day, month and year) of the record and, if the cards are changed before sunset, the time of insertion and withdrawal. This should be done immediately after the card has been withdrawn from the instrument.

* For special regulations at Health Resort Stations, *see* Supplement No. 4.



MEASUREMENT OF SUNSHINE CARDS.

The illustration shows a typical record on part of an equinoctial card. Marks have been made on the card (purely for purposes of illustration) to show between what points the measurements should be taken. The first and second portions A and B, and the beginning of the third portion C of the record have rounded ends and allowance is made for the spread of the burn. The record becomes faint after about 16h.20m. and the measurement is taken as far as the trace can fairly be seen.

To obtain the total duration, the lengths of the separate portions are marked in succession along the edge of a strip of paper, and the total for the day is then read off by applying the marked strip, as shown, to the scale on the card. In the case of a curved card, the edge of another curved card should be used and the measurement may be made by placing the marked edge on a blank curved card, as near as possible in the same position as the actual burn.

Observers in connexion with the Meteorological Office are requested to forward their cards as soon as possible after the close of each month to The Director, Meteorological Office, Headstone Drive, Harrow, Middlesex.

In packing for transmission through the post the cards should be kept flat and should not be folded. Suitable envelopes can be obtained from the Office.

TYPES OF CARDS

Three types of card are supplied for use with the instruments.

(1) The long curved cards are to be used during summer from **April 12 to September 2** inclusive; they should be inserted, with their convex edge uppermost, beneath the flanges marked "summer card" in Fig. 21.

(2) The short curved cards are to be used during winter from **October 15 to the last day of February** inclusive; they should be inserted, with their concave edges uppermost, beneath the flanges marked "winter card" in Fig. 21.

(3) The straight cards are for use about the times of the equinoxes from **March 1 to April 11** and again from **September 3 to October 14**, both periods inclusive; they should be inserted beneath the central pair of flanges marked "equinoctial card" in Fig. 21. When inserting the equinoctial cards care must be taken that the *hour figures are erect*, otherwise the morning sunshine will be recorded on the portion of the card intended to receive the afternoon record and *vice versa*.

Before bringing a new type of card into use it is desirable to clean away any dirt which may have accumulated in the grooves into which the cards will be placed.

TABULATION OF THE CARDS

Observers must bear in mind that the duration of "bright sunshine" to be published is not the number of hours and tenths during which the sun is visible to the human eye, but the number of hours and tenths which can be estimated from the record according to long-established practice; this duration is approximately the duration of sunshine of sufficient intensity to scorch the standard card when it is concentrated by the standard glass sphere.

The amount of bright sunshine should be expressed in hours and decimal fractions of an hour. The figures should not be carried beyond the first place of decimals (0.1 hour = 6 minutes).

The points on which observers have generally asked for information have been two :—

- (1) How to deal with cases in which the scorch is *faint*, such as is usually the case near sunrise and sunset, or when the sun is shining through a slight haze.

- (2) How much of the trace to measure when the sun has been shining *brightly* but *intermittently*, or when a strong burn has been abruptly stopped.

In the first of these cases it is recommended that the whole of the brown trace, *as far as it can FAIRLY be seen*, should be measured, the measurement being carried right to its extreme ends.

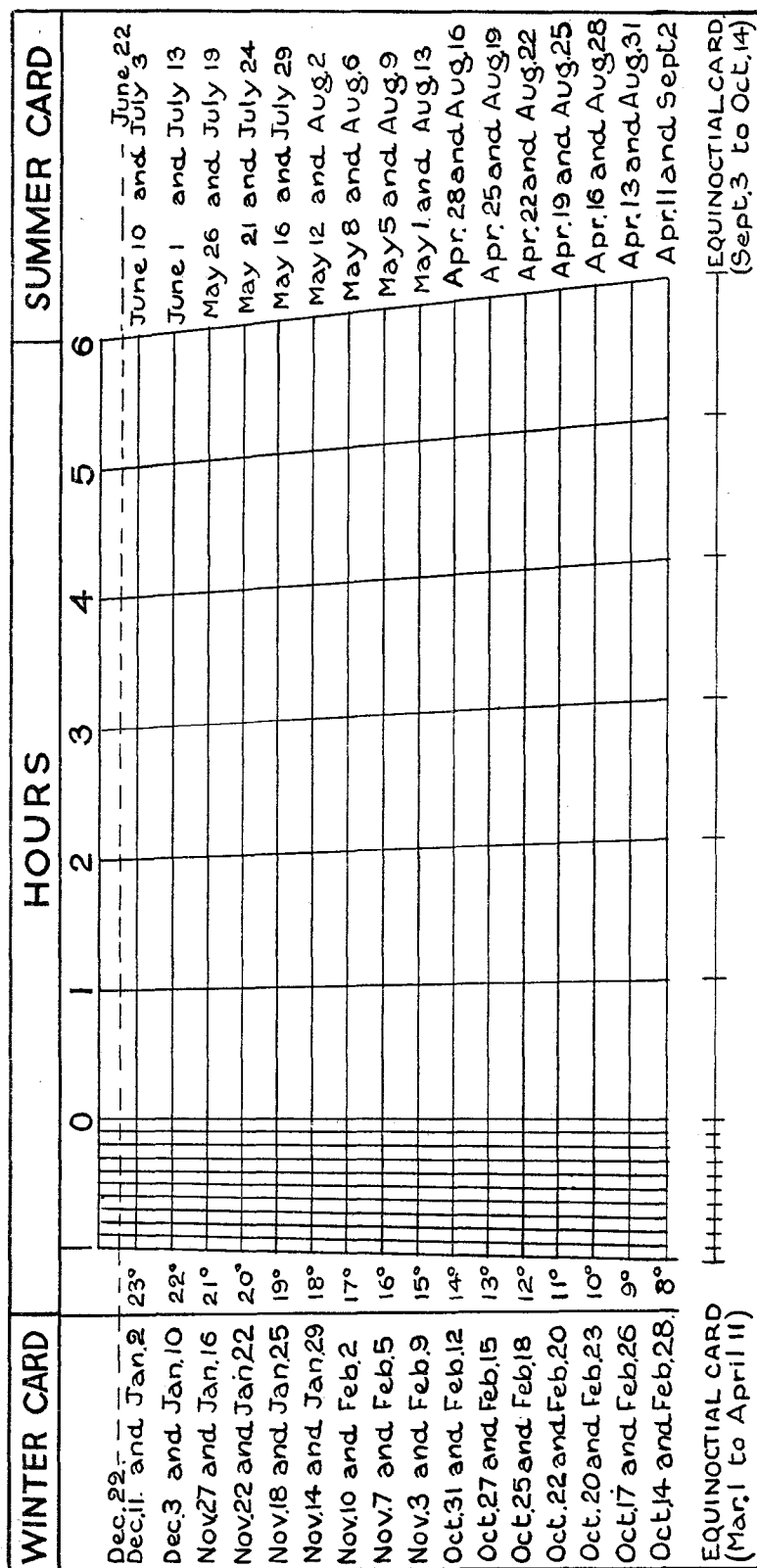
In the second case it must be remembered that there is always a slight lateral extension of the trace, due to the fact that the image of the sun formed by the sphere has an appreciable diameter and also to smouldering of the card. In consequence the trace will be very nearly as long for a few seconds of sunshine as for two or three minutes. For these effects a slight allowance should be made and the measurement should not in such cases be carried to the extreme limits of each of the burns. In Plate XII a reproduction of an actual record is given together with the duration of sunshine assigned to each of the separate portions of it.

A close approximation to the true duration of bright sunshine can be obtained if the measurement is carried to the centre of the semi-circular end of each part of the trace, but in practice the allowance made for the lateral extension of the burn is considerably smaller than this. In order to secure uniformity in the method of estimating, it is desirable that a central authority should have an opportunity of examining the tabulations made at different stations and for this reason observers who desire their returns to be included in official publications are required to send their cards to the Meteorological Office for inspection at the end of each month.

The observer should make a careful study of the evaluations of the record on specimen cards, made in the Office, and will thus learn whether his tendency is to over-estimate or underestimate. For guidance, it may be mentioned that close agreement with the official estimates will be obtained in the case of intermittent burns if the measurement is made between points which are situated halfway between the extreme ends of the burns and the centre of curvature of their rounded extremities.

A convenient method of evaluating a trace is to place the edge of a sheet of paper along it and to mark on the paper with a sharp pencil, lengths equal to the lengths of successive burns. The paper is slid along the trace so that these lengths form a continuous line, the addition being thus done mechanically. The length of the line is then read off on the special scale shown in Fig. 23. When reading off, the paper must be placed against the line on the diagram corresponding with the date of the record. All records on equinoctial cards must be measured along the line so marked. The length of the burn may also be read off on the time scale shown on the cards, but in the cases of the curved summer and winter cards, on which the length of an hour space is not the same throughout the whole width of the card, care must be taken to measure along the portion of the card on which the burn falls on the day in question. It is convenient in such a case to integrate the burn along the edge of the back of a similar curved card.

SCALE FOR MEASURING THE DURATION OF BRIGHT SUNSHINE RECORDED BY CAMPBELL-STOKES RECORDERS OF STANDARD DIMENSIONS



Equinoctial Card. 6 hrs = 4.50 in. Curved Cards { Declination 8° 6 hrs = 4.46 in.
Declination 23° 27' (at solstices)
6 hrs = 4.12 in.

§ 16A. EVAPORATION

Records of evaporation from a free water surface are obtained by exposing a body of water in a tank and observing the daily change of level. From the difference between consecutive daily measurements is deducted the rainfall for the same period, as measured in an adjacent rain-gauge. Observations of both the evaporation tank and rain-gauge are made at 0900 G.M.T. So far as is practicable, the level of the water is kept about 2 to 3 in. below the top of the lip of the tank. This necessitates water being added in summer and removed in winter. Readings must be taken immediately before and after either operation to measure the depth added or removed. During the winter months there is some difficulty in securing a reading when the water freezes. In such cases the ice is broken away from the side of the tank and the measurement of the water level is made while the ice is floating. If this cannot be done any morning, owing to the thickness of the ice, a measurement is made as soon as possible (on a subsequent morning) and the amount of evaporation calculated over the whole period.

The accuracy of the measurements of evaporation depends on the depth of water caught as rain in the evaporation tank being identical with that measured directly in the rain-gauge alongside. Some of the factors which are likely to vitiate the measurements of evaporation are discussed in *British Rainfall*, 1925, pp. 127-8, and in *British Rainfall*, 1931, pp. 268-74. During periods of snow the procedure set out in Section 14, snow and frozen rain-water, should be followed so far as the rain-gauge measurements are concerned and precautions taken to secure reasonable readings of the evaporation tank.

Tank.—The standard tank is 6 ft. $\times$ 6 ft. $\times$ 2 ft. deep. It is made of wrought iron plates $\frac{1}{4}$ in. thick, overlapped and rivetted, the rivets being not more than 2 in. apart. A horizontal flange is rivetted 3 in. from the top on the outside. The tank is sunk in the ground to the level of the flange. Care must be taken to prevent leaking, and the soil should be, if possible, impervious to water, otherwise it should be puddled.

The still-water pond is 4 in. $\times$ 4 in. $\times$ 12 in. deep of galvanized iron or zinc about $\frac{3}{32}$ in. thick, with a round hole $\frac{3}{4}$ in. diameter in the middle of the bottom. Flat metal hooks are soldered on one side. The whole is suspended by the hooks in the middle of one side of the tank, the object being to break ripples when an observation is being made by the hook-gauge (see Fig. 23A).

The hook-gauge consists of a hollow brass rule, engraved in inches on one side. In the hollow interior runs a movable slide (C) adjusted by rack and pinion (F). At the lower end of the slide is attached a brass hook (D), the end of which is cut square and accurately (G).

A vernier is engraved on the slide, terminating level with (G). A steel spring is provided to keep the slide taut, and the tension is adjusted by a small screw (H). A movable brass clamp (E) is attached to the rule by a milled-head screw. It is usually kept with the lower edge (J) at 4 in. on the scale.

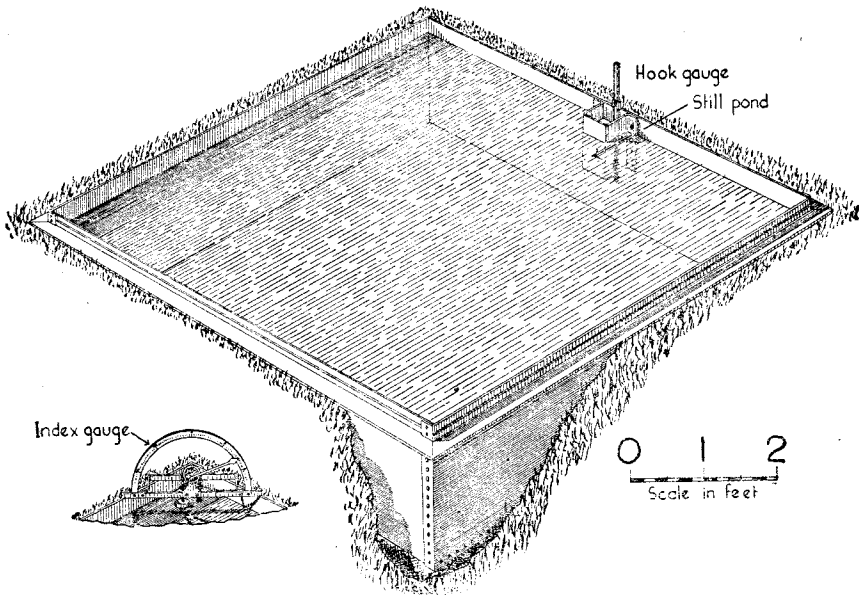


FIG. 23A. EVAPORATION TANK—BRITISH STANDARD

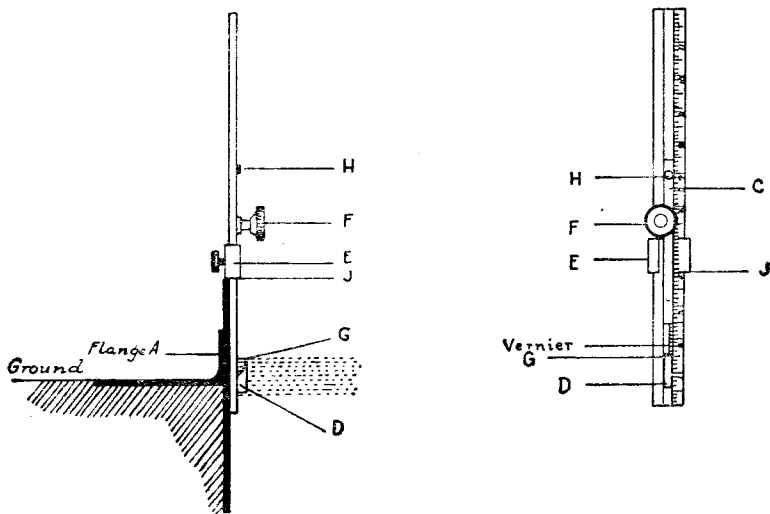


FIG. 23B. HOOK-GAUGE

METHOD OF READING

The slide is inserted in the water with the clamp (E) resting by its lower edge (J) on the edge of the tank between the two hooks of the still-water pond, at spot (K). The hook is then adjusted by the pinion (F) until it just cuts the surface of the water, moving upwards is most satisfactory. The vernier then gives the depth of water (to .01 in.) from a point 4 in. below the lip of the tank. Allowance being made for rainfall measured by a rain-gauge alongside, the loss since the previous reading is obtainable. The depth of water in the tank can be altered when convenient, a reading both before and after the change being necessary, in order to make due allowance.

An alternative method dispenses with the still-water pond and hook-gauge, and substitutes an "Index evaporation gauge". This is usually fixed across one corner of the tank. It is advisable to use both methods as a mutual check.

PART II.—SELF-RECORDING INSTRUMENTS

Instruments have been constructed to give continuous records of the majority of meteorological elements. In most of these instruments the motion of the working parts is magnified by a system of multiplying levers to the end of which is attached a pen, which records on a chart fixed on a revolving drum driven by clockwork. A good self-recording instrument should afford the means of determining, either directly or indirectly, the absolute value of the element recorded for any instant. As a rule this end can only be attained by using the continuous record to interpolate between the values given by eye observations at fixed intervals taken with "standard" or "control" instruments.

§ 17. GENERAL INSTRUCTIONS

Certain precautions and considerations which apply equally to all forms of recording instruments will now be discussed.

DATING OF CHARTS

The date (time, day, month and YEAR) of commencement and end of the record should be entered on each chart either before it is fixed on the instrument or immediately after it is taken off. The place at which the record is taken, and, if a number of instruments of the same kind are kept, the number of the instrument used should be entered on the chart. Should a record be missed in consequence of an accident (pen not marking, etc.), the chart should be filed with the successful records, and not be destroyed or used again. When recording rainfall or sunshine it will frequently happen that the chart, when taken out of the apparatus, is blank. In such cases it should always be dated and filed with the remaining records.

FRICTION

Friction between the working parts of the apparatus must be avoided as far as possible. The bearings should be cleaned occasionally and oiled with good clock oil, care being taken to remove excess of oil.

The most serious friction generally occurs between the pen and the paper on which it writes. The pressure of the pen on the paper should be reduced to the minimum consistent with a continuous trace for which simple contact with the paper will suffice.

Modern instruments are arranged so that the pen or the style which carries it is suspended like a gate, and arrangements are made for the slope of the gate bearings to be adjustable. In this way it is possible to regulate the pressure of the pen on the chart from zero to a certain

small value. The gate suspension of the barograph is seen at B in Plate XIV.

In instruments in which the elasticity of the style is made use of to keep the pen in contact with the paper the pressure should be adjusted by means of the milled head near the base of the style, so that the pen falls away from the paper when the instrument is slightly tilted forward.

The pen should be well washed from time to time in water or methylated spirit.

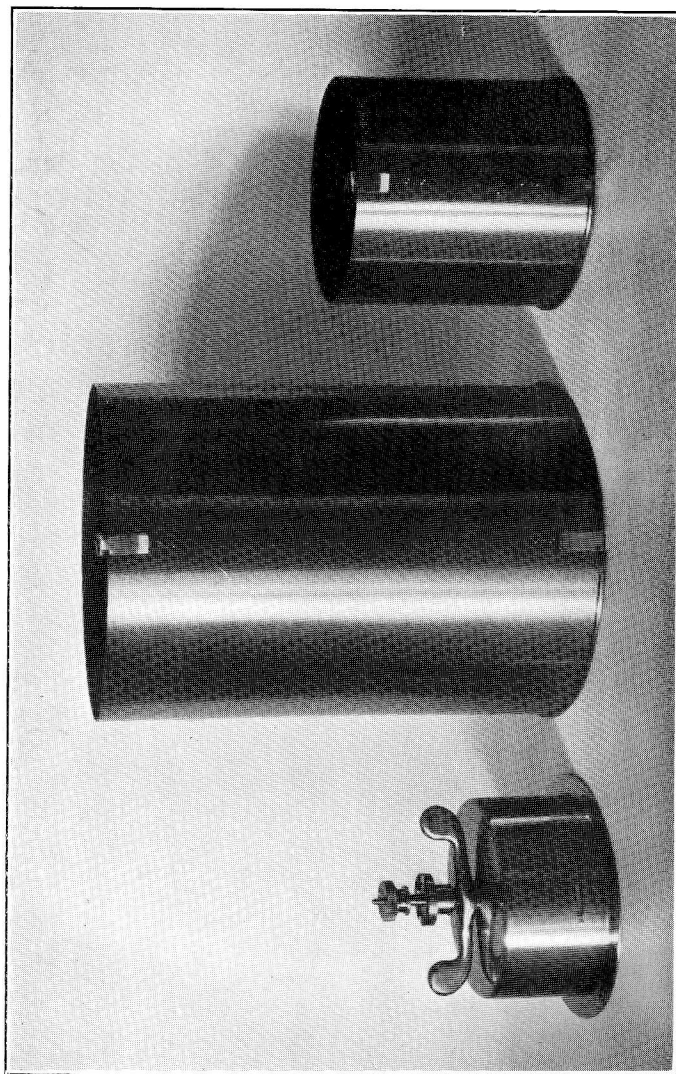
A thin clear trace should be aimed at, for if the trace be thick and blurred many of the smaller variations such as those shown on the barogram reproduced in Fig. 24, p. 113, which are most interesting meteorologically, become obliterated.

The point of the pen should be fine so as to give a narrow trace but it must not be so fine as to scratch or stick to the paper. A new pen may frequently be improved by drawing the point once or twice along an oil-stone, but any trace of oil should afterwards be carefully removed.

Excess of ink should be avoided. Special care must be taken not to let the ink come in contact with the metal style which carries the pen, as this will cause the pen to adhere firmly to the style so that it cannot be removed and cleaned. The ink may also cause the metal to become brittle and break.

SELECTION OF CHARTS

In many instruments the recording pen is fixed to a lever, the "pen-arm," which is pivoted at one end. When, owing to variation of the element being recorded, the arm rotates about the pivot, the pen moves along a curved line. If the record were made on a flat surface the path of the pen would be an arc of a circle centred at the pivot and of radius equal to the length of the pen-arm, and the same statement is true enough for practical purposes when the record is made on a chart wrapped round a cylindrical drum. The time lines on charts supplied for use on such instruments are therefore arcs of circles complying with this specification. As the instruments of different firms, or even different patterns by the same firm, differ in dimensions, even though the size of the drum be the same, it is necessary to make sure that the charts are suitable for the particular instrument in use. When ordering a new supply of charts the maker's name and, whenever it is given, the number of the chart should always be quoted, and a sample should accompany the order. The use of charts with arcs of wrong radius will throw the time scale very considerably wrong, even though the range may appear to be correct. The width of the lower margin of the chart is also of importance. If it be too narrow or too wide the centre of the arcs on the charts will not be at the same level as the pivot on which the pen arm turns.



STANDARD METEOROLOGICAL OFFICE CLOCKS AND DRUMS

If the observer has any doubt as to the suitability of a chart for his particular instrument he may test it by moving the pen across it from its highest to its lowest position and observing whether the trace is everywhere coincident with, or parallel to, the arcs engraved on the chart.

In order not to strain any part of the apparatus, the pen arm should be disconnected from the recording apparatus before this is done, by removing one of the pins at some part in the system of levers by which the motion of the receiving apparatus is communicated to the pen, or by loosening the screw that clamps the pen arm to the spindle.

The attention of the observer is once more directed to the fact that ink, if allowed to come in contact with the style which carries the pen may corrode it, with the result that the style breaks. A new style is then required as the use of a pen arm which is too short renders both time scale and range inaccurate.

STANDARD METEOROLOGICAL OFFICE CLOCKS AND DRUMS

The Meteorological Office standard clock is designed to fit either of two different sizes of drum, the "S" type which is 93 mm. in diameter and 92 mm. high, and the "O" type which is 140 mm. in diameter and 190 mm. high (see Plate XIII). It is provided with two movements, one for daily and the other for weekly charts. The driving spindle, which is in the main train of gears, emerges centrally from the cylindrical case of the clock and to it is keyed a collar with radial teeth on its upper surface. The drum is a hollow cylinder provided with a diaphragm, through the centre of which passes the driving spindle when the drum is in position. At the centre of the diaphragm is a collar with a set of radially cut teeth on its under surface that engage with the teeth on the lower collar. The upper collar extends vertically through the central hole of the diaphragm and through a spring washer that rests on the upper surface of the diaphragm, and its top is riveted over so as to press down on the washer and give a friction drive between the collar and the diaphragm. This allows the drum to be turned by hand when bringing the pen to the correct position on the time scale of the chart, but the two sets of toothed collars are kept locked together by a locking screw on the top end of the spindle, thereby ensuring that the movement of the clock spindle is always transmitted without backlash to the upper collar. These clocks can be used on open scale and small barographs, bimetallic thermographs, hygrographs and recording rain-gauges. All clocks should be wound at the time of changing the chart.

FIXING THE CHARTS ON THE DRUM

The chart is placed round the drum containing the clock, where it is held in position by two short spring clips that hold the bottom and top edges of the chart. When fixing on the drum, care must be

taken that the horizontal lines printed on the chart are parallel to the flange at the base of the drum. If the chart is carefully cut so that its lower edge is parallel to the horizontal lines, this will be the case when the edge of the chart is in contact with the flange all round the drum.

If the charts are not accurately cut, allowance should be made for the fact by seeing that the horizontal lines are continuous where the two ends of the chart overlap while one end of the lower edge of the chart touches the flange. In Meteorological Office charts the central horizontal lines are extended to the edge of the paper in order that this may be secured. Another method of overcoming the difficulty is to have a second and fixed pen attached to the instrument which will mark a horizontal base line on the chart. All measurements are then referred to this base line.

TIME SCALE

It is important that the time when the pen is at any particular point on the record should be determinable accurately. Three main causes of error exist :—

- (a) Backlash between the clock and the spindle on which it turns. This may be reduced to a minimum if the cylinder be turned on its spindle so as to bring the pen *back* to the required time from a point in advance of its proper setting.
(This defect is only serious with clocks which are not of the Standard Meteorological Office type.)
- (b) Error of clock. It may gain or lose. An error in the ruling of the time scale of the chart produces the same result. The rate of revolution of the cylinder can be adjusted to agree approximately with the time scale of the charts by means of the clock regulator.
- (c) Errors due to the chart becoming too damp.

In order that any errors of these kinds may be indicated, it is essential that accurate time marks should be made on the records themselves. For the majority of records it is sufficient to have the time accurate to the nearest minute.

In the case of charts changed weekly, it is essential to have a time mark made every day. Although it is preferable to have the mark made at about the same time of day on each occasion, this is not essential. The essential thing is to know the exact time at which the mark was made. This object is secured if the observer enters in his pocket register, or in a notebook kept beside the instrument, a note of the actual times at which the marks are made each day and copies these times on the record when it is taken off at the end of the week. He should also write on the record the exact time at which the pen is lifted off the paper before taking off the record. The time mark should not be made within half an hour of the commencement of the record.

In the case of charts changed daily, a time mark within 2 hours of the commencement of the record in conjunction with the actual time at which the pen is lifted off the paper at the end of the record, constitutes the minimum information which will enable the time at any point on the trace to be identified with accuracy. Office barographs are now fitted with a "time marker" (A, Plate XIV, facing p. 111) for slightly depressing the pen arm and so causing it to record a time mark; when this is not provided a mark may be made by gently tapping the instrument but, if that be done, care must be taken not to shake the drum on its spindle or otherwise to interfere with the record. In the case of thermographs and hygrographs there is no necessity for a special lever, as the pen arm can be easily moved from the outside. If the instrument is as free from friction as it ought to be, no discontinuity need be caused in the trace by the time marks. The absence of discontinuity in the trace furnishes good evidence that the instrument is working well.

The clock from which the time is taken for entering on the records should be compared regularly with a wireless time signal.

INTERPOLATION

The observer should satisfy himself that his instrument is working properly by frequent comparison of its indications with the readings of standard or control instruments.* In the ideal case the difference between the reading of the standard and the value deduced from the curve is zero. In practice small discrepancies always occur.

Three common kinds of discrepancy are :—

(1) When the difference is constant at all points of the scale, an error in setting is indicated.

(2) When the difference is zero at one point on the scale but increases proportionately on either side of this point, we may infer that the scale-value of the instrument does not correspond with that marked on the chart.

(3) Irregular variations are due mainly to friction in the working parts; lagging, structural defects, etc., produce similar effects. In practice all these cases may be combined.

If cases (1) and (2) are alone in question we may obtain accurate values for any intermediate point as follows :—

Let C_1 and C_2 be the curve readings corresponding with the fixed hour readings S_1 and S_2 , taken on the standard instruments before and after the point in question.

* A satisfactory, though somewhat laborious, method of doing this is to tabulate the readings of the curve for the hours of the fixed observations, and compare them with the readings of the standard instruments. An incidental advantage of this procedure is that it helps to identify errors in reading the standards, such as .05 or .01 in. or 5 or 10 mb. in the case of the barometer, 5° or 10° in the case of the thermometer.

Let c be the change shown by the curve between the fixed hour corresponding with S_1 and the desired point, and let s be the true change in the same interval :

$$\text{then } \frac{s}{S_1 - S_2} = \frac{c}{C_1 - C_2}$$

$$\text{or } s = c \times \frac{S_1 - S_2}{C_1 - C_2}$$

The value for s so found, when added to or subtracted from S_1 , gives the true value required.

The irregular variations of the difference described under case 3 cannot be satisfactorily allowed for ; they must be reduced to a minimum by careful attention to the instrument.

§ 18. THE BAROGRAPH

The motion in most barographs is furnished by a set of aneroid boxes. (Plate XIV.) Instruments commonly used are of three sizes. The dimensions of those parts of the apparatus which affect the size and ruling of the charts are (1) the length of the arm carrying the pen, measured from pivot to pen point ; (2) the height of the pivot of the pen-arm above the flange on the drum, against which the chart rests ; (3) the pressure scale, *i.e.*, the vertical distance on the chart corresponding with a change of pressure of one millibar ; (4) the time scale as determined by the diameter and rate of rotation of the recording drum. The magnification depends on the number and size of the aneroid boxes and on the arrangement of the levers.

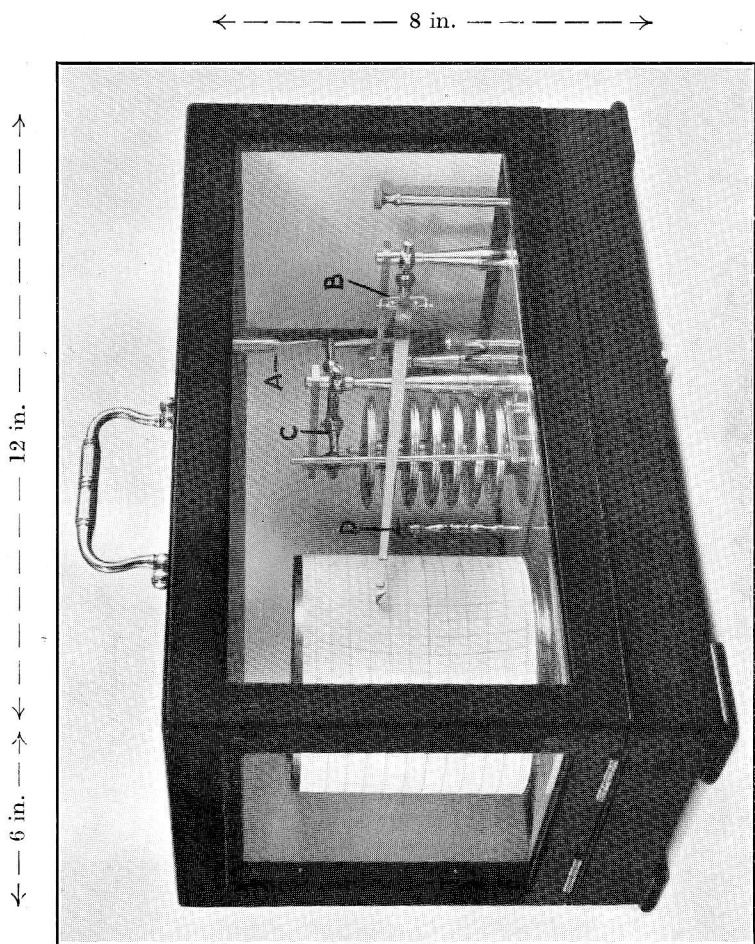
These dimensions are as follows :—

	Open scale.	Large.	Small.*
Length of pen arm	mm. 203·0	mm. 260·0	mm. 185·0
Height of pen axis above flange	93·0	79·0	40·0
Pressure scale (movement equivalent to 1 mb.)	1·8	1·5	0·75
12 hours on time scale	30·0	27·2	20·0
Diameter of clock drum	140·0	129·0	93·0

The scale usually reads from 950 to 1050 millibars or from 28 to 31 inches. This range is sufficiently great to include all pressure values usually met with in the British Isles, if the instrument be set to agree with the reading of a standard mercury barometer reduced to mean sea level. Both these limits have, however, been passed.

If a barograph is properly compensated for temperature and is free from mechanical defects, the record shows the variations of

* A still smaller instrument is on the market, but it is not in general use in this country.



pressure at station level. It is customary, however, to set the pen on the chart so that the reading agrees approximately with the reading of a standard barometer, corrected and reduced to sea level, and to assume that the trace then shows the variations of pressure at sea level. This assumption is not strictly valid, because the difference between the pressure at station level and at sea level depends upon the density of the air in the intervening layer and is therefore not constant (*see* Table IV, p. 142). If a barograph at a station 500 ft. above sea level be set to agree with the pressure at sea level on an occasion when the air temperature is 50° F. it will show a pressure about 1mb. too low when the air temperature is 80° F. and about 1mb. too high when the air temperature is 25° F.

Different methods for setting the position of the pen on the chart are adopted in different instruments. The standard method is to raise or lower the point in the base plate to which the lowest of the set of aneroid boxes is fixed by means of the milled head screw D shown in the illustration, but in some instruments the adjustment is made by a screw underneath the instrument. If the pen is observed to be very near the top or bottom of the chart the danger of the loss of a particularly interesting record may be averted by using the adjustment to bring the pen nearer the centre of the chart. If this be done, it is important that the record in its new position should be carefully standardised by readings from the standard mercury barometer and that the normal position of the record should be resumed as soon as the pressure attains a more usual value.

Barographs in which the motion of the pen is furnished by a set of aneroid boxes are subject to changes of zero owing to the imperfect elasticity of the metal. When absolute pressure values are required, their use must accordingly be confined to interpolating between the readings of standard mercury barometers. If the instrument is in good order and if the pressure is changing slowly, the height of the barometer at any desired epoch may be determined as follows. Read off from the curve the amount the barometer has risen or fallen since the previous reading of the mercury barometer was taken, the time scale being checked and, if necessary, corrected by means of the time marks (*see* p. 106), and add or subtract this amount from the corrected reading of the mercury barometer. The result should be checked by working backwards from the next following reading of the standard. As a rule the difference between the two values so deduced will be slight. Suppose we desire to find the pressure at sea level in London at noon on Thursday, January 4, 1917, from the barogram reproduced in Fig. 23. The time marks were made at 10h. 0m., but as the clock was gaining, the marks do not agree with the ruling of the chart. The readings of the mercury barometer at South Kensington at 9h. and at 18h. on the day in question indicate that the sea level pressures at those hours were 1010.4mb. and 1015.1mb. Due allowance being made for the clock being fast the curve readings for 9h., 12h. and 18h. are 1013.5, 1014.5 and

1018.0mb. The rise in the interval from 9h. to 12h. was, therefore, 1.0mb. and the estimated pressure for 12h. is 1011.4mb. Similarly, working back from 18h. we get the estimate 1011.6mb. The mean of these two estimates, 1011.5mb., may be accepted as the best interpolation available.

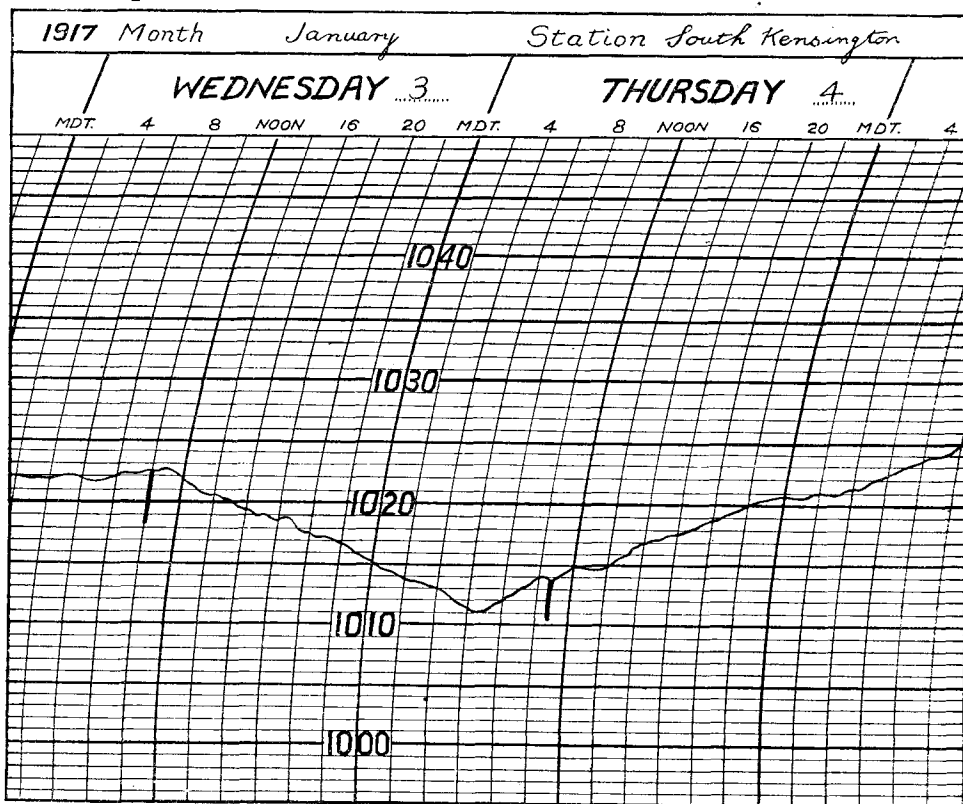
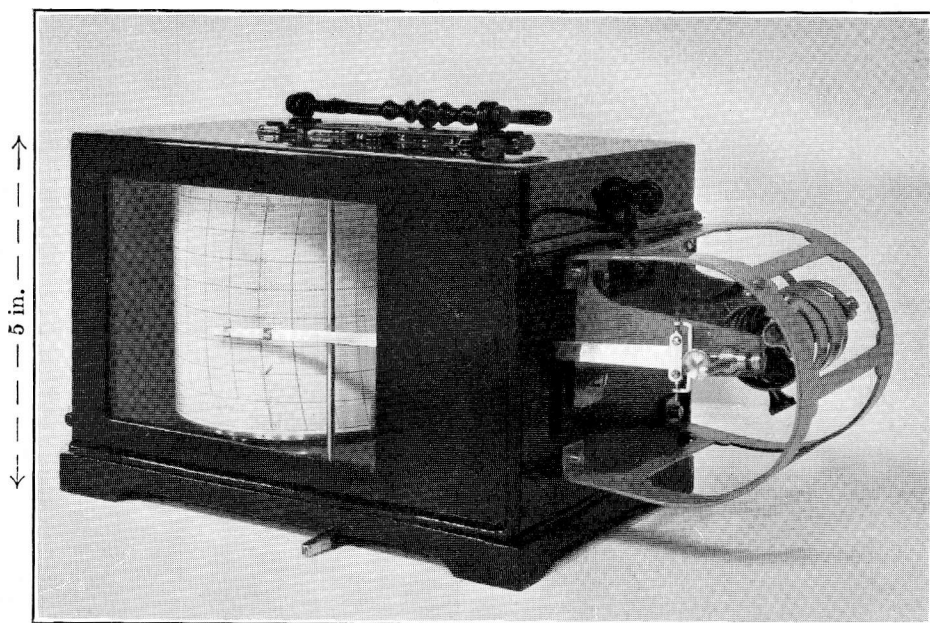


FIG. 24. REPRODUCTION OF BAROGRAM

A barograph, like an aneroid barometer, is subject not only to permanent changes in zero but also to a phenomenon known as creep or hysteresis. Owing to the imperfect elasticity of the metal of the aneroid boxes the instrument does not respond immediately and completely to the pressure changes, especially if these are large and rapid, but lags behind to some extent. Thus an instrument adjusted to read correctly at 1040mb. and then subjected to a diminution of pressure to 970mb. followed by a rise to 1040mb. again will usually indicate something less than that value and the difference may amount to several millibars. If the pressure be now kept constant at 1040mb. the barograph will gradually attain that value after a few hours. In consequence of this phenomenon the change of pressure in, say, 3 hours, as indicated by the barograph, may not only be incorrect in amount but in certain circumstances

← — — — — 7 in. — — — — → ← — 5 in. — →



THERMOGRAPH

A bimetallic coil, acting as a thermometer, controls the motion of the pen arm. The latter is fitted with gate suspension which is rotated until the weight of the pen arm brings the pen lightly against the drum. The coil is attached near to each of its ends to one or other of two levers perpendicular to the coil, through which passes the axis of the coil; the lever at the back of the coil can be rotated around the coil axis by means of a milled head screw. This provides a fine adjustment for the pen. Coarse adjustment is effected by undoing the screw which attaches the right-hand end of the pen arm to the coil axis, and rotating the pen arm relative to the coil arm.

may be in the wrong direction. Instruments issued by the Office are tested for creep, and are rejected if the error is excessive. A barograph should also be "compensated for temperature." A rise of temperature on an uncompensated instrument produces the same effect as a rise of pressure.

Exposure.—A position should be selected where the instrument will be protected from shaking and from sudden changes of temperature, and from dirt. It should be shielded from direct sunshine.

An excellent cushion for a barograph may be formed with two pieces of rubber tubing.

Mercurial barographs.—For observatory use, barographs have been designed in which the movements of the mercury in a barometer are recorded either photographically or mechanically. A description of the photographic barograph used at British Observatories is given in the "Reports of the Meteorological Committee," 1867 and 1869. The best known example of a mercurial barograph with mechanical registration is W. H. Dines's float barograph, a full description of which will be found in *London, Quart. J. R. met. Soc.*, 1929, pp. 37-53. In this instrument the movements of the mercury in the lower cistern of a syphon barometer are communicated by means of a glass float and a platinum wire suspension to the smaller of two light wheels, mounted on the same axis. The larger wheel carries a bifilar platinum suspension to which the recording pen is attached.

The barometer tube is constructed with the upper portion of the same diameter as the cistern so that the movement of the mercury in the cistern is very much greater than in a barometer of normal pattern. The magnification introduced by the differential wheels causes changes of pressure to be reproduced on about twice the scale of the mercurial barometer. Compensation for temperature changes is obtained by enclosing a definite volume of air under the float, and friction is practically eliminated by surrounding the float with steel balls and by supporting the axis of the wheel system on anti-friction wheels.

§ 19. THE THERMOGRAPH

In most thermographs the thermometer consists of a slightly curved metal tube filled with spirit (Bourdon tube) the curvature of which changes with change of temperature, or of a bimetallic spiral which coils or uncoils as the temperature changes. One end of the thermometer is fixed rigidly to the instrument while the other is connected either directly or by levers to the recording pen.

Thermographs for meteorological use must be exposed out of doors, preferably in a Stevenson screen, and hence it is necessary to clean and oil their bearings much more frequently than is the case with barographs, especially in towns where dirt accumulates rapidly.

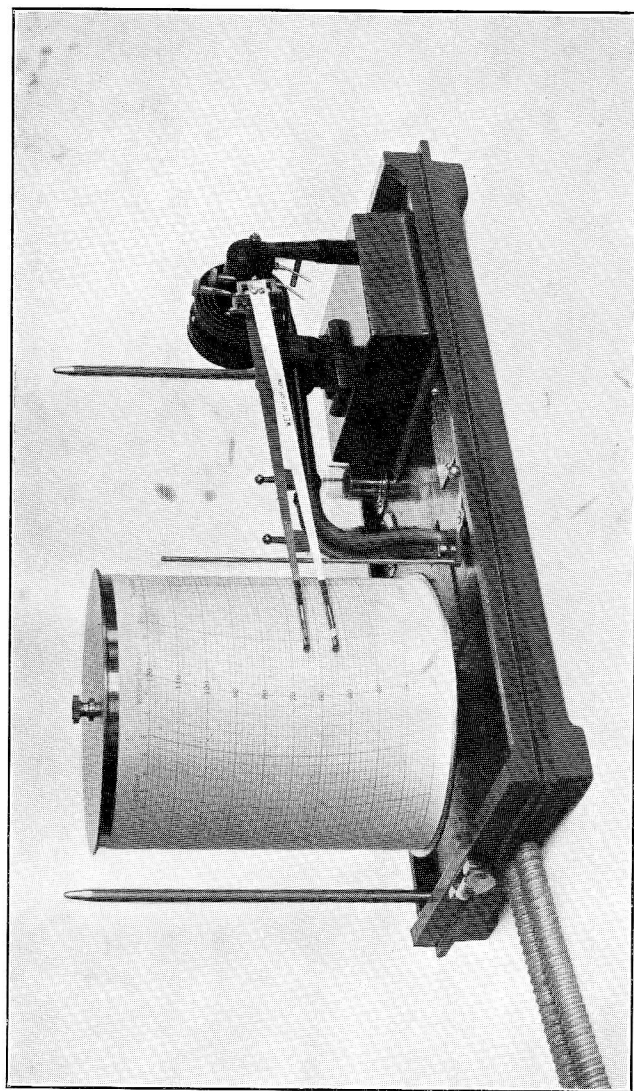
The M.O. pattern bimetallic spiral thermograph (*see* Plate XV) is issued with a clock drum for a weekly chart or a daily chart as may be required. There is a device for altering the position of the pen on the chart and so setting the instrument for different climates or different seasons. Two ranges are used in the British Isles: the *winter chart* has a range from -10° F. to 70° F., the *summer chart* from 20° F. to 100° F. The proper date for changing from one set of charts to another varies with the locality. For London the change should be

made about the middle of April and the middle of October. The setting may be accomplished by using the mechanism provided in the thermograph to adjust the indication of the new chart to agree with the reading of a mercury thermometer placed beside it in the screen. The change should only be made at times when the temperature is constant or changing slowly, and only when the pen is near the middle of its range. In most instruments there is no device for altering the scale value, *i.e.*, the amount of motion of the pen corresponding with a change of temperature of one degree.

In some instruments the scale value can be adjusted by altering the amount of the coil which is used to operate the pen arm. This is an adjustment, however, which is best left to an instrument maker.

In another form of thermograph, known as the "mercury-in-steel," or distant-reading thermograph, the pen arm is directly attached to a bourdon tube, which is connected by fine capillary steel tubing to the bulb, also made of steel and filled with mercury at high pressure. As the capillary tubing may be of considerable length, this type of instrument is well adapted for recording at a distance. When the tubing is very long, compensating links are inserted to prevent the expansion and contraction of the mercury in the tubing from affecting the readings. In "twin-pen" instruments two pens are operated by separate bulbs and tubes, and may be used to record dry- and wet-bulb temperatures, or the temperatures in two separate environments, on the same charts. A twin-pen instrument is shown in Plate XVI with the case cover removed. The bourdon tube is at the extreme right and the two capillaries enter at the extreme left and pass up through the floor of the case just to the right of the chart drum and thence to the bourdon tube, at the near end of which can be seen the two fine adjustment screws for setting the pens. This adjustment is effected by the makers. "Distance thermographs" operated by electrical resistance thermometers are also sometimes employed.

The readings of the thermograph require frequent checking by comparison with control instruments. A convenient plan is to place a standard maximum and a standard minimum thermometer in the screen with the instrument and to read and set these at regular hours, time marks being made at the hours of reading. It should be borne in mind that in cases where the trace shows that the extreme was of very short duration the sluggishness of the thermometers may cause an appreciable difference between the reading of the control and that of the recorder. It is not desirable to crowd a wet- and dry-bulb thermometer, a maximum and minimum thermometer, a thermograph and perhaps also a hygrograph into a Stevenson screen of ordinary dimensions. Such a course interferes with the adequate ventilation of the instruments. We may either use a separate screen for the recording instruments, or use a large screen (p. 25). A clear space of at least 3 in. should be left between the various instruments and between the instruments and the louvres of the screen.



DISTANT-READING THERMOGRAPH.

§ 20. THE HAIR HYGROGRAPH

This instrument depends for its action on the fact that the length of a human hair, which has been freed from fat by boiling in caustic soda or potash, varies considerably with the relative humidity, but only very little with other meteorological elements. It increases in length as the humidity increases and *vice versa*, but the changes are not in proportion. A change of 5 per cent. in the relative humidity at the top of the scale, say, from 90 to 95 per cent., gives a much smaller change in the length of the hair than an equal change lower in the scale, say, from 40 to 45 per cent. In practice, a small bundle of hair is used for actuating the lever bearing the recording pen.

As in the case of the thermograph, the instrument must be exposed out of doors (in a Stevenson screen, *see above*), so that frequent cleaning and oiling of the bearings are necessary. After exposure to wind carrying salt spray the hygrograph reads too high. In these circumstances the hairs should be washed. Unfortunately, the properties of hair are subject to gradual changes, so that the reading is not always the same under the same conditions of humidity.

The following refers to the Richard hygrograph :—

The instrument is shown in elevation and plan in Fig. 25, the wire cage and the case being omitted. The bundle of hair is held by the two jaws AA₁ and caught up at approximately its centre by the hook B. The horizontal axis of the lever C, to which the hook is fixed, is fastened to the cam piece D, which is just kept in contact with the second cam piece E by means of the light spring F. The second cam piece E is clamped to the pen arm axis by the screw G. Alterations in the length of the hair with humidity are in this way magnified and communicated to the pen. The greater part of the magnification of the changes in length of the hair is produced by the pen arm and the lever C, although some magnification is produced by the angle in the hair and by the cam pieces.

To keep the hairs in good order they should be wetted once a week with a camel-hair brush. It is convenient to do this when the charts are changed. When the hairs have been thoroughly wetted the reading of the hygrograph should be 95.* This forms the test for “zero” error. Any necessary adjustment is made as described below.

If an error in the scale value is suspected, calibration in an indoor room is desirable. As a standard the ventilated psychrometer should be used (*see p. 37*). If one of these instruments is not available ordinary dry- and wet-bulb thermometers may be set up and fanned.

Adjustments can be made in the following way :—

(1) *For zero error.*—(a) Large adjustments for zero should be performed by moving the jaw A; this can be done by unscrewing

* The reason for this instruction, which is supported by practical experience, appears to be that the weight of water applied in this way is appreciable, causing slight sagging of the hairs corresponding in effect with a reduction of humidity from 100 to 95 per cent. when the hairs are dry.

the capstan headed screw H. (b) Small adjustments for zero error (within 5 per cent. relative humidity on the chart) may be made by turning the screw I. Large alterations of the angle in the hair affect the magnification and should be avoided.

(2) *For scale value.*—(a) The magnification may be very nearly proportionately increased or decreased by lowering or raising hook B on the lever C; the small screw J allows one to effect such

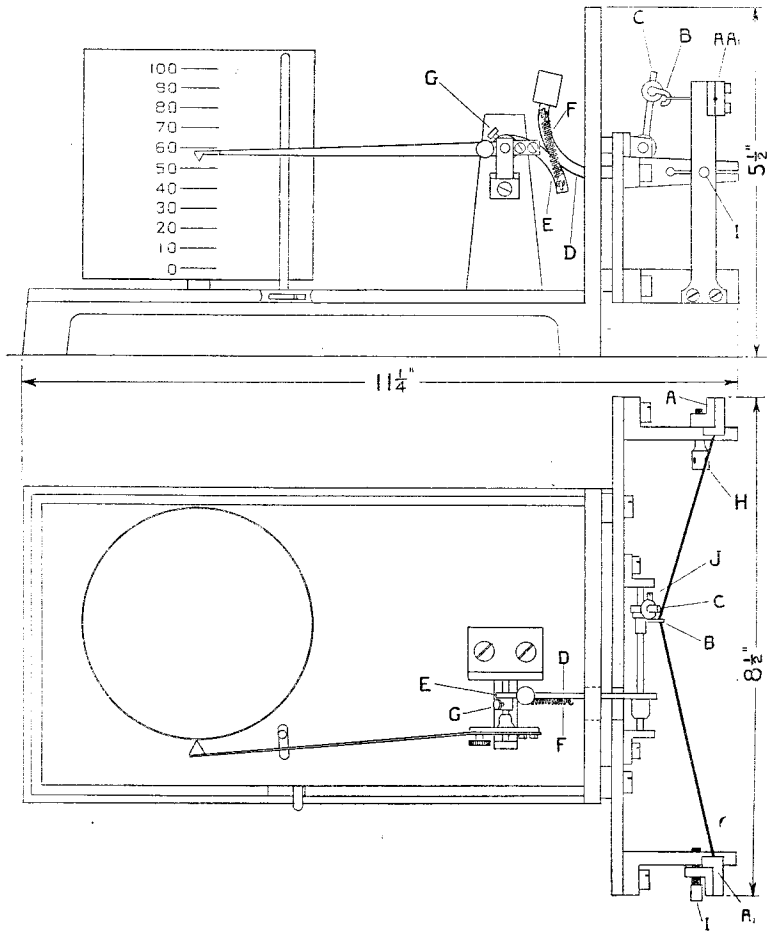


FIG. 25. ELEVATION AND PLAN OF HAIR HYGROGRAPH.

a change. (b) The magnification may also be varied by rotating the pen arm axis relative to the cam pieces. For this purpose the screw G may be utilised. Clockwise rotation of the pen arm decreases the magnification over the whole range of the chart, whilst anticlockwise rotation has the contrary effect.

A small secondary effect of clockwise rotation of the pen is that the magnification is decreased to a slightly greater extent towards the bottom of the chart than the top. Anticlockwise rotation has, of course, the opposite effect.

A little experience with a hygrograph will show that the humidity of the air frequently varies very rapidly, so that small errors in the time scale may become very serious. Accurate time marks (*see* p. 106) are therefore very important.

For the same reason the comparison of the values of the humidity obtained from the curves with simultaneous values calculated from readings of dry- and wet-bulb thermometers is difficult. Sluggishness in either instrument may give rise to discrepancies. Another cause of difference lies in the fact that the reading of a wet bulb depends to some extent on the rate at which air is flowing past it. A single comparison is thus of little value, but in a long series of observations the mean difference between the readings should be small.

§ 21. DINES DIRECT RECORDING PRESSURE TUBE ANEMOGRAPH

Great care is required in selecting a site for an anemometer (*see* p. 4). The general aim should be to secure an "effective height" (*see* p. 43) approximating to 10 metres (33 ft.). In the standard Meteorological Office mast for use in open situations, this is secured by placing the vane at a height of 40 ft. above ground (*see* Plate XVII). In the vicinity of trees or buildings the vane must be raised to a greater height, each case requiring individual consideration.

The Dines direct recording pressure tube anemograph consists of four distinct parts—

- | | |
|----------------------------|--|
| (1) the head, | |
| (2) the transmitting gear, | |
| (3) the velocity recorder | } usually combined in
one instrument. |
| (4) the direction recorder | |

The two recorders must be housed under cover; a small wooden hut provides adequate shelter provided there is some means of warming the air inside the hut in winter to prevent the water in the tank becoming frozen. Instruments provided with a direction recorder must be arranged in such a way that the recorder is vertically below the vane. If there is no direction recorder this condition is unnecessary.

Full instructions for installing the instrument are obtainable from the Meteorological Office.

THE HEAD

In the Dines direct recording pressure tube anemograph the receiving apparatus consists of a comparatively light head, which is mounted on the top of a mast, and connected with the recording apparatus by means of tubing.

The construction of the head will be understood from the diagram, Fig. 26. The upper part is free to rotate, and the vane V thus keeps the horizontal tube A facing the direction from which the wind is coming. The wind blowing into this open tube A produces an increase

of pressure inside it, which is transmitted through the central tube of the head to the recording apparatus by means of tubing attached to the tube B. The fixed part of the central tube is surrounded by an outer tube S in which there are four rows of holes. Wind blowing past these produces a diminution of pressure in the annular space between the two tubes, and this is transmitted to the recorder by means of a pipe attached at C. The pipes may be of considerable length, say 40 ft. or 50 ft., so that the recorder can be placed a long way from the head. The pressure and suction outlets at the base of the head are covered by a cylindrical shield with a conical top, the purpose of which is to eliminate variations in the suction effect due to the disturbance in the wind stream which would otherwise arise from the presence of the projecting outlets.

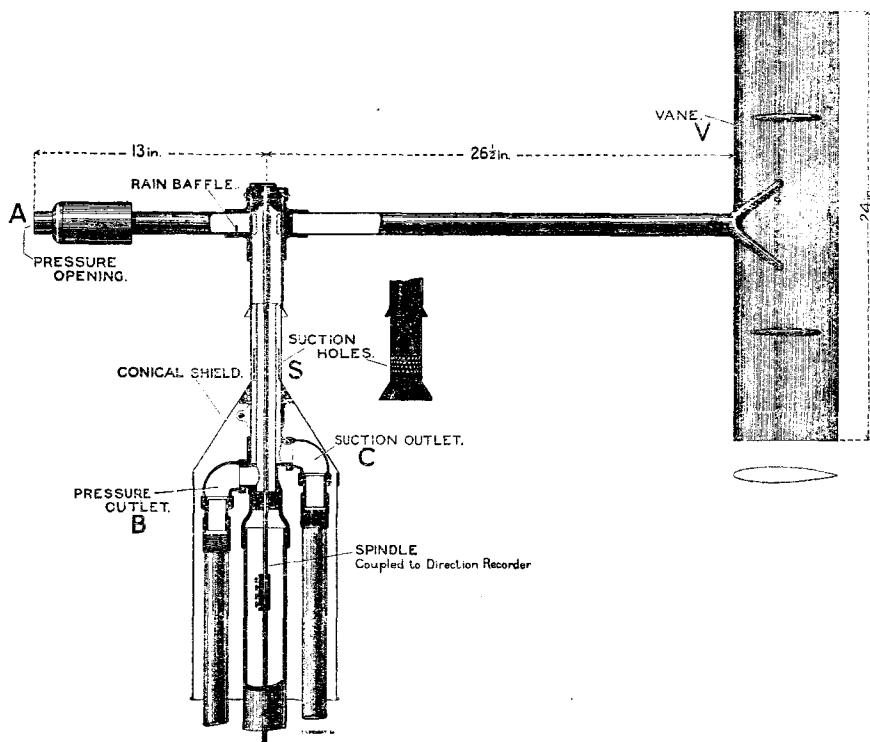
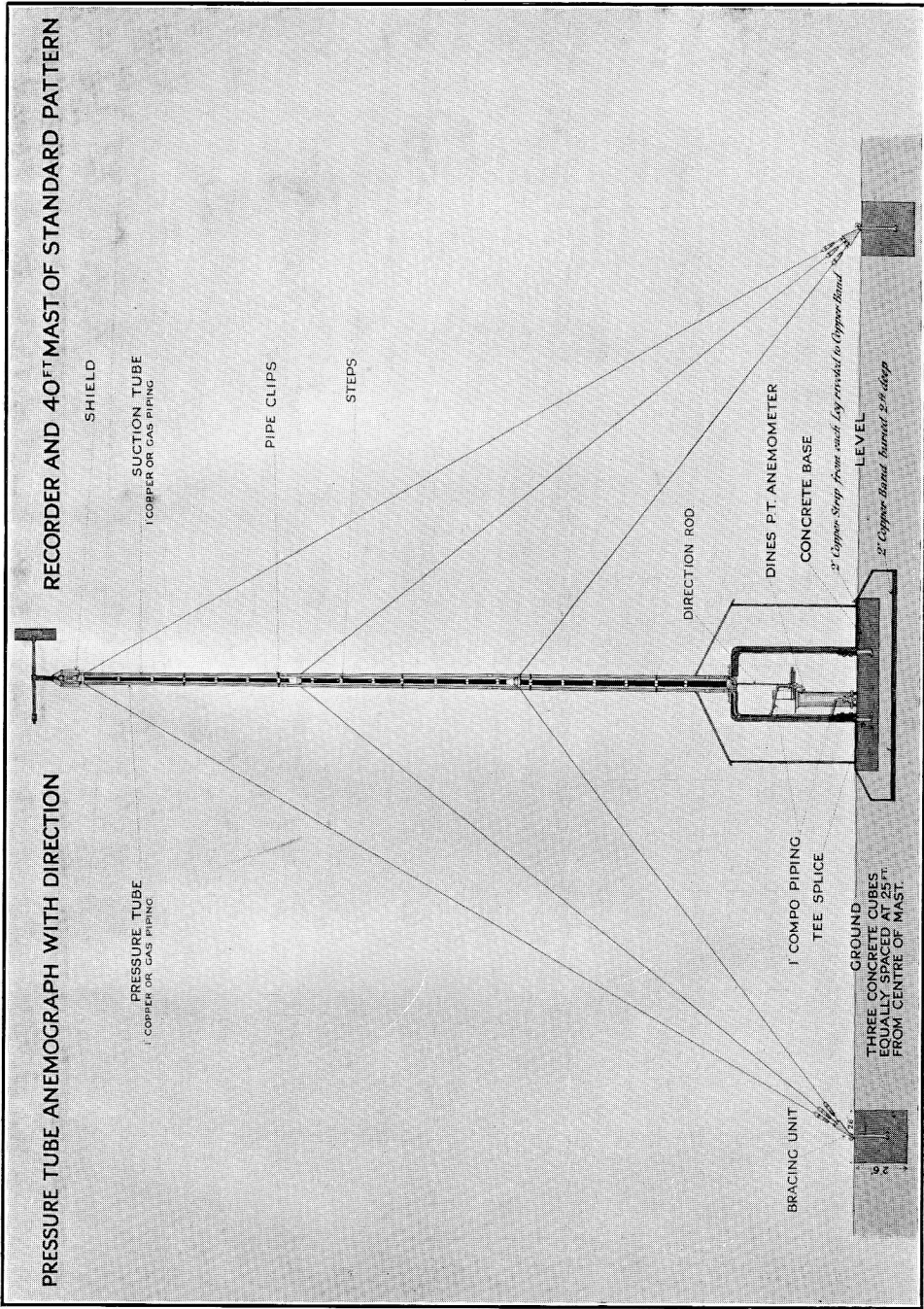
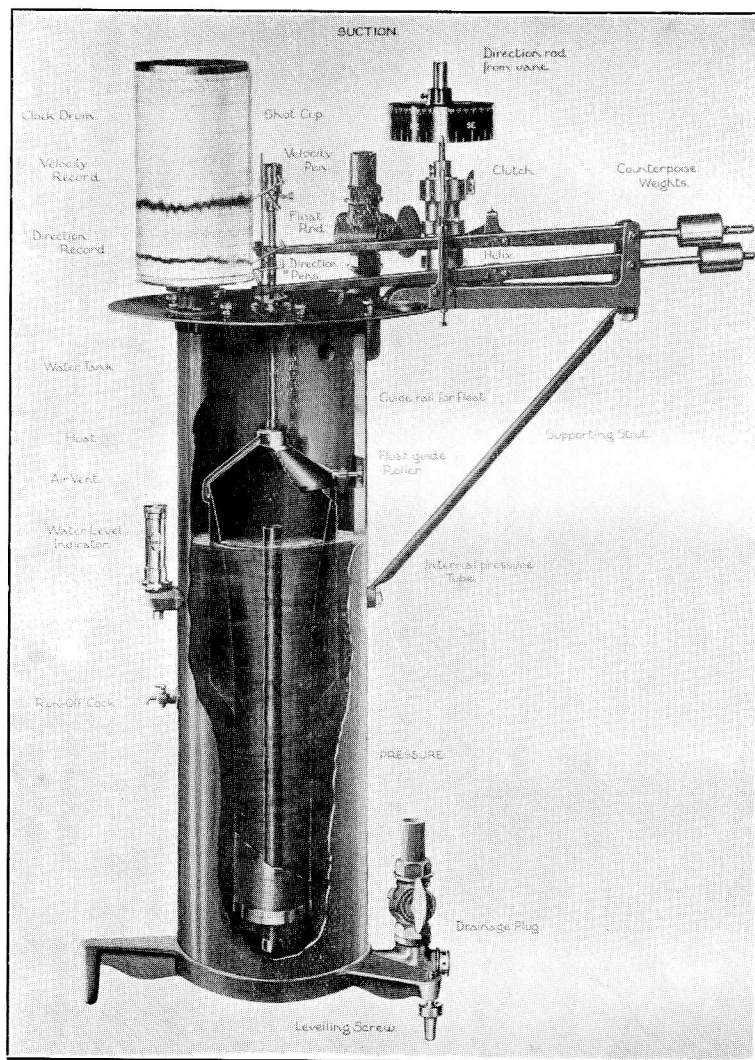


FIG. 26. HEAD OF DINES ANEMOGRAPH (Mark II).

When setting up the head care must be taken that the axis about which the vane rotates is vertical and that the pipes have a fall throughout so as to prevent the lodgment of water. When once fixed the head requires little attention, beyond being occasionally cleaned. No oil or grease should be used except that a little Vaseline may with advantage be placed in the ball bearing on which the vane turns.





DINES DIRECT RECORDING PRESSURE TUBE ANEMOGRAPH, MK. II

THE TRANSMITTING GEAR

The outlets at the base of the head are connected by brass unions to steel or copper pipes, normally of 1 in. bore, which transmit the variations of pressure to the velocity recorder. Copper is necessary in localities where steel is subject to excessive corrosion; when steel is used the pipes should be galvanized or treated with some anti-corrosive preparation such as Dr. Angus Smith's solution. The movements of the vane are transmitted by means of shafting made from light steel or duralumin tubing connected to the direction recorder through a flexible coupling. The whole assembly is supported by a rigid steel mast, down the centre of which the direction shaft is passed. The mast must be furnished with steps to permit of periodical inspection of the head and pipes (*see* Plate XVII).

THE VELOCITY RECORDER

When arranged for automatic recording, the Dines anemograph possesses the great advantage over the cup anemometer that it records changes in the wind velocity of short period and not merely the average velocity for an interval of several minutes.

The recorder (Plate XVIII) consists of a float, which is placed mouth downwards in a closed tank partially filled with water. Tubes marked respectively suction and pressure lead into the air spaces above and below the float and are connected with the two tubes from the head. The connexions are so arranged that the tube transmitting the increase of pressure communicates with the space below the float while that transmitting the decrease of pressure communicates with the space above it. The increase and decrease of pressure on the two sides of the float combine to raise the float and a record of the motion of the latter is thus a record of the wind blowing past the head.

The arrangement for tracing the record is as follows:—To the top of the float is attached a vertical rod which passes through what is practically an air-tight collar in the cover of the tank; this rod carries a pen which records on a drum rotated by clockwork. To the float is attached a small wheel which moves in a vertical guide and prevents the float from rotating.

The shape of the inner surface of the float is of great importance. It is so constructed that the displacement of the recording pen from the zero of the scale is proportional to the velocity of the wind at the head. The combination of the pressure and suction effects in the manner described increases the motion of the float, but its **primary object is to eliminate the effects of changes in the pressure of the air in the room in which the recorder is placed.**

When adjusting the apparatus it is necessary that the air pressure should be the same on both sides of the float. To effect this, two three-way stop-cocks are provided which enable us to close the tubes leading to the head and to place the air spaces above and below the float in communication with the air of the room.

A word of warning may usefully be given regarding the behaviour of the instrument when either of these taps is open to the room. It is commonly assumed that the opening of either tap will invariably lead to the pen falling on the chart. This is not always the case and apparently anomalous results are sometimes found. These results are usually capable of explanation if it is remembered that the air pressure in the room may differ appreciably from the "static" air pressure, owing to the pressure or suction effects produced by the wind or open windows or chimneys.

These may have a material effect on the reading of the anemograph when either tap is opened to the room. A case has also been reported where a large fire burning in the grate with all windows and doors closed lowered the pressure in the room sufficiently to produce most unexpected results when either tap was turned. Apart from departures of pressure in the room from "static," the effect of bright sunshine on the pressure and suction pipes alongside the mast heating the air in them and lowering its density below that of the surrounding air will magnify the suction effect and decrease the pressure effect at the bottom of the pipes. In a light wind the pressure effect may be entirely annulled by this means. No error in the record will be introduced so long as both taps are closed to the room and the two pipes are equally heated by the sun.

Calibration.—According to Mr. W. H. Dines' experiments, which led to the construction of the anemograph, the pressure difference W , in inches of water, established by a steady wind of velocity V miles per hour is given by the formula $W = \cdot 000731 V^2$.

If w is the pressure measured in millimeters of water the formula becomes :—

$$w = \cdot 0186 V^2 \text{ or } \sqrt{w} = \cdot 136 V.$$

If v is the velocity in metres per second the formula may be written

$$w = \cdot 093 v^2 \text{ or } \sqrt{w} = \cdot 305 v.$$

Either of the above formulae may be used for calibrating the recorder, the following method being adopted :—

Instructions for calibration.—An accurate pressure-gauge capable of measuring pressure differences to 0.1 mm. of water is required. Attach to the pressure-gauge an indiarubber tube to which a T-piece has been fixed. Disconnect the tube which goes to the anemograph head from the pipe which leads into the space below the float and connect the latter with one arm of the T by means of an indiarubber tube. Turn the other tap so as to close the tube leading to the head and put the air above the float into communication with the air of the room. To the open arm of the T attach a small piece of indiarubber tubing which can be closed at will with a pinch-cock. Now raise the pressure in the enclosed space by blowing down the T-piece until the pen on the chart reaches one of the horizontal lines. Note the reading on the chart and the corresponding difference in level of the water in the two arms of the gauge.

The following tables, derived from W. H. Dines' formulae, give the standard equivalents of pressure and indicated velocity.

Pressure in millimetres of water and speed in miles per hour :—

V	10	20	30	40	50	60	70	80	90	100
w	1.9	7.4	17.1	29.8	46.5	67.0	91.0	119	151	186
$\sqrt{w}$	1.4	2.7	4.1	5.4	6.8	8.2	9.5	10.9	12.2	13.6

Pressure in millimetres of water and speed in metres per second :—

v	5	10	15	20	25	30	35	40	45
w	2.3	9.3	21	37	58	84	114	149	188
$\sqrt{w}$	1.5	3.1	4.6	6.1	7.6	9.2	10.7	12.2	13.7

For practical purposes we require to know the error, in velocity units, corresponding to a given error in the pressure required to raise the pen to a stated indicated velocity. The following table shows the velocity equivalent of 1 mm. difference of pressure for various velocities :—

Indicated velocity (m.p.h.)	10	20	30	40	50	60	70	80	90	100
Difference in m.p.h. corresponding to 1 mm. of water.	2.69	1.34	0.90	0.67	0.54	0.45	0.38	0.34	0.29	0.27

It is important to notice that a calibration carried out in this manner gives results which are only applicable when the recording apparatus is connected to a head for which the formula used in the calibration ($W = .000731 V^2$) is strictly true. The most satisfactory method of ascertaining that this is the case is to expose the head to air currents of known speed in a wind channel. In actual practice it is sufficient to know the ratio of suction to pressure for various wind speeds. The standard value of this ratio is 0.490.

Correction for variations in air density.—Since the pressure difference indicated by a pressure-tube anemograph is proportional to ρV^2 where ρ is the density of the air, a correction to the indicated values of velocity becomes necessary when the density of the air is appreciably different from the normal value near sea level. It is evident that the smaller the density the greater the velocity indicated by a given elevation of the pen above the zero, and *vice versa*. If

V is the true velocity and V_0 the indicated velocity (corresponding with density ρ_0) then

$$V = \sqrt{\frac{\rho_0}{\rho}} V_0.$$

For the purpose of applying this correction the standard density should be taken as 1,226 gm./m.³*

THE DIRECTION RECORDER

The movements of the vane of the instrument are transmitted through the supporting mast to the stand of the recording drum, vertically beneath. By an apparatus designed by Mr. W. H. Dines, F.R.S., the motion is recorded on the paper which takes the velocity record. On the recording sheet the directions are set out between two horizontal lines, both of which are marked N., and which form the top and bottom lines of the direction chart. The variation of the direction of the vane is transformed into motion up or down the sheet by means of a cam. Two pens are employed, one or other of which moves with the vane, even if the vane makes more than a complete revolution. In working the instrument it is important to see that the pens are so adjusted that one marks the top and the other the bottom of the direction chart, and that they come close together, but do not foul, as the vane passes through north.

A reproduction of an actual record appears on Plate XIX.

In the direction recorder designed by Mr. J. Baxendell, the record is obtained on a separate drum coupled directly to the direction shaft.

INSTRUCTIONS FOR THE CARE OF DINES DIRECT RECORDING PRESSURE TUBE ANEMOGRAPHS WITH DIRECTION RECORDERS (twin-pen, lever type)

Daily routine.—*To change the chart.*—

(1) Close the stop-cocks and note the correct time G.M.T. to the nearest minute.

(2) Allow the velocity pen to come to rest without touching it, but if the air is calm, raise the float (slightly) and allow it to fall so that a vertical time mark is produced by the velocity pen.

(3) Rotate the clock cylinder slightly, so that the velocity pen marks its resting position upon the chart (*see* instances at A, B and C, Fig. 27).

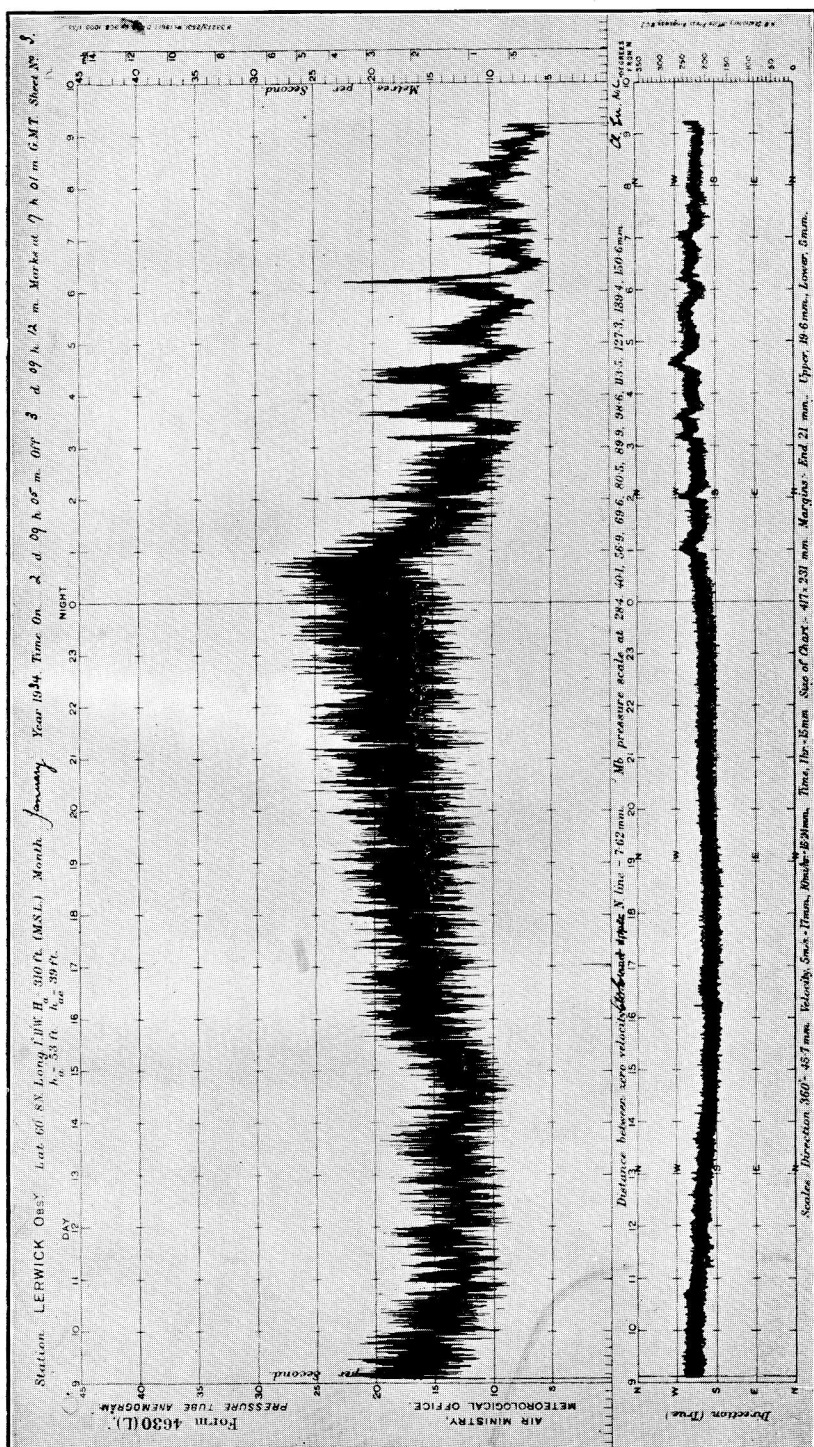
(4) Swing the three pens away from the paper by means of the pen lifter.

(5) Remove the completed chart from the (clock) cylinder.

(6) Insert a blank chart in position taking care—

(a) that the new chart be not folded, creased or crumpled in any way before use :

* In earlier editions this was given as 1,250 gm./m.³ which was applicable to the original experiments by Mr. W. H. Dines. The value of 1,226 gm./m.³ is approved by the International Commission for Air Navigation and has been used in effect since 1926.



REPRODUCTION OF THE PRESSURE TUBE ANEMOGRAM, LERWICK OBSERVATORY, 1934, JANUARY 2, 0905 TO JANUARY 3, 0912.
Note the Time Mark at 1701. (The reduction is to approximately half-scale, linear.)

- (b) that the ends of the two long horizontal lines which are carried to the edges of the chart overlap ;
- (c) that the bottom edge of the chart is as close to the flange on the clock cylinder as (b) allows. It should touch it at one point at least. If the bottom edge is not cut exactly parallel to the horizontal lines on the chart, it will not be possible to place it on the cylinder so that the edge touches the flange throughout its length ;
- (d) that the paper fits closely to the cylinder.

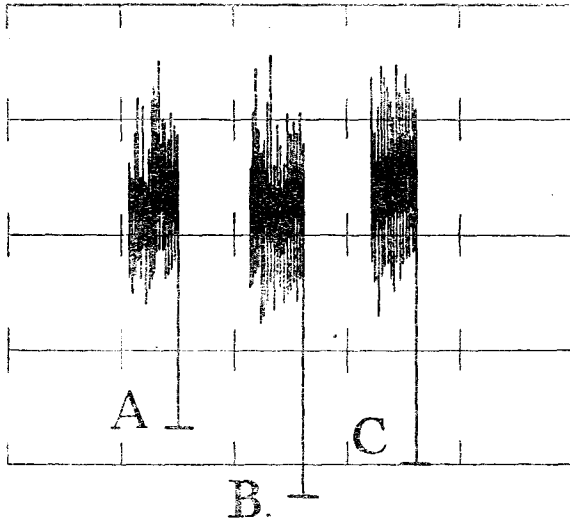


FIG. 27. ADJUSTMENT OF VELOCITY RECORDER

Adjustment of pens.

(7) Fill the pens with ink after seeing that they are clean. If they are not clean, lift them out of their sockets and wash them. Methylated spirit may be used with advantage for removing old ink.

(8) Swing the two direction pens into contact with the paper, so that they indicate approximately the correct Greenwich time, avoiding any splashing of ink. One pen will indicate the wind direction, the other will rest on one of the N. lines.

(9) If necessary, raise or lower the clock cylinder by means of the milled headed screw inside the cylinder until the upper or lower pen (as the case may be) rests exactly upon the upper or lower N. line of the record. The centre screw is a locking screw, the lower milled head is the one which raises or lowers the cylinder.

(10) There should be clear evidence upon each chart that both the resting pen and the acting pen will come to rest upon their respective N. resting lines—otherwise there may be some doubt as to the accuracy of the record produced by the acting pen. This is secured as follows :—

Having been assured that the pens are marking well open the one-point clutch or raise the locking ring and turn the helix through

a complete circle in such a way that the acting pen rises or falls, as the case may be, to its resting line (*see* Fig. 28). If the acting pen is that carried by the upper pen lever, the helix should be turned in the same direction as the hands of a watch placed face upwards upon the instrument. If the acting pen is that carried by the lower pen lever, the helix should be turned in the opposite direction to that of the hands of the watch. The resting line of the former pen is the upper N. line, while that of the latter pen is the lower N. line. Close the one-point clutch after the complete rotation has been made.

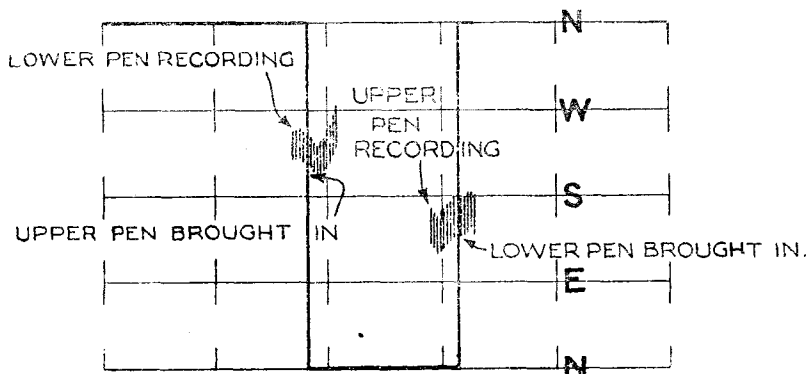


FIG. 28. ADJUSTMENT OF DIRECTION RECORDER

If the acting pen comes to rest on its appropriate line nothing further need be done. If it does not it should be adjusted until it does by means of its socket screw, or, if necessary, by following the instructions under "General remarks—Direction Pens."

(11) If necessary, shot should be added to or removed from the shot cup until the setting line on the float rod is just level with the top edge of the collar.

(12) Swing the velocity pen into contact with the paper.

(13) If necessary, adjust the velocity pen to fall exactly upon the zero line of the velocity record by means of its socket screw, *not by raising or lowering the clock cylinder.*

Starting the record.

(14) Note the correct time G.M.T. to the nearest minute and set the clock cylinder so that the pen marks the correct time on the chart. Remove backlash by turning the cylinder on its spindle in an anticlockwise direction so as to bring the pen back by steady motion to the required time from a point in advance of its proper setting, *i.e.*, from a time on the chart later in the day. A few trials will make this clear and will also show that unless this method is strictly followed the clock cylinder does not begin to rotate for some minutes, resulting in a loss of time on the record.

(*Note.*—In the latest pattern of clock, backlash has been eliminated.)

(15) Open the two stop-cocks. If the air is calm, raise the float (slightly) and allow it to fall again so that a vertical time mark is produced by the velocity pen.

(16) See that all the pens are marking.

Time mark

(17) A time mark should be made on the record, preferably within two or three hours of the start of the record. The mark is made by closing the two taps so as to allow the pen to fall to the zero line of the record. The taps should then be opened again. Greenwich time correct to the nearest minute should be noted at the time the mark is made and this should be entered on the chart in the space provided after the chart has been removed from the cylinder.

If the air is calm, this time mark should not be made. In no circumstances should the pen be raised by hand for the purpose of making this mark.

Writing up the chart

(18) Number the chart with the day of the year as given in the "Meteorological Office Calendar."

(19) Enter name of station, etc., month, year and day, also the time at which the chart was started and stopped and the time of the time mark described under (17).

(20) Write upon the front of the chart any known explanation of abnormal features, *e.g.*, failure to mark, clock stopping, etc.

General Remarks.—*Cleanliness.*—The observer should give the utmost attention to general cleanliness. Ink should not be allowed to clog upon the underside of the pens or on the penholders. Drops of ink that may fall upon the top of the tank or trickle down the chart to the clock cylinder flange should be cleaned off at once with a damp cloth. Older stains should be removed by the application of a small quantity of whitening applied with a damp cloth. Methylated spirit may be used with the whitening if there is no risk of this getting on lacquered brass or polished woodwork.

Freedom from friction.—To prevent sticking of the velocity pen, the float rod must be kept clean and dry. **No metal polish or lubricating oil or cleaning material should be used**, but it is beneficial to rub the rod with a piece of blotting paper previously treated with lead pencil. It is also important that the instrument should be accurately level. This should be tested occasionally by placing a spirit level on the top plate and if necessary adjusting by means of the levelling screws.

Water level.—The gauge should be examined about once a fortnight and corrected if necessary. Water may be lost by evaporation and there is just a possibility of rain finding its way down the air tubes. Distilled water should be added by removing the milled cap of the water-level indicator. Any excess should be run off at the little stop-cock just below. The level is correct when the tip of the pointer is in the surface of the water, the stop-cocks being closed and adjustment (11) being correct.

Draining plug.—The screwed plug by the lower stop-cock should be removed from time to time to allow any trapped water to escape. It will be convenient to see to this at the same time as the water level is examined. A tommy bar will be found with the accessories. The plug must always be screwed firmly back in place after the water has been removed.

Renewing pens.—The *velocity pen* is easily replaced. See that the distance from the pen point to the little grip sleeve is as nearly as possible the same as with the old pen or it will seem to need much other adjustment. When looked at from above the pen should seem to be at right angles to the paper. See that the new pen agrees with the direction pens in time—that is, they all fall upon the same vertical hour line at once. *Direction pens* require a little more attention as they must work in with one another and be in alignment (see (3) below). If the pen wires have not been strained or damaged in any way it will be found that the point mentioned in regard to the velocity pen, namely, the distance from pen point to grip sleeve, is of the greatest importance and much other adjustment can be saved by slight variations in this distance. Repeated trials on the lines indicated in (10) above and in (2) below, under “Adjustment of direction recorder,” will enable the observer to detect and remove any error.*

Orientation.—The observer should check the record by comparing it with his own reading of the vane. Some instruments have a compass card index fitted—in these cases comparison is simple though the readings of the card should occasionally be checked against those of the vane. Any discrepancy should be reported.

The vane should never be turned from below by means of the direction rod unless the air is calm, otherwise the rod may be strained.

The recorder is sometimes set up with its three feet standing on a box. The latter is usually filled with concrete but, unless it is firmly fixed to the floor of the hut, it is liable to be displaced if accidentally kicked and the orientation thereby altered. Wherever possible, the box should be screwed to the floor, but if this cannot be done, strips of wood should be fixed to the floor against the sides of the box so that it cannot be shifted.

If the feet of the anemograph rest directly upon the floor it is also liable to be shifted accidentally. If the feet are not otherwise fixed in position, cups are provided for them, the cups being screwed to the floor of the hut.

Oiling.—The direction mechanism should have a drop of oil about once a month in the hole at the top of the helix and the bearings of the long levers may need oiling at about the same period. The surface of the helices should be wiped over with an oily rag, but free oil there tends to gather dust and grit and should be avoided.

Adjustment of direction recorder

When first installed the direction recorder should be in correct working order. It may subsequently, however, be necessary to make certain adjustments, particulars of which are given below. These adjustments should on no account be attempted unless the recorder is definitely not working properly. If the observer feels in doubt as to the necessity of making adjustments, advice should be sought from the Superintendent of Instruments, Meteorological Office, Headstone Drive, Harrow, Middlesex, specimen charts being forwarded indicating the defect in question.

Adjustment of range of pen arms

- (1) Remove lower pen and free the clutch.
- (2) Rotate the helix in a counter-clockwise direction and adjust the screw holder of the upper pen until this pen just reaches the lower N. line on the chart at the lowest point of its travel.
- (3) When the pen has reached the top of its travel and its direction arm is resting on the dead stop, adjust the stop until the pen is on the upper N. line.
- (4) Remove the upper pen and replace the lower one.

* A new nib can be made to mark freely if it is first held in the flame of a match for a second.

(5) Rotate the helix in a clockwise direction and adjust the screw holder of the lower pen until the pen just reaches the upper line at the highest point of its travel.

(6) When the pen has reached the bottom of its travel and its direction arm is resting on the dead stop, adjust the stop until the pen is on the lower N. line.

After these adjustments have once been made, the correct setting of the pens from day to day will be carried out by lowering or raising the clock drum by the screw provided so as to bring that direction pen which is not giving the record on to the N. line of the chart.

Adjustment of alignment of pen arms

If the pens are not in vertical alignment with the velocity pen, the error being small, loosen the two screws that hold the brass sockets of the pen arm pivots when the arm can be moved bodily forwards or backwards. Tighten up the screws after adjustment.

Adjustment of rate of rise and fall of arms when passing over

If the top pen rises or the bottom pen falls too rapidly or too slowly, when approaching their respective datum lines, the counter-poise weights should be adjusted to prevent shock or too uncertain a motion.

Adjustment of cams

Movement of cams in and out can be made easy or stiff by loosening or tightening the cam pivot screws. The depth of engagement of a cam is adjusted by means of the set screw making contact with the end of the plate carrying the cam. This screw is to be found projecting from the pen arm about the mid position. If the depth is too great, the movement of the helix will be stopped at certain points. If not sufficient, the cam will not engage in the helix and there will be loss of record.

§ 22. DINES REMOTE RECORDING PRESSURE TUBE ANEMOGRAPH

The Dines remote recording pressure tube anemograph was designed for use in cases where it is not convenient to have the recorder vertically beneath the head, and where the recorder is required to be further from the head than the greatest permissible length of pressure and suction tubing.

The motion is communicated from the transmitting end (the vane, head and float) to the receiving end (the recorder) by small electric motors, one pair (transmitter and receiver) for velocity and one pair for direction. These are three-phase motors, of which the armatures are connected to an A.C. supply. The three poles of the field windings of the transmitter are connected to the corresponding poles of the receiver. Electro-motive forces are induced in the field coils by the alternating current in the armatures. If the armatures of transmitter and receiver are out of phase, the resulting torque draws the receiver armature into phase with that of the transmitter, in which position the electro-motive forces in the field coils of receiver and transmitter are in opposition. Thus the receiver armature rotates in phase with the transmitter.

The armatures of transmitter and receiver must be connected to the same A.C. supply, in order that the currents in them may be in phase. Those used in the recording of direction are connected direct to the mains (230 volts, 50 cycles) but the others (for recording velocity) are connected through transformers which reduce the voltage to 32.

The float and tank are placed at a convenient place near the head, and connected to the pressure and suction tubing, as in the direct recording anemograph. A fine chain is attached to the shot cup on top of the float rod and passes over a pulley on the spindle of the velocity transmitter. Thus the armature of the motor rotates as the float rises and falls. The receiver is mounted on a support fixed to the base of the recorder, and carries a pulley on its spindle. Over this pulley passes a chain on which hangs the velocity pen carriage. As the receiver rotates in phase with the transmitter, the movements of the float are reproduced by the pen.

The zero of the velocity pen may be adjusted by rotating the field coils of the receiving motor. A small arm, pivoted to the case, engages with a slot on the pulley, locking the pulley with respect to the case (*i.e.*, the armature with respect to the field coils). The instrument is adjusted at installation so that in this position the transmitter and receiver are in phase when the float is resting on the bottom of the tank. The pen may now be brought to the zero line of the chart by rotating the receiving motor in its support, by means of a rod screwed into the case, without the need for visiting the transmitter to turn off the pressure and suction cocks.

A velocity record may also be made at the transmitting end by a pen carried on the float rod in the usual way.

The transmitting motor for direction is immediately under the head, its spindle being rigidly connected to the vane. There is no direction rod. The receiver is mounted on a platform above the helix of the direction recorder, and its spindle is coupled to that of the helix by a clutch consisting of a ball-catch between two arms. The purpose of this is to avoid damage to the helix and cams if the current is turned on when the receiver is greatly out of phase with the transmitter: if the phase difference is more than about 30° , the clutch should open and thus avoid excessive shock to the recording mechanism.

INSTRUCTIONS FOR CARE OF DINES REMOTE RECORDING PRESSURE TUBE ANEMOGRAPH

Daily Routine.—*To change the chart—*

- (1) Switch off current and note the time (G.M.T.) to the nearest minute.
- (2) Rotate pulley of velocity receiver until locking arm will engage with slot.
- (3) Rotate the clock cylinder slightly, so that the velocity pen marks its resting position upon the chart (*see* instances at A, B and C, Fig. 27).
- (4) Swing the three pens away from the paper by means of the pen lifter.
- (5) Remove the completed chart from the (clock) cylinder.

- (6) Insert a blank chart in position taking care :—
- (a) that the new chart be not folded, creased or crumpled in any way before use ;
 - (b) that the ends of the two long horizontal lines which are carried to the edges of the chart overlap ;
 - (c) that the bottom edge of the chart is as close to the flange on the clock cylinder as (b) allows. It should touch it at one point at least. If the bottom edge is not cut exactly parallel to the horizontal lines on the chart, it will not be possible to place it on the cylinder so that the edge touches the flange throughout its length ;
 - (d) that the paper fits closely to the cylinder.

Adjustment of pens

(7) Fill the pens after seeing that they are clean. If they are not clean, lift them out of their sockets and wash them. Methylated spirit may be used with advantage for removing old ink.

(8) Swing the two direction pens into contact with the paper, so that they indicate approximately the correct Greenwich time, avoiding any splashing of ink. One pen will indicate the wind direction, the other will rest on one of the N. lines.

(9) If necessary, raise or lower the clock cylinder by means of the milled headed screw inside the cylinder until the upper or lower pen (as the case may be) rests exactly upon the upper or lower N. line of the record. The centre screw is a locking screw, the lower milled head is the one which raises or lowers the cylinder.

(10) There should be clear evidence upon each chart that both the resting pen and the acting pen will come to rest upon their respective N. resting lines—otherwise there may be some doubt as to the accuracy of the record produced by the acting pen. This is secured as follows :—

Having been assured that the pens are marking well open the clutch and turn the helix through a complete circle in such a way that the acting pen rises or falls, as the case may be, to its resting line (*see* Fig. 28). If the acting pen is that carried by the upper pen lever, the helix should be turned in the same direction as the hands of a watch placed face upwards upon the instrument. If the acting pen is that carried by the lower pen lever, the helix should be turned in the opposite direction to that of the hands of the watch. The resting line of the former pen is the upper N. line, while that of the latter pen is the lower N. line. Close the clutch after the complete rotation has been made.

If the acting pen comes to rest on its appropriate line nothing further need be done. If it does not it should be adjusted until it does by means of its socket screw, or, if necessary, by following the instructions under "General Remarks—Direction Pens."

(11) If necessary, shot should be added to or removed from the counterpoise until the velocity pen is balanced when raised to the 20 m.p.h. line. (Then if raised above this it will tend to rise further, on account of the weight of chain transferred to the other side of the pulley, while at positions below 20 m.p.h. it will have a slight tendency to fall.)

(12) Swing the velocity pen into contact with the paper.

(13) If necessary, adjust the zero of the velocity pen as already described, not by raising or lowering the clock cylinder.

Starting the record

(14) Note the time G.M.T. to the nearest minute and set clock cylinder so that pens show correct time on chart.

(15) Raise locking arm; raise velocity pen to approximately correct reading. Set direction disc to approximately correct reading. Switch on current.

(16) See that all the pens are marking.

Time Mark

(17) A time mark should be made on the record, preferably within two or three hours of the start. This is done by switching off the current, lowering the velocity pen to zero and engaging the locking arm. The arm should then be disengaged, the pen raised to its former position and the current turned on. The time should be noted and entered in the space provided after the chart has been removed. If the air is calm, the mark may be made by raising the pen a short distance, instead of lowering it.

The remainder of the instructions and remarks relating to the direct recording anemograph (pp. 129-31) apply to the remote recording anemograph. The float and tank should be inspected occasionally and the water level and weight of shot adjusted.

§ 23. THE ANEMOBIAGRAPH

The head of the anemobiograph is identical in principle with that of the Dines anemograph. The float of the recorder is cylindrical, however, and its motion is controlled by springs. In place of pure water, a mixture of water and glycerine with a little colouring matter is used so as to minimise the risk of freezing. Any variation in the specific gravity of this liquid from its standard value 1.16 alters the zero and the scale value of the record. The instrument is calibrated according to the Dines formula. It may be noted that as the float is acted on by springs as well as by fluid pressure the level of the liquid in the float chamber is variable when the anemobiograph is in action. The level is adjusted with both taps open to the air of the room, *i.e.*, at the zero of the record. There is no shot cup for adjusting the weight of the float, and the recorder is insensitive to small changes of level of the liquid.

§ 24. SELF-RECORDING RAIN-GAUGES

Autographic rain-gauges in ordinary use are of two types—

- (1) float gauges,
- (2) tilting-bucket gauges.

FLOAT GAUGES

Three types of float gauge will be described briefly. In the first the collecting vessel itself floats on mercury, in the others the water is collected in a cylindrical vessel containing a light metal float. The vertical motion of the latter is communicated through a float rod to the pen which records on a clock drum in the usual way. A continuous record of rainfall is thus obtained.

(a) **The Beckley gauge.**—This instrument, which is described in the "Report of the Meteorological Committee for 1869," is in use at certain Meteorological Office observatories. The water is collected in a small vessel which floats on mercury and which is emptied by a siphon. The rainfall and time scales of the instrument are rather contracted. This defect, and the high cost, made it necessary to design for general use a less expensive instrument with more open

scales. A feature which is worthy of note, however, is the housing of the clock, which is contained in a hermetically closed case. The latter forms a much more efficient protection than is usually provided in recording instruments.

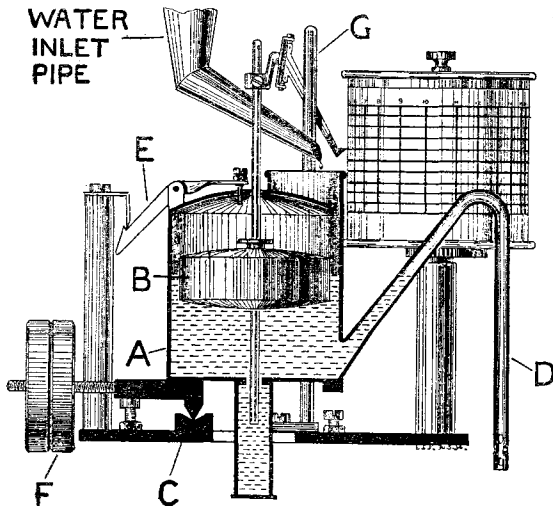


FIG. 29. DINES TILTING SIPHON RAIN-GAUGE.

(b) **The Dines Tilting Siphon Rain-gauge.**—The trouble which is frequently experienced in recording rain-gauges, owing to irregularity in the action of the siphon was overcome by Mr. W. H. Dines in an ingenious manner in a

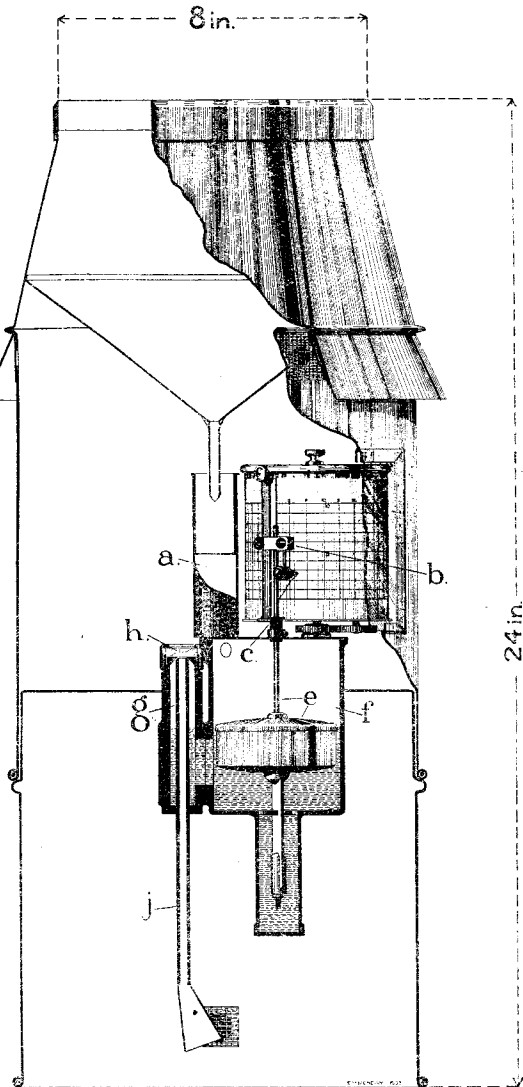
gauge which was in use at Benson Observatory during the War, and which has been adopted with only slight modification as the standard Meteorological Office pattern. The drawing, Fig. 29, shows the principle of the gauge but not the details of construction.

In this pattern the water falls into a chamber, A, and raises a light float, B, carrying the pen in the customary manner, but the chamber is mounted on knife edges, C, and is so arranged that it overbalances when full of water, sending a surge of water through the siphon tube, D, and starting the siphon in a positive manner.

The overbalancing is controlled by a trip, E, which is released by the rising float at a predetermined point. As the float chamber empties, the centre of gravity shifts to the left and under the action of the counter-weight, F, the system re-sets itself in its normal working position. In the earlier instruments the overbalancing of the float chamber caused the pen to make an irregular mark on the chart. This drawback has been overcome by fitting an upright rod, G, which automatically lifts the pen from the paper immediately the chamber commences to overbalance.

The gauge has been designed to be contained within an approximately cylindrical cover with a funnel diameter of 11.31 inches.

(c) The natural siphon rain - gauge. — Instruments fitted with automatic siphons have rarely been found reliable in the past owing to the tendency of the siphon to dribble continuously, resulting in a loss of record. The natural siphon gauge represents an attempt to overcome this defect by the use of a special type of siphon. In two instruments produced* in this country the two arms of the siphon are arranged co-axially, the long delivery tube being placed inside the shorter arm which is connected to the collecting vessel. The upper end of the



- | | |
|-----------------------|--------------------|
| a. ENTRANCE TUBE. | f. FLOAT CHAMBER. |
| b. PEN CARRIER. | g. SIPHON CHAMBER. |
| c. THREADED COLLAR. | h. GLASS COVER. |
| e. FLOAT & FLOAT ROD. | j. DISCHARGE PIPE. |

FIG. 30. NATURAL SIPHON RECORDING RAIN-GAUGE.

* The design illustrated in Fig. 30 is by C. F. Casella & Co.

outer tube is closed by a glass cap and the vertical clearance between this and the upper end of the inner tube is almost of capillary dimensions. At the same time the area is large enough to carry away the whole of the collected water at sufficient speed so that the discharge is a definite operation and freedom from dribbling is ensured. (Fig. 30.)

(d) **The Hyetograph.**—In this instrument introduced in 1908 by Negretti and Zambra the automatic siphon is entirely dispensed with. The float chamber is large enough to hold a little over 4 in. (about 100mm.) of rain and the float rod is fitted with a number of projecting pins, arranged at equal intervals, which engage successively with a projection on the pen lever. When the pen reaches the top of the chart, recording 10mm. of rain, the lever automatically disengages with the first pin and falls on to the next lower pin, the pen returning at the same time to the base-line of the chart. The pen is prevented from falling too quickly by a dash-pot under the lever, which for the successful working of the instrument must be kept supplied with clean, thick oil. The process is repeated until the float chamber is full. Emptying the chamber is effected by means of a hand-started siphon.

This instrument gives a useful idea of the rate and the duration of rainfall, but later development has produced instruments capable of a higher order of accuracy.

TIPPING-BUCKET GAUGES

In these instruments the rain water passes from the collecting funnel to the "tipping bucket" in which it is measured. The latter consists of an elongated flat-bottomed trough with open ends which is divided into two parts by a central transverse partition and pivoted about its central point like the beam of a balance. When the left-hand end of the trough is depressed the rain-water is collected on the right-hand side of the partition. The balance is so adjusted that the weight of the water collected causes the bucket to tip over as soon as it reaches the amount of $\cdot 01$ in., or in more sensitive instruments, $\cdot 005$ in. This tipping causes the water to flow from the bucket into a small receiving funnel whence it passes to a collecting vessel or runs away. If rain continues to fall it is now received in the trough on the left-hand side of the partition until another $\cdot 01$ in. has fallen, when a second tip will occur.

The instrument is made autographic by arranging for each tip of the bucket to raise an arm bearing a pen which records on a revolving drum, through a short step. The height through which the pen is raised is thus proportional to the amount of rain which has fallen. A simple arrangement allows the pen to fall back to the zero of the scale when it reaches the top of the drum. If desired, the tipping bucket and the recording apparatus may be put in separate cases and connected electrically. With this form of apparatus the gauge may be suitably exposed, while the recorder is placed within doors in any place that happens to be convenient. It will be perceived that the record is not continuous; each step on the chart corresponds with a fall of $\cdot 01$ in. during the interval between it and the previous step.

This type of gauge gives fair results for heavy falls, but it is useless for measuring the duration of gentle rain. On account of evaporation, light falls may be seriously underestimated.

INSTRUCTIONS FOR THE CARE OF SELF-RECORDING RAIN-GAUGES

The precautions detailed on pp. 109–14 must be observed in all types of automatic rain-gauges.

An automatic rain-gauge should always be set up on the same site as the ordinary non-recording gauge, and the records from the former should be standardised by comparison with the observations from the latter.

It is essential that the instruments should be tested at regular intervals, especially when no rain has fallen for some time. This is best accomplished by pouring into the funnel successively equal quantities of water corresponding with definite intervals on the chart. In the case of a funnel of 8 in. diameter, the ordinary 8-in. measuring glass would be used, but in some instruments, such as the hyetograph, the diameter of the funnel is 6 in., and if a 5-in. or 8-in. rain measure is used, the quantity of water to be measured must be carefully calculated.*

In cold weather precautions against freezing are necessary. In many cases a night-light placed below the funnel of the gauge will suffice. Where electric mains are available a 25-watt lamp forms a convenient source of heat; a higher power should not be used as it would give rise to excessive evaporation of the rain or snow.

* For a 6-in. funnel, using a 5-in. rain measure, the reading in the measure corresponding with 2 mm. on the chart is $2 \times \frac{36}{25}$ or 2.88 mm. If an 8-in. rain measure is used the reading corresponding with 2 mm. on the chart would be $2 \times \frac{36}{64} = 1.13$ mm. For a funnel of 11.31-in. diameter as in the Dines tilting siphon rain-gauge 2 mm. in an 8-in. measure corresponds with 1 mm. on the chart.

PART III.—TABLES

Tables for correcting and reducing to sea level readings of mercurial barometers, whether in inches or in millibars, are printed on the following pages; also a table for computing the velocity-height ratio of clouds from observations with the standard Fineman nephoscope.

The tables for correcting and reducing readings of mercurial barometers are derived from those published in the "International Meteorological Tables" (Gauthier-Villars, Paris, 1890) or from formulae which, within the limits of accuracy of the accompanying tables, are equivalent to those given in the Introduction to the International Tables.

Table I is obtained from the formula—

$$c = \alpha p (285 - t)$$

where c is the required correction in millibars, p is the observed reading of the barometer in millibars, t is the temperature of the attached thermometer in absolute degrees, and α is .000163, the difference between the coefficients of cubical expansion of mercury in glass and of the linear expansion of brass, expressed in C.G.S. units.

Table II is similarly derived from the formula

$$c = (\alpha p + \beta) (285 - t),$$

where the letters have the same meanings as before, while β , though strictly depending on the dimensions of the barometer, is actually assumed to have the average value of .008 (for a discussion of this matter see "Dictionary of Applied Physics," Vol. 3, p. 153).

The fact that there is a slight difference between the temperature corrections of Fortin and Kew pattern barometers was not realised when the International Tables were compiled.

Table III is a transcript from the "International Meteorological Tables," pp. 154–75.

Table IV is transcribed from the "International Meteorological Tables," pp. 208–9, it being observed that the tabulated values of the quantity M , there given, are the values required for entry in this table.

Table V is also derived from the International Tables, pp. 208–9, the values of M there given being multiplied by .027 in order to obtain the corrections appropriate to a station-level reading of 27 in., and by .03 for a station-level reading of 30 in.

In Table VI the values expressed in mercury-inches are taken from the International Tables, p. 179; those expressed in millibars were computed directly from the formula printed on page B.31 of the International Tables.

Table VII is computed directly from the formula given on p. 88 of this handbook using a value of 25 mm. for the distance between the radii of the consecutive circles engraved upon the mirror of the nephoscope.

TABLE I
TEMPERATURE CORRECTION OF THE FORTIN BAROMETER
(Millibar graduations.)

Corrections to be applied to the readings of *Fortin Mercury Barometers* to reduce them to 285°A.

If the temperature of the attached thermometer is $\left\{ \begin{array}{l} \text{above} \\ \text{below} \end{array} \right\}$ 285°A
 $\left\{ \begin{array}{l} \text{subtract} \\ \text{add} \end{array} \right\}$ the correction.

Attached ther- mometer (add correction).	BAROMETER READINGS (mb.).										Attached ther- mometer (subtract correction).
	860	880	900	920	940	960	980	1000	1020	1040	
°A	Corrections (mb.)										°A
284	·14	·14	·15	·15	·15	·16	·16	·16	·17	·17	286
283	·28	·29	·29	·30	·31	·31	·32	·33	·33	·34	287
282	·42	·43	·44	·45	·46	·47	·48	·49	·50	·51	288
281	·56	·57	·59	·60	·61	·63	·64	·65	·67	·68	289
280	·70	·72	·73	·75	·77	·78	·80	·82	·83	·85	290
279	·84	·86	·88	·90	·92	·94	·96	·98	1·00	1·02	291
278	·98	1·00	1·03	1·05	1·07	1·09	1·12	1·14	1·16	1·19	292
277	1·12	1·15	1·17	1·20	1·23	1·25	1·28	1·30	1·33	1·36	293
276	1·26	1·29	1·32	1·35	1·38	1·40	1·44	1·47	1·50	1·53	294
275	1·40	1·43	1·47	1·50	1·53	1·56	1·60	1·63	1·66	1·70	295
274	1·54	1·58	1·61	1·65	1·69	1·72	1·76	1·79	1·83	1·87	296
273	1·68	1·72	1·76	1·80	1·84	1·88	1·92	1·96	2·00	2·04	297
272	1·82	1·86	1·91	1·95	1·99	2·03	2·08	2·12	2·16	2·21	298
271	1·96	2·01	2·05	2·10	2·15	2·19	2·24	2·28	2·33	2·38	299
270	2·10	2·15	2·20	2·25	2·30	2·34	2·40	2·45	2·49	2·54	300
269	2·25	2·30	2·35	2·40	2·45	2·50	2·55	2·60	2·66	2·71	301
268	2·39	2·44	2·49	2·55	2·61	2·66	2·71	2·77	2·83	2·88	302
267	2·53	2·58	2·64	2·70	2·76	2·81	2·87	2·93	2·99	3·05	303
266	2·67	2·73	2·79	2·85	2·91	2·97	3·03	3·10	3·16	3·22	304
265	2·81	2·87	2·93	3·00	3·07	3·13	3·19	3·26	3·33	3·39	305
264	2·95	3·01	3·08	3·15	3·22	3·28	3·35	3·42	3·49	3·56	306
263	3·09	3·15	3·23	3·30	3·37	3·44	3·51	3·59	3·66	3·73	307
262	3·23	3·30	3·37	3·45	3·53	3·60	3·67	3·75	3·83	3·90	308
261	3·37	3·44	3·52	3·60	3·68	3·75	3·83	3·91	3·99	4·07	309
260	3·51	3·58	3·67	3·75	3·83	3·91	3·99	4·08	4·16	4·24	310
259	3·65	3·73	3·81	3·90	3·99	4·06	4·15	4·24	4·32	4·41	311
258	3·79	3·87	3·96	4·05	4·14	4·22	4·31	4·40	4·49	4·58	312
257	3·93	4·01	4·11	4·20	4·29	4·38	4·47	4·56	4·66	4·75	313
256	4·07	4·16	4·25	4·35	4·45	4·53	4·63	4·73	4·82	4·92	314
255	4·21	4·30	4·40	4·50	4·60	4·69	4·79	4·89	4·99	5·09	315

TABLE II

TEMPERATURE CORRECTION OF THE KEW PATTERN BAROMETER
(Millibar graduations.)

Corrections to be applied to the readings of *Kew Pattern Mercury Barometers* to reduce them to 285°A.

If the temperature of the attached thermometer is $\left\{ \begin{array}{l} \text{above} \\ \text{below} \end{array} \right\}$ 285°A
 $\left\{ \begin{array}{l} \text{subtract} \\ \text{add} \end{array} \right\}$ the correction.

Attached ther- mometer (add correction).	BAROMETER READINGS (mb.).										Attached ther- mometer (subtract correction).
	860	880	900	920	940	960	980	1000	1020	1040	
°A	Corre ction (mb.)										°A
284	·15	·15	·15	·16	·16	·16	·17	·17	·17	·18	286
283	·30	·30	·31	·32	·32	·33	·34	·34	·35	·36	287
282	·44	·45	·46	·47	·48	·49	·50	·51	·52	·53	288
281	·59	·61	·62	·63	·64	·66	·67	·68	·70	·71	289
280	·74	·76	·77	·79	·81	·82	·84	·86	·87	·89	290
279	·89	·91	·93	·95	·97	·99	1·01	1·03	1·05	1·07	291
278	1·04	1·06	1·08	1·11	1·13	1·15	1·17	1·20	1·22	1·24	292
277	1·19	1·21	1·24	1·26	1·29	1·32	1·34	1·37	1·39	1·42	293
276	1·33	1·36	1·39	1·42	1·45	1·48	1·51	1·54	1·57	1·60	294
275	1·48	1·51	1·55	1·58	1·61	1·64	1·68	1·71	1·74	1·78	295
274	1·63	1·66	1·70	1·74	1·77	1·81	1·85	1·88	1·92	1·95	296
273	1·78	1·82	1·86	1·90	1·93	1·97	2·01	2·05	2·09	2·13	297
272	1·93	1·97	2·01	2·05	2·10	2·14	2·18	2·22	2·27	2·31	298
271	2·08	2·12	2·17	2·21	2·26	2·30	2·35	2·39	2·44	2·49	299
270	2·22	2·27	2·32	2·37	2·42	2·47	2·52	2·57	2·61	2·66	300
269	2·37	2·42	2·48	2·53	2·58	2·63	2·68	2·74	2·79	2·84	301
268	2·52	2·57	2·63	2·69	2·74	2·80	2·85	2·91	2·96	3·02	302
267	2·67	2·73	2·78	2·84	2·90	2·96	3·02	3·08	3·14	3·20	303
266	2·82	2·88	2·94	3·00	3·06	3·13	3·19	3·25	3·31	3·37	304
265	2·97	3·03	3·09	3·16	3·22	3·29	3·35	3·42	3·49	3·55	305
264	3·11	3·18	3·25	3·32	3·39	3·45	3·52	3·59	3·66	3·73	306
263	3·26	3·33	3·40	3·48	3·55	3·62	3·69	3·76	3·83	3·91	307
262	3·41	3·48	3·56	3·63	3·71	3·78	3·86	3·93	4·01	4·08	308
261	3·56	3·63	3·71	3·79	3·87	3·95	4·03	4·10	4·18	4·26	309
260	3·71	3·79	3·87	3·95	4·03	4·11	4·19	4·28	4·36	4·44	310
259	3·86	3·94	4·02	4·11	4·19	4·28	4·36	4·45	4·53	4·62	311
258	4·00	4·09	4·18	4·26	4·35	4·44	4·53	4·62	4·71	4·79	312
257	4·15	4·24	4·33	4·42	4·51	4·61	4·70	4·79	4·88	4·97	313
256	4·30	4·39	4·49	4·58	4·68	4·79	4·86	4·96	5·05	5·15	314
255	4·45	4·54	4·64	4·74	4·84	4·93	5·03	5·13	5·23	5·33	315

TABLE III
TEMPERATURE CORRECTION OF THE FORTIN BAROMETER
(Inch graduations.)

Corrections to be applied to the readings of Fortin Mercury Barometers to reduce them to 28·6° F. (*i.e.*, brass scale 62° F., mercury 32° F.).

Attached ther- mometer	BAROMETER READINGS (INCHES)											Attached ther- mometer
	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	
0	+·068	+·069	+·070	+·072	+·073	+·074	+·076	+·077	+·078	+·080	+·081	0
1	+·065	+·067	+·068	+·069	+·070	+·072	+·073	+·074	+·076	+·077	+·078	1
2	+·063	+·064	+·065	+·067	+·068	+·069	+·070	+·072	+·073	+·074	+·075	2
3	+·061	+·062	+·063	+·064	+·065	+·066	+·068	+·069	+·070	+·071	+·072	3
4	+·058	+·060	+·061	+·062	+·063	+·064	+·065	+·066	+·067	+·069	+·070	4
5	+·056	+·057	+·058	+·059	+·060	+·061	+·062	+·064	+·065	+·066	+·067	5
6	+·054	+·055	+·056	+·057	+·058	+·059	+·060	+·061	+·062	+·063	+·064	6
7	+·051	+·052	+·053	+·054	+·055	+·056	+·057	+·058	+·059	+·060	+·061	7
8	+·049	+·050	+·051	+·052	+·053	+·053	+·054	+·055	+·056	+·057	+·058	8
9	+·046	+·047	+·048	+·049	+·050	+·051	+·052	+·053	+·054	+·054	+·055	9
10	+·044	+·045	+·046	+·046	+·047	+·048	+·049	+·050	+·051	+·052	+·053	10
11	+·042	+·043	+·043	+·044	+·045	+·046	+·047	+·047	+·048	+·049	+·050	11
12	+·039	+·040	+·041	+·042	+·042	+·043	+·044	+·044	+·045	+·046	+·047	12
13	+·037	+·038	+·038	+·039	+·040	+·040	+·041	+·042	+·043	+·043	+·044	13
14	+·035	+·035	+·036	+·036	+·037	+·038	+·039	+·039	+·040	+·041	+·041	14
15	+·032	+·033	+·033	+·034	+·035	+·035	+·036	+·036	+·037	+·038	+·038	15
16	+·030	+·030	+·031	+·031	+·032	+·033	+·033	+·034	+·034	+·035	+·036	16
17	+·027	+·028	+·029	+·029	+·030	+·030	+·031	+·031	+·032	+·032	+·033	17
18	+·025	+·026	+·026	+·027	+·027	+·028	+·028	+·029	+·029	+·030	+·030	18
19	+·023	+·023	+·024	+·024	+·025	+·025	+·025	+·026	+·026	+·027	+·027	19
20	+·020	+·021	+·021	+·022	+·022	+·022	+·023	+·023	+·024	+·024	+·024	20
21	+·018	+·018	+·019	+·019	+·019	+·020	+·020	+·021	+·021	+·021	+·022	21
22	+·016	+·016	+·016	+·017	+·017	+·017	+·017	+·018	+·018	+·018	+·019	22
23	+·013	+·014	+·014	+·014	+·014	+·015	+·015	+·015	+·015	+·016	+·016	23
24	+·011	+·011	+·011	+·012	+·012	+·012	+·012	+·012	+·013	+·013	+·013	24
25	+·009	+·009	+·009	+·009	+·009	+·009	+·010	+·010	+·010	+·010	+·010	25
26	+·006	+·006	+·006	+·007	+·007	+·007	+·007	+·007	+·007	+·007	+·007	26
27	+·004	+·004	+·004	+·004	+·004	+·004	+·004	+·004	+·004	+·005	+·005	27
28	+·001	+·002	+·002	+·002	+·002	+·002	+·002	+·002	+·002	+·002	+·002	28
29	-·001	-·001	-·001	-·001	-·001	-·001	-·001	-·001	-·001	-·001	-·001	29
30	-·003	-·003	-·003	-·003	-·003	-·004	-·004	-·004	-·004	-·004	-·004	30
31	-·006	-·006	-·006	-·006	-·006	-·006	-·006	-·006	-·006	-·007	-·007	31
32	-·008	-·008	-·008	-·008	-·009	-·009	-·009	-·009	-·009	-·009	-·009	32
33	-·010	-·011	-·011	-·011	-·011	-·011	-·012	-·012	-·012	-·012	-·012	33
34	-·013	-·013	-·013	-·013	-·014	-·014	-·014	-·014	-·015	-·015	-·015	34
35	-·015	-·015	-·016	-·016	-·016	-·017	-·017	-·017	-·017	-·018	-·018	35
36	-·017	-·018	-·018	-·018	-·019	-·019	-·019	-·020	-·020	-·020	-·021	36
37	-·020	-·020	-·021	-·021	-·021	-·022	-·022	-·022	-·023	-·023	-·024	37
38	-·022	-·023	-·023	-·023	-·024	-·024	-·025	-·025	-·026	-·026	-·026	38
39	-·024	-·025	-·025	-·026	-·026	-·027	-·027	-·028	-·028	-·029	-·029	39
40	-·027	-·027	-·028	-·028	-·029	-·029	-·030	-·031	-·031	-·032	-·032	40
41	-·029	-·030	-·030	-·031	-·031	-·032	-·033	-·033	-·034	-·034	-·035	41
42	-·032	-·032	-·033	-·033	-·034	-·035	-·035	-·036	-·036	-·037	-·038	42
43	-·034	-·035	-·035	-·036	-·036	-·037	-·038	-·038	-·039	-·040	-·040	43
44	-·036	-·037	-·038	-·038	-·039	-·040	-·040	-·041	-·042	-·043	-·043	44
45	-·039	-·039	-·040	-·041	-·042	-·042	-·043	-·044	-·045	-·045	-·046	45
46	-·041	-·042	-·043	-·043	-·044	-·045	-·046	-·047	-·047	-·048	-·049	46
47	-·043	-·044	-·045	-·046	-·048	-·048	-·048	-·049	-·050	-·051	-·052	47
48	-·046	-·047	-·047	-·048	-·049	-·050	-·051	-·052	-·053	-·054	-·054	48
49	-·048	-·049	-·050	-·051	-·052	-·053	-·054	-·055	-·055	-·056	-·057	49
50	-·050	-·051	-·052	-·053	-·054	-·055	-·056	-·057	-·058	-·059	-·060	50

TABLE III—continued

TEMPERATURE CORRECTION OF THE FORTIN BAROMETER
(Inch graduations.)

Attached ther- mometer	BAROMETER READINGS (INCHES)											Attached ther- mometer
	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	
51	·053	·054	·055	·056	·057	·058	·059	·060	·061	·062	·063	51
52	·055	·056	·057	·058	·059	·060	·061	·062	·064	·065	·066	52
53	·057	·059	·060	·061	·062	·063	·064	·065	·066	·067	·068	53
54	·060	·061	·062	·063	·064	·065	·067	·068	·069	·070	·071	54
55	·062	·063	·064	·065	·067	·068	·069	·071	·072	·073	·074	55
56	·064	·066	·067	·068	·069	·070	·072	·073	·074	·076	·077	56
57	·067	·068	·069	·071	·072	·073	·075	·076	·077	·078	·080	57
58	·069	·071	·072	·073	·074	·076	·077	·078	·080	·081	·082	58
59	·072	·073	·074	·076	·077	·078	·080	·081	·083	·084	·085	59
60	·074	·075	·077	·078	·080	·081	·082	·084	·085	·087	·088	60
61	·076	·078	·079	·080	·082	·084	·085	·087	·088	·090	·091	61
62	·079	·080	·082	·083	·085	·086	·088	·089	·091	·092	·094	62
63	·081	·083	·084	·086	·087	·089	·090	·092	·093	·095	·096	63
64	·083	·085	·086	·088	·090	·092	·093	·095	·096	·097	·099	64
65	·086	·088	·089	·091	·092	·094	·095	·097	·099	·101	·102	65
66	·088	·090	·091	·093	·095	·097	·098	·100	·101	·103	·105	66
67	·090	·092	·094	·096	·097	·099	·101	·102	·104	·106	·108	67
68	·093	·095	·096	·098	·100	·102	·103	·105	·107	·109	·110	68
69	·095	·097	·099	·101	·102	·104	·106	·108	·110	·112	·113	69
70	·097	·099	·101	·103	·105	·107	·109	·111	·112	·114	·116	70
71	·100	·102	·103	·105	·107	·109	·111	·113	·115	·117	·119	71
72	·102	·104	·106	·108	·110	·112	·114	·116	·118	·120	·122	72
73	·104	·106	·108	·110	·112	·114	·116	·118	·120	·122	·124	73
74	·107	·109	·111	·113	·115	·117	·119	·121	·123	·125	·127	74
75	·109	·111	·113	·115	·117	·120	·122	·124	·126	·128	·130	75
76	·111	·113	·116	·118	·120	·122	·124	·126	·128	·131	·133	76
77	·114	·116	·118	·120	·122	·125	·127	·129	·131	·134	·136	77
78	·116	·118	·120	·123	·125	·127	·129	·132	·134	·136	·138	78
79	·118	·121	·123	·125	·127	·130	·132	·135	·137	·139	·141	79
80	·121	·123	·125	·128	·130	·133	·135	·137	·139	·142	·144	80
81	·123	·126	·128	·130	·132	·135	·137	·140	·142	·145	·147	81
82	·125	·128	·130	·133	·135	·138	·140	·143	·145	·148	·149	82
83	·128	·131	·133	·136	·138	·140	·142	·145	·147	·150	·152	83
84	·130	·133	·135	·138	·140	·143	·145	·148	·150	·153	·155	84
85	·132	·135	·137	·140	·143	·146	·148	·151	·153	·156	·158	85
86	·135	·138	·140	·143	·145	·148	·150	·153	·155	·158	·161	86
87	·137	·140	·142	·145	·148	·151	·153	·156	·158	·161	·163	87
88	·139	·143	·145	·148	·150	·153	·155	·158	·161	·164	·166	88
89	·142	·145	·147	·150	·153	·156	·158	·161	·164	·167	·169	89
90	·144	·147	·150	·153	·155	·158	·161	·164	·166	·169	·172	90
91	·146	·149	·152	·155	·158	·161	·163	·166	·169	·172	·175	91
92	·149	·152	·154	·157	·160	·163	·166	·169	·172	·175	·177	92
93	·151	·154	·157	·160	·163	·166	·168	·171	·174	·177	·180	93
94	·153	·156	·159	·162	·165	·168	·171	·174	·177	·180	·183	94
95	·156	·159	·162	·165	·168	·171	·174	·177	·180	·183	·186	95
96	·158	·161	·164	·167	·170	·173	·176	·179	·182	·185	·188	96
97	·160	·164	·167	·170	·173	·176	·179	·182	·185	·188	·191	97
98	·163	·166	·169	·172	·175	·178	·181	·185	·188	·191	·194	98
99	·165	·168	·171	·175	·178	·181	·184	·187	·190	·194	·197	99
100	·167	·171	·174	·177	·180	·184	·187	·190	·193	·197	·200	100

TABLE IV

REDUCTION OF PRESSURE IN MILLIBARS TO MEAN SEA LEVEL
Pressure at Station Level, 1000 millibars.*

Height in feet.	AIR TEMPERATURE (° F.). (Dry bulb in screen.)										Height in feet.
	0°F.	10°F.	20°F.	30°F.	40°F.	50°F.	60°F.	70°F.	80°F.	90°F.	
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	
10	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	10
20	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	20
30	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.0	1.0	30
40	1.6	1.6	1.6	1.5	1.5	1.4	1.4	1.4	1.4	1.4	40
50	2.0	2.0	2.0	1.9	1.9	1.8	1.8	1.8	1.7	1.7	50
60	2.4	2.4	2.4	2.3	2.3	2.2	2.2	2.1	2.1	2.0	60
70	2.8	2.8	2.8	2.7	2.7	2.6	2.5	2.5	2.4	2.4	70
80	3.3	3.2	3.1	3.0	3.0	2.9	2.9	2.8	2.8	2.7	80
90	3.7	3.6	3.5	3.4	3.4	3.3	3.2	3.2	3.1	3.1	90
100	4.1	4.0	3.9	3.8	3.8	3.7	3.6	3.5	3.5	3.4	100
110	4.5	4.4	4.3	4.2	4.2	4.1	4.0	3.9	3.8	3.7	110
120	4.9	4.8	4.7	4.6	4.5	4.4	4.3	4.2	4.2	4.1	120
130	5.3	5.2	5.1	5.0	4.9	4.8	4.7	4.6	4.5	4.4	130
140	5.7	5.6	5.5	5.4	5.2	5.1	5.0	4.9	4.9	4.8	140
150	6.1	6.0	5.9	5.8	5.6	5.5	5.4	5.3	5.2	5.1	150
160	6.5	6.4	6.3	6.2	6.0	5.9	5.8	5.7	5.6	5.4	160
170	6.9	6.8	6.7	6.6	6.4	6.3	6.1	6.0	5.9	5.8	170
180	7.4	7.2	7.0	6.9	6.7	6.6	6.5	6.4	6.3	6.1	180
190	7.8	7.6	7.4	7.3	7.1	7.0	6.8	6.7	6.6	6.5	190
200	8.2	8.0	7.8	7.7	7.5	7.4	7.2	7.1	7.0	6.8	200
210	8.6	8.4	8.2	8.1	7.9	7.8	7.6	7.5	7.3	7.2	210
220	9.0	8.8	8.6	8.5	8.3	8.1	7.9	7.8	7.7	7.5	220
230	9.4	9.2	9.0	8.8	8.6	8.5	8.3	8.2	8.0	7.9	230
240	9.8	9.6	9.4	9.2	9.0	8.8	8.6	8.5	8.4	8.2	240
250	10.2	10.0	9.8	9.6	9.4	9.2	9.0	8.9	8.7	8.6	250
260	10.6	10.4	10.2	10.0	9.8	9.6	9.4	9.3	9.1	8.9	260
270	11.0	10.8	10.6	10.4	10.2	10.0	9.8	9.6	9.4	9.3	270
280	11.5	11.2	11.0	10.7	10.5	10.3	10.1	10.0	9.8	9.6	280
290	11.9	11.6	11.4	11.1	10.9	10.7	10.5	10.3	10.1	10.0	290
300	12.3	12.0	11.8	11.5	11.3	11.1	10.9	10.7	10.5	10.3	300
310	12.7	12.4	12.2	11.9	11.7	11.5	11.3	11.1	10.8	10.6	310
320	13.1	12.8	12.6	12.3	12.1	11.8	11.6	11.4	11.2	11.0	320
330	13.6	13.3	13.0	12.7	12.4	12.2	12.0	11.8	11.5	11.3	330
340	14.0	13.7	13.4	13.1	12.8	12.5	12.3	12.1	11.9	11.7	340
350	14.4	14.1	13.8	13.5	13.2	12.9	12.7	12.5	12.2	12.0	350
360	14.8	14.5	14.2	13.9	13.6	13.3	13.1	12.8	12.6	12.3	360
370	15.2	14.9	14.6	14.3	14.0	13.7	13.4	13.2	12.9	12.7	370
380	15.6	15.3	14.9	14.6	14.3	14.0	13.8	13.5	13.3	13.0	380
390	16.0	15.7	15.3	15.0	14.7	14.4	14.1	13.9	13.6	13.4	390
400	16.4	16.1	15.7	15.4	15.1	14.8	14.5	14.2	14.0	13.7	400
410	16.8	16.5	16.1	15.8	15.5	15.2	14.9	14.6	14.3	14.0	410
420	17.2	16.9	16.5	16.2	15.9	15.6	15.2	14.9	14.7	14.4	420
430	17.7	17.3	16.9	16.6	16.2	15.9	15.6	15.3	15.0	14.7	430
440	18.1	17.7	17.3	17.0	16.6	16.3	15.9	15.6	15.4	15.1	440
450	18.5	18.1	17.7	17.4	17.0	16.7	16.3	16.0	15.7	15.4	450
460	18.9	18.5	18.1	17.8	17.4	17.1	16.7	16.4	16.1	15.8	460
470	19.3	18.9	18.5	18.2	17.8	17.4	17.1	16.7	16.4	16.1	470
480	19.8	19.3	18.9	18.5	18.1	17.8	17.4	17.1	16.8	16.5	480
490	20.2	19.7	19.3	18.9	18.5	18.1	17.8	17.4	17.1	16.8	490
500	20.6	20.1	19.7	19.3	18.9	18.5	18.2	17.8	17.5	17.2	500

* For other pressures the corrections to be applied are in proportion.

TABLE IV—continued

REDUCTION OF PRESSURE IN MILLIBARS TO MEAN SEA LEVEL
Pressure at Station Level, 1000 millibars.*

Height in feet.	AIR TEMPERATURE (° F.). (Dry bulb in screen.)										Height in feet.
	0°F.	10°F.	20°F.	30°F.	40°F.	50°F.	60°F.	70°F.	80°F.	90°F.	
500	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	500
510	20.6	20.1	19.7	19.3	18.9	18.5	18.2	17.8	17.5	17.2	510
520	21.0	20.5	20.1	19.7	19.3	18.9	18.6	18.2	17.9	17.5	520
530	21.4	20.9	20.5	20.1	19.7	19.3	18.9	18.5	18.2	17.9	530
540	21.9	21.4	20.9	20.5	20.0	19.6	19.3	18.9	18.6	18.2	540
550	22.3	21.8	21.3	20.9	20.4	20.0	19.6	19.2	18.9	18.6	550
560	22.7	22.2	21.7	21.3	20.8	20.4	20.0	19.6	19.3	18.9	560
570	23.1	22.6	22.1	21.7	21.2	20.8	20.4	20.0	19.6	19.2	570
580	23.5	23.0	22.5	22.1	21.6	21.2	20.8	20.3	20.0	19.6	580
590	23.9	23.4	22.9	22.4	21.9	21.5	21.1	20.7	20.3	19.9	590
600	24.3	23.8	23.3	22.8	22.3	21.9	21.5	21.0	20.7	20.3	600
610	24.7	24.2	23.7	23.2	22.7	22.3	21.9	21.4	21.0	20.6	610
620	25.1	24.6	24.1	23.6	23.1	22.7	22.3	21.8	21.4	21.0	620
630	25.5	25.0	24.5	24.0	23.5	23.1	22.6	22.1	21.7	21.3	630
640	26.0	25.5	24.9	24.4	23.9	23.4	23.0	22.5	22.1	21.7	640
650	26.4	25.9	25.3	24.8	24.3	23.8	23.3	22.8	22.4	22.0	650
660	26.8	26.3	25.7	25.2	24.7	24.2	23.7	23.2	22.8	22.4	660
670	27.2	26.7	26.1	25.6	25.1	24.6	24.1	23.6	23.2	22.7	670
680	27.6	27.1	26.5	26.0	25.5	24.9	24.4	24.0	23.5	23.1	680
690	28.1	27.5	26.9	26.3	25.8	25.3	24.8	24.3	23.9	23.4	690
700	28.5	27.9	27.3	26.7	26.2	25.6	25.1	24.7	24.2	23.8	690
710	28.9	28.3	27.7	27.1	26.6	26.0	25.5	25.1	24.6	24.1	700
720	29.3	28.7	28.1	27.5	27.0	26.4	25.9	25.5	25.0	24.5	710
730	29.7	29.1	28.5	27.9	27.4	26.8	26.3	25.8	25.3	24.8	720
740	30.2	29.6	28.9	28.3	27.7	27.1	26.6	26.2	25.7	25.2	730
750	30.6	30.0	29.3	28.7	28.1	27.5	27.0	26.5	26.0	25.5	740
760	31.0	30.4	29.7	29.1	28.5	27.9	27.4	26.9	26.4	25.9	750
770	31.4	30.8	30.1	29.5	28.9	28.3	27.8	27.3	26.7	26.2	760
780	31.8	31.2	30.5	29.9	29.3	28.7	28.1	27.6	27.1	26.6	770
790	32.3	31.6	30.9	30.3	29.6	29.0	28.5	28.0	27.4	26.9	780
800	32.7	32.0	31.3	30.7	30.0	29.4	28.8	28.3	27.8	27.3	790
810	33.1	32.4	31.7	31.1	30.4	29.8	29.2	28.7	28.1	27.6	800
820	33.5	32.8	32.1	31.5	30.8	30.2	29.6	29.1	28.5	28.0	810
830	33.9	33.2	32.5	31.9	31.2	30.6	30.0	29.4	28.8	28.3	820
840	34.4	33.7	32.9	32.2	31.6	30.9	30.3	29.8	29.2	28.7	830
850	34.8	34.1	33.3	32.6	32.0	31.3	30.7	30.1	29.5	29.0	840
860	35.2	34.5	33.7	33.0	32.4	31.7	31.1	30.5	29.9	29.4	850
870	35.6	34.9	34.1	33.4	32.8	32.1	31.5	30.9	30.3	29.7	860
880	36.1	35.3	34.5	33.8	33.2	32.5	31.9	31.2	30.6	30.1	870
890	36.5	35.7	35.0	34.2	33.5	32.8	32.2	31.6	31.0	30.4	880
900	37.0	36.1	35.4	34.6	33.9	33.2	32.6	31.9	31.3	30.8	890
910	37.4	36.5	35.8	35.0	34.3	33.6	33.0	32.3	31.7	31.1	900
920	37.8	36.9	36.2	35.4	34.7	34.0	33.4	32.7	32.1	31.5	910
930	38.2	37.3	36.6	35.8	35.1	34.4	33.7	33.1	32.4	31.8	920
940	38.7	37.8	37.0	36.2	35.4	34.7	34.1	33.4	32.8	32.2	930
950	39.1	38.2	37.4	36.6	35.8	35.1	34.4	33.8	33.1	32.5	940
960	39.5	38.6	37.8	37.0	36.2	35.5	34.8	34.2	33.5	32.9	950
970	39.9	39.0	38.2	37.4	36.6	35.9	35.2	34.6	33.9	33.2	960
980	40.3	39.4	38.6	37.8	37.0	36.3	35.6	34.9	34.2	33.6	970
990	40.8	39.9	39.0	38.2	37.4	36.6	35.9	35.3	34.6	33.9	980
1000	41.2	40.3	39.4	38.6	37.8	37.0	36.3	35.6	34.9	34.3	990
1000	41.6	40.7	39.8	39.0	38.2	37.4	36.7	36.0	35.3	34.6	1000

* For other pressures the corrections to be applied are in proportion.

TABLE V

REDUCTION OF PRESSURE IN MERCURY-INCHES TO MEAN SEA LEVEL
Reading at Station Level, 27 in.

Height in feet.	AIR TEMPERATURE. (Dry bulb in screen.)										Height in feet.
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	
10	·011	·011	·011	·010	·010	·010	·010	·009	·009	·009	10
20	·023	·022	·021	·021	·021	·020	·020	·019	·019	·018	20
30	·034	·033	·032	·032	·031	·030	·029	·029	·028	·028	30
40	·044	·043	·042	·041	·040	·040	·039	·038	·038	·037	40
50	·056	·054	·053	·052	·050	·049	·049	·048	·047	·046	50
60	·067	·065	·064	·062	·061	·059	·058	·058	·056	·055	60
70	·078	·076	·075	·073	·071	·069	·068	·067	·066	·064	70
80	·088	·086	·085	·083	·082	·080	·078	·076	·075	·073	80
90	·100	·097	·096	·094	·092	·091	·088	·085	·085	·083	90
100	·111	·108	·106	·104	·102	·100	·097	·096	·094	·091	100
110	·122	·119	·116	·115	·112	·110	·107	·105	·103	·101	110
120	·133	·130	·127	·124	·123	·120	·117	·116	·113	·110	120
130	·143	·140	·138	·135	·132	·129	·126	·123	·121	·120	130
140	·154	·151	·148	·145	·143	·139	·136	·133	·132	·129	140
150	·165	·162	·159	·156	·152	·148	·146	·143	·141	·138	150
160	·176	·173	·170	·166	·162	·159	·156	·153	·150	·147	160
170	·188	·184	·180	·177	·172	·169	·166	·162	·160	·156	170
180	·199	·194	·191	·186	·182	·178	·175	·172	·168	·166	180
190	·210	·205	·201	·196	·193	·188	·184	·182	·178	·175	190
200	·221	·216	·211	·207	·202	·199	·195	·191	·188	·184	200
210	·232	·227	·221	·217	·212	·209	·204	·201	·197	·193	210
220	·243	·238	·232	·228	·223	·219	·214	·211	·207	·203	220
230	·254	·248	·243	·238	·233	·229	·224	·220	·217	·212	230
240	·265	·259	·254	·249	·244	·238	·234	·229	·226	·222	240
250	·275	·270	·265	·259	·254	·248	·244	·239	·236	·232	250
260	·287	·281	·275	·269	·264	·258	·254	·250	·245	·241	260
270	·298	·292	·286	·280	·274	·269	·264	·260	·255	·250	270
280	·310	·302	·297	·290	·284	·279	·274	·269	·264	·260	280
290	·320	·313	·308	·301	·295	·290	·284	·279	·274	·269	290
300	·332	·324	·319	·310	·305	·300	·294	·289	·283	·278	300
310	·344	·336	·329	·321	·315	·310	·304	·299	·292	·287	310
320	·355	·346	·340	·332	·326	·320	·314	·309	·301	·296	320
330	·366	·358	·351	·343	·336	·329	·323	·318	·311	·306	330
340	·377	·369	·362	·354	·346	·338	·333	·328	·320	·315	340
350	·389	·381	·373	·364	·356	·348	·343	·337	·329	·324	350
360	·400	·391	·383	·374	·366	·358	·353	·346	·339	·333	360
370	·410	·402	·393	·385	·377	·369	·363	·355	·349	·342	370
380	·421	·413	·403	·395	·387	·379	·372	·365	·358	·352	380
390	·432	·424	·414	·406	·398	·390	·382	·374	·368	·361	390
400	·443	·435	·424	·416	·408	·400	·391	·383	·378	·370	400
410	·454	·446	·435	·427	·418	·409	·401	·393	·387	·379	410
420	·465	·456	·445	·437	·428	·420	·411	·403	·396	·388	420
430	·477	·467	·456	·448	·438	·430	·420	·412	·406	·398	430
440	·488	·478	·467	·459	·449	·441	·430	·422	·415	·407	440
450	·499	·489	·478	·470	·459	·451	·440	·432	·424	·416	450
460	·511	·499	·489	·480	·469	·461	·450	·442	·434	·426	460
470	·522	·510	·499	·490	·480	·471	·461	·452	·444	·436	470
480	·534	·521	·510	·500	·490	·480	·471	·461	·453	·445	480
490	·544	·532	·521	·511	·500	·490	·481	·471	·463	·454	490
500	·556	·543	·532	·521	·510	·499	·491	·481	·473	·464	500

TABLE V—*continued*

REDUCTION OF PRESSURE IN MERCURY-INCHES TO MEAN SEA LEVEL
Reading at Station Level, 27 in.

Height in feet.	AIR TEMPERATURE. (Dry bulb in screen.)										Height in feet.
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	
500	·556	·543	·532	·521	·510	·499	·491	·481	·473	·464	500
510	·568	·554	·543	·532	·520	·509	·501	·490	·482	·473	510
520	·579	·565	·553	·543	·531	·520	·511	·500	·492	·482	520
530	·591	·577	·564	·554	·541	·530	·520	·509	·501	·492	530
540	·601	·588	·575	·564	·552	·541	·530	·519	·511	·501	540
550	·613	·599	·586	·575	·562	·551	·540	·529	·521	·510	550
560	·624	·610	·597	·585	·572	·561	·550	·539	·530	·519	560
570	·634	·621	·607	·596	·582	·571	·561	·549	·539	·528	570
580	·645	·632	·618	·606	·592	·581	·571	·558	·549	·538	580
590	·656	·643	·629	·617	·603	·592	·581	·568	·558	·547	590
600	·667	·653	·640	·626	·613	·602	·591	·578	·567	·556	600
610	·677	·665	·651	·637	·624	·612	·601	·588	·577	·566	610
620	·689	·676	·662	·648	·634	·623	·611	·598	·587	·576	620
630	·701	·688	·672	·659	·645	·633	·620	·607	·596	·585	630
640	·712	·698	·683	·670	·656	·643	·630	·616	·606	·595	640
650	·724	·710	·694	·680	·667	·653	·640	·626	·616	·605	650
660	·735	·721	·705	·690	·677	·663	·650	·636	·625	·614	660
670	·746	·732	·715	·701	·688	·673	·660	·647	·635	·623	670
680	·758	·742	·726	·711	·697	·682	·669	·657	·644	·633	680
690	·769	·753	·737	·722	·708	·692	·679	·668	·654	·642	690
700	·780	·764	·748	·732	·718	·702	·688	·678	·664	·651	700
710	·792	·776	·759	·742	·728	·712	·698	·688	·674	·661	710
720	·803	·787	·769	·753	·739	·723	·709	·697	·684	·670	720
730	·815	·798	·780	·764	·749	·733	·719	·706	·693	·679	730
740	·825	·809	·791	·775	·760	·743	·730	·716	·703	·689	740
750	·837	·821	·802	·786	·769	·753	·740	·726	·713	·699	750
760	·849	·832	·813	·796	·779	·763	·750	·736	·722	·708	760
770	·859	·842	·823	·807	·790	·774	·760	·746	·731	·717	770
780	·871	·853	·834	·818	·800	·784	·769	·755	·741	·727	780
790	·882	·864	·845	·829	·811	·795	·778	·765	·750	·736	790
800	·894	·875	·856	·840	·821	·805	·788	·775	·759	·745	800
810	·905	·886	·867	·850	·832	·814	·798	·785	·769	·755	810
820	·916	·897	·877	·860	·842	·825	·809	·795	·778	·765	820
830	·928	·909	·888	·870	·853	·835	·819	·804	·787	·774	830
840	·939	·920	·899	·881	·864	·846	·830	·814	·797	·784	840
850	·950	·931	·910	·891	·875	·856	·840	·823	·807	·794	850
860	·962	·942	·922	·902	·885	·866	·850	·833	·817	·803	860
870	·974	·953	·932	·913	·895	·877	·860	·843	·827	·812	870
880	·986	·964	·944	·923	·905	·886	·870	·852	·836	·822	880
890	·998	·975	·955	·934	·916	·897	·881	·862	·846	·831	890
900	1·010	·985	·967	·945	·926	·907	·891	·872	·856	·840	900
910	1·021	·997	·977	·956	·936	·917	·901	·883	·866	·850	910
920	1·032	1·008	·988	·967	·947	·928	·911	·893	·876	·859	920
930	1·044	1·020	·999	·977	·957	·938	·920	·903	·885	·868	930
940	1·055	1·030	1·010	·988	·967	·949	·930	·913	·895	·878	940
950	1·066	1·042	1·021	·999	·977	·958	·940	·924	·904	·888	950
960	1·078	1·054	1·031	1·010	·988	·968	·950	·933	·914	·897	960
970	1·089	1·065	1·042	1·021	·999	·979	·960	·942	·924	·906	970
980	1·101	1·076	1·053	1·031	1·010	·989	·970	·952	·934	·916	980
990	1·111	1·087	1·064	1·042	1·021	1·000	·981	·962	·943	·925	990
1000	1·123	1·099	1·075	1·053	1·031	1·010	·991	·972	·953	·934	1000

TABLE V—*continued*

REDUCTION OF PRESSURE IN MERCURY-INCHES TO MEAN SEA LEVEL
Reading at Station Level, **30 in.**

Height in feet.	AIR TEMPERATURE. (Dry bulb in screen.)										Height in feet.
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	
10	·012	·012	·012	·011	·011	·011	·011	·010	·010	·010	10
20	·025	·024	·023	·023	·023	·022	·022	·021	·021	·020	20
30	·037	·036	·035	·035	·034	·033	·032	·032	·031	·031	30
40	·049	·048	·047	·046	·045	·044	·043	·042	·042	·041	40
50	·062	·060	·059	·058	·056	·055	·054	·053	·052	·051	50
60	·074	·072	·071	·069	·068	·066	·065	·064	·062	·061	60
70	·086	·084	·083	·081	·079	·077	·076	·074	·073	·071	70
80	·098	·096	·094	·092	·091	·089	·087	·085	·083	·081	80
90	·111	·108	·106	·104	·102	·101	·098	·095	·094	·092	90
100	·123	·120	·118	·115	·113	·111	·108	·106	·104	·101	100
110	·135	·132	·129	·127	·124	·122	·119	·116	·114	·112	110
120	·147	·144	·141	·138	·136	·133	·130	·127	·125	·122	120
130	·159	·156	·153	·150	·147	·143	·140	·137	·135	·133	130
140	·171	·168	·164	·161	·158	·154	·151	·148	·146	·143	140
150	·183	·180	·176	·173	·169	·165	·162	·159	·156	·153	150
160	·196	·192	·188	·184	·180	·176	·173	·170	·166	·163	160
170	·209	·204	·200	·196	·191	·187	·184	·180	·177	·173	170
180	·221	·216	·212	·207	·202	·198	·195	·191	·187	·184	180
190	·233	·228	·223	·218	·214	·209	·205	·202	·198	·194	190
200	·246	·240	·235	·230	·225	·221	·217	·212	·209	·205	200
210	·258	·252	·246	·241	·236	·232	·227	·223	·219	·215	210
220	·270	·264	·258	·253	·248	·243	·238	·234	·230	·226	220
230	·282	·276	·270	·265	·259	·254	·249	·245	·241	·236	230
240	·294	·288	·282	·277	·271	·265	·260	·255	·251	·247	240
250	·306	·300	·294	·288	·282	·276	·271	·266	·262	·258	250
260	·319	·312	·306	·299	·293	·287	·282	·278	·272	·268	260
270	·331	·324	·318	·311	·305	·299	·293	·289	·283	·278	270
280	·344	·336	·330	·322	·316	·310	·305	·299	·293	·289	280
290	·356	·348	·342	·334	·328	·322	·316	·310	·304	·299	290
300	·369	·360	·354	·345	·339	·333	·327	·321	·315	·309	300
310	·382	·373	·366	·357	·350	·344	·338	·332	·325	·319	310
320	·394	·385	·378	·369	·362	·355	·349	·343	·335	·329	320
330	·407	·398	·390	·381	·373	·365	·359	·353	·346	·340	330
340	·419	·410	·402	·393	·385	·376	·370	·364	·356	·350	340
350	·432	·423	·414	·405	·396	·387	·381	·375	·366	·360	350
360	·444	·435	·425	·416	·407	·398	·392	·385	·377	·370	360
370	·456	·447	·437	·428	·419	·410	·403	·395	·388	·380	370
380	·468	·459	·448	·439	·430	·421	·413	·406	·398	·391	380
390	·480	·471	·460	·451	·442	·433	·424	·416	·409	·401	390
400	·492	·483	·471	·462	·453	·444	·435	·426	·420	·411	400
410	·505	·495	·483	·474	·464	·455	·446	·437	·430	·421	410
420	·517	·507	·495	·486	·476	·467	·457	·448	·440	·431	420
430	·530	·519	·507	·498	·487	·478	·467	·458	·451	·442	430
440	·542	·531	·519	·510	·499	·490	·478	·469	·461	·452	440
450	·555	·543	·531	·522	·510	·501	·489	·480	·471	·462	450
460	·568	·555	·543	·533	·521	·512	·500	·491	·482	·473	460
470	·580	·567	·555	·545	·533	·523	·512	·502	·493	·484	470
480	·593	·579	·567	·556	·544	·533	·523	·512	·503	·494	480
490	·605	·591	·579	·568	·556	·544	·535	·523	·514	·505	490
500	·618	·603	·591	·579	·567	·555	·546	·534	·525	·516	500

TABLE V—*continued*

REDUCTION OF PRESSURE IN MERCURY-INCHES TO MEAN SEA LEVEL
Reading at Station Level, **30 in.**

Height in feet.	AIR TEMPERATURE. (Dry bulb in screen.)										Height in feet.
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	
500	.618	.603	.591	.579	.567	.555	.546	.534	.525	.516	500
510	.631	.616	.603	.591	.578	.566	.557	.545	.536	.526	510
520	.643	.628	.615	.603	.590	.578	.568	.556	.547	.536	520
530	.656	.641	.627	.615	.601	.589	.578	.566	.557	.547	530
540	.668	.653	.639	.627	.613	.601	.589	.577	.568	.557	540
550	.681	.666	.651	.639	.624	.612	.600	.588	.579	.567	550
560	.693	.678	.663	.650	.635	.623	.611	.599	.589	.577	560
570	.705	.690	.675	.662	.647	.635	.623	.610	.599	.587	570
580	.717	.702	.687	.673	.658	.646	.634	.620	.610	.598	580
590	.729	.714	.699	.685	.670	.658	.646	.631	.620	.608	590
600	.741	.726	.711	.696	.681	.669	.657	.642	.630	.618	600
610	.754	.739	.723	.708	.693	.680	.668	.653	.641	.629	610
620	.766	.751	.735	.720	.705	.692	.679	.664	.652	.640	620
630	.779	.764	.747	.732	.717	.703	.689	.674	.662	.650	630
640	.791	.776	.759	.744	.729	.715	.700	.685	.673	.661	640
650	.804	.789	.771	.756	.741	.726	.711	.696	.684	.672	650
660	.817	.801	.783	.767	.752	.737	.722	.707	.695	.682	660
670	.829	.813	.795	.779	.764	.748	.733	.719	.706	.692	670
680	.842	.825	.807	.790	.775	.758	.743	.730	.716	.703	680
690	.854	.837	.819	.802	.787	.769	.754	.742	.727	.713	690
700	.867	.849	.831	.813	.798	.780	.765	.753	.738	.723	700
710	.880	.862	.843	.825	.809	.791	.776	.764	.749	.734	710
720	.892	.874	.855	.837	.821	.803	.788	.775	.760	.745	720
730	.905	.887	.867	.849	.832	.814	.799	.785	.770	.755	730
740	.917	.899	.879	.861	.844	.826	.811	.796	.781	.766	740
750	.930	.912	.891	.873	.855	.837	.822	.807	.792	.777	750
760	.943	.924	.903	.885	.866	.848	.833	.818	.802	.787	760
770	.955	.936	.915	.897	.878	.860	.844	.829	.812	.797	770
780	.968	.948	.927	.909	.889	.871	.854	.839	.823	.808	780
790	.980	.960	.939	.921	.901	.883	.865	.850	.833	.818	790
800	.993	.972	.951	.933	.912	.894	.876	.861	.843	.828	800
810	1.006	.985	.963	.944	.924	.905	.887	.872	.854	.839	810
820	1.018	.997	.975	.956	.936	.917	.899	.883	.865	.850	820
830	1.031	1.010	.987	.967	.948	.928	.910	.893	.875	.860	830
840	1.043	1.022	.999	.979	.960	.940	.922	.904	.886	.871	840
850	1.056	1.035	1.011	.990	.972	.951	.933	.915	.897	.882	850
860	1.069	1.047	1.024	1.002	.983	.962	.944	.926	.908	.892	860
870	1.082	1.059	1.036	1.014	.995	.974	.956	.937	.919	.902	870
880	1.096	1.071	1.049	1.026	1.006	.985	.967	.947	.929	.913	880
890	1.109	1.083	1.061	1.038	1.018	.997	.979	.958	.940	.923	890
900	1.122	1.095	1.074	1.050	1.029	1.008	.990	.969	.951	.933	900
910	1.135	1.108	1.086	1.062	1.040	1.019	1.001	.980	.962	.944	910
920	1.147	1.120	1.098	1.074	1.052	1.031	1.012	.992	.973	.955	920
930	1.160	1.133	1.110	1.086	1.063	1.042	1.022	1.003	.983	.965	930
940	1.172	1.145	1.122	1.098	1.075	1.054	1.033	1.015	.994	.976	940
950	1.185	1.158	1.134	1.110	1.086	1.065	1.044	1.026	1.005	.987	950
960	1.198	1.171	1.146	1.122	1.098	1.076	1.055	1.037	1.016	.997	960
970	1.210	1.183	1.158	1.134	1.110	1.088	1.067	1.048	1.027	1.007	970
980	1.223	1.196	1.170	1.146	1.122	1.099	1.078	1.058	1.037	1.018	980
990	1.235	1.208	1.182	1.158	1.134	1.111	1.090	1.069	1.048	1.028	990
1000	1.248	1.221	1.194	1.170	1.146	1.122	1.101	1.080	1.059	1.038	1000

TABLE VI

CORRECTIONS FOR REDUCING BAROMETRIC READINGS TO STANDARD
GRAVITY IN LATITUDE 45°

For latitudes 0° to 44° the correction is to be *subtracted*.

For latitudes 46° to 90° the correction is to be *added*.

Latitude N. or S.		Pressure in millibars.			Pressure in mercury-inches.				Latitude N. or S.	
		950	1000	1050	28	29	30	31		
°	°	Corrections (millibars)			Corrections (mercury-inches)				°	°
45	45	-00	-00	-00	-000	-000	-000	-000	45	45
44	46	-09	-09	-09	-003	-003	-003	-003	44	46
43	47	-17	-18	-19	-005	-005	-005	-006	43	47
42	48	-26	-27	-28	-008	-008	-008	-008	42	48
41	49	-34	-36	-38	-010	-010	-011	-011	41	49
40	50	-43	-45	-47	-013	-013	-013	-014	40	50
39	51	-51	-54	-57	-015	-016	-016	-017	39	51
38	52	-60	-63	-66	-018	-018	-019	-019	38	52
37	53	-67	-71	-75	-020	-021	-021	-022	37	53
36	54	-76	-80	-84	-022	-023	-024	-025	36	54
35	55	-85	-89	-93	-025	-026	-027	-027	35	55
34	56	-92	-97	-102	-027	-028	-029	-030	34	56
33	57	-100	-105	-110	-029	-031	-032	-033	33	57
32	58	-108	-114	-120	-032	-033	-034	-035	32	58
31	59	-116	-122	-128	-034	-035	-036	-038	31	59
30	60	-124	-130	-137	-036	-038	-039	-040	30	60
29	61	-130	-137	-144	-038	-040	-041	-043	29	61
28	62	-138	-145	-152	-041	-042	-043	-045	28	62
27	63	-144	-152	-160	-043	-044	-046	-047	27	63
26	64	-151	-159	-167	-045	-046	-048	-049	26	64
25	65	-158	-166	-174	-047	-048	-050	-052	25	65
24	66	-164	-173	-182	-049	-050	-052	-054	24	66
23	67	-171	-180	-189	-050	-052	-054	-056	23	67
22	68	-177	-186	-195	-052	-054	-056	-058	22	68
21	69	-182	-192	-202	-054	-056	-058	-060	21	69
20	70	-188	-198	-208	-056	-058	-060	-062	20	70
19	71	-194	-204	-214	-057	-059	-061	-063	19	71
18	72	-200	-210	-221	-059	-061	-063	-065	18	72
17	73	-204	-215	-226	-060	-062	-064	-067	17	73
16	74	-209	-220	-231	-061	-064	-066	-068	16	74
15	75	-213	-224	-235	-063	-065	-067	-070	15	75
14	76	-218	-229	-240	-064	-066	-069	-071	14	76
13	77	-221	-233	-245	-065	-068	-070	-072	13	77
12	78	-225	-237	-249	-066	-069	-071	-073	12	78
11	79	-228	-240	-252	-067	-070	-072	-074	11	79
10	80	-231	-243	-255	-068	-071	-073	-075	10	80
9	81	-234	-246	-258	-069	-071	-074	-076	9	81
8	82	-236	-249	-261	-070	-072	-075	-077	8	82
7	83	-238	-251	-264	-070	-073	-075	-078	7	83
6	84	-240	-253	-266	-071	-073	-076	-079	6	84
5	85	-242	-255	-268	-071	-074	-077	-079	5	85
4	86	-243	-256	-269	-072	-074	-077	-080	4	86
3	87	-244	-257	-270	-072	-075	-077	-080	3	87
2	88	-245	-258	-271	-072	-075	-078	-080	2	88
1	89	-246	-259	-272	-072	-075	-078	-080	1	89
0	90	-246	-259	-272	-073	-075	-078	-080	0	90

TABLE VII

TABLE FOR COMPUTING THE VELOCITY-HEIGHT RATIO OF CLOUDS IN
RADIAN PER HOUR FROM FINEMAN NEPHOSCOPE READINGS

Height of pointer in milli- metres.	Time in seconds for the image to travel from one circle to the next.																		
	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200			
30	60	50	43	37	33	30	27	25	23	21	20	19	18	17	16	15			
32	56	47	40	35	31	28	26	23	22	20	19	18	17	16	15	14			
34	53	44	38	33	29	26	24	22	20	19	18	17	16	15	14	13			
36	50	42	36	31	28	25	23	21	19	18	17	16	15	14	13	12			
38	47	39	34	30	26	24	22	20	18	17	16	15	14	13	12	12			
40	45	37	32	28	25	23	21	19	17	16	15	14	13	13	12	11			
42	43	36	31	27	24	21	19	18	16	15	14	13	13	12	11	11			
44	41	34	29	26	23	20	19	17	16	15	14	13	12	11	11	10			
46	39	33	28	24	22	20	18	16	15	14	13	12	12	11	10	10			
48	38	31	27	23	21	19	17	16	14	13	13	12	11	10	9.9	9.4			
50	36	30	26	22	20	18	16	15	14	13	12	11	11	10	9.5	9.0			
52	35	29	25	22	19	17	16	14	13	13	12	11	10	9.6	9.1	8.7			
54	33	28	24	21	19	17	15	14	13	12	11	10	9.8	9.3	8.8	8.3			
56	32	27	23	20	18	16	15	13	12	12	11	10	9.5	9.0	8.5	8.0			
58	31	26	22	19	17	15	14	13	12	11	10	9.7	9.1	8.6	8.1	7.8			
60	30	25	21	19	17	15	14	13	12	11	10	9.4	8.8	8.3	7.9	7.5			
62	29	24	21	18	16	15	13	12	11	10	9.7	9.1	8.5	8.1	7.6	7.3			
64	28	23	20	18	16	14	13	12	11	10	9.4	8.8	8.3	7.8	7.4	7.0			
66	27	23	19	17	15	14	12	11	10	9.8	9.1	8.5	8.0	7.6	7.2	6.8			
68	26	22	19	17	15	13	12	11	10	9.5	8.8	8.3	7.8	7.4	7.0	6.6			
70	26	21	18	16	14	13	12	11	9.9	9.2	8.6	8.0	7.5	7.1	6.8	6.4			
72	25	21	18	16	14	13	11	10	9.6	8.9	8.3	7.8	7.3	6.9	6.6	6.2			
74	24	20	17	15	14	12	11	10	9.4	8.7	8.1	7.6	7.1	6.8	6.4	6.1			
76	24	20	17	15	13	12	11	9.9	9.1	8.5	7.9	7.4	7.0	6.6	6.2	5.9			
78	23	19	16	14	13	12	10	9.6	8.9	8.3	7.7	7.2	6.8	6.4	6.1	5.8			
80	23	19	16	14	13	11	10	9.4	8.8	8.0	7.5	7.0	6.6	6.3	5.9	5.6			

The difference between the radii of two consecutive circles on the mirror is 25 mm.

NOTE.—If the observed time of passage of the cloud image from one circle to the next falls outside the limits of the table, multiply the observed time by a simple factor so as to bring it within the compass of the table and multiply the corresponding tabulated value of the velocity-height ratio by the same factor in order to obtain the required result. A similar rule can be applied if the observed height of the pointer falls outside the range of the table.

The operation of the instrument is described on p. 84.

APPENDIX I

METHOD OF PREPARATION OF BAROMETER REDUCTION
CARDS FROM TABLES

In preparing reduction cards the corrections may be combined together in various ways, but in general at least two operations are necessary to arrive at the pressure at sea level, as allowance has to be made for three factors which have to be observed on each occasion, viz., the temperature of the attached thermometer, the temperature of the air (dry bulb in screen) and the reading of the barometer. It is only in the case of stations at heights up to about 500 ft. that all the corrections can be combined into a single table as described on page 19. We proceed to give a brief account of the preparation of such cards.

(1) If it is desired to work out the corrected pressure both at station level and at sea level, it will be convenient to combine into a single table the corrections for index error, temperature and latitude.

We proceed as follows:—

Set out from the certificate the corrections for index error, converted if necessary into millibars by the table given on p. 17, and the appropriate correction for latitude from Table VI, and add the results, paying due regard to the signs of the corrections.

Barometer M.O. 72, for use in latitude 60° N.

Pressure (mb.) ...	920	940	960	980	1000	1020	1040
Standard temperature (°A) as in N.P.L. Certificate,	284.9	284.7	284.6	284.4	284.4	284.3	284.2
Equivalent correction in millibars...	— .02	— .04	— .06	— .09	— .11	— .13	— .14
Correction for latitude (Table VI)...	+1.20	+1.22	+1.25	+1.28	+1.30	+1.32	+1.35
Sums ...	+1.18	+1.18	+1.19	+1.19	+1.19	+1.19	+1.21

The values so found are then algebraically added to the corrections for temperature (Table II), remembering that these corrections are *positive* for temperatures below 285°A, and *negative* for temperatures above that limit. The table takes the form (some lines being omitted for brevity of illustration):—

COMBINED CORRECTION FOR INDEX ERROR, TEMPERATURE AND
LATITUDE

Attached thermometer.	Barometer reading (mb.).						
	920	940	960	980	1000	1020	1040
°A							
273	+3.08	+3.11	+3.16	+3.20	+3.24	+3.28	+3.34
*	*	*	*	*	*	*	*
280	1.97	1.99	2.01	2.03	2.05	2.06	2.10
281	1.81	1.82	1.85	1.86	1.87	1.89	1.92
282	1.65	1.66	1.68	1.69	1.70	1.71	1.74
283	1.50	1.50	1.52	1.53	1.53	1.54	1.57
284	1.34	1.34	1.35	1.36	1.36	1.36	1.39
285	1.18	1.18	1.19	1.19	1.19	1.19	1.21
286	1.02	1.02	1.03	1.02	1.02	1.02	1.03
287	.86	.86	.86	.85	.85	.84	.85
288	.71	.70	.70	.69	.68	.67	.68
289	.55	.54	.53	.52	.51	.49	.50
*	*	*	*	*	*	*	*
293	—0.08	—0.11	—0.13	—0.15	—0.18	—0.20	—0.21
*	*	*	*	*	*	*	*

The table should be compiled for the range of temperature likely to be experienced in the room in which the barometer is hung. In the final table intended for daily use the corrections should be rounded to the *nearest tenth* of a millibar, but in preparing the table the figures should be worked to hundredths of a millibar. These corrections when applied to the observed reading will give the corrected reading at station level. If pressure at mean sea level is also required a second table giving the reduction appropriate to the height should be prepared from Table IV for suitable ranges of dry-bulb temperature and pressure. For example, for a station at 277 ft. we have the following table :—

REDUCTION TO MEAN SEA LEVEL

Dry Bulb.	Barometer reading (mb.).						
	920	940	960	980	1000	1020	1040
0°	10·4	10·6	10·8	11·1	11·3	11·6	11·8
10	10·3	10·5	10·7	10·9	11·1	11·4	11·6
20	10·0	10·2	10·4	10·6	10·9	11·1	11·2
30	9·8	10·0	10·2	10·4	10·6	10·8	11·0
40	9·6	9·8	10·0	10·2	10·4	10·6	10·8
50	9·4	9·6	9·8	10·0	10·2	10·4	10·6
60	9·2	9·4	9·6	9·8	10·0	10·2	10·4
70	9·1	9·3	9·5	9·7	9·9	10·1	10·3
80	8·9	9·1	9·3	9·5	9·7	9·9	10·1
90	8·8	8·9	9·1	9·3	9·5	9·7	9·9

In preparing this table we first enter the corrections for 1000mb., the appropriate values being derived from Table IV by interpolation between the values there shown for 270 ft. and 280 ft. We next complete the columns for 920mb. and 960mb. by *subtracting* 80/1000 (or 8 per cent.) and 4 per cent. respectively from the values entered in the column for 1000mb. Similarly, the column for 1040mb. is completed by *adding* 4 per cent. to those values. The figures for the remaining columns are derived by interpolation between the values already entered.

For stations at or near sea level the tables should be constructed to cover a range of pressure from 940mb. to 1040mb. At 500 ft. tables extending from 920mb. to 1020mb. would cover all readings likely to be experienced in the British Isles.

(2) If the final values are required at mean sea level only it may be found more convenient to combine the corrections for index error and latitude with the reduction to sea level, thus enabling the figures printed in Table II to be used for the correction for temperature without alteration.

APPENDIX II

PHOTOGRAPHS OF CLOUDS

LIST OF PHOTOGRAPHS

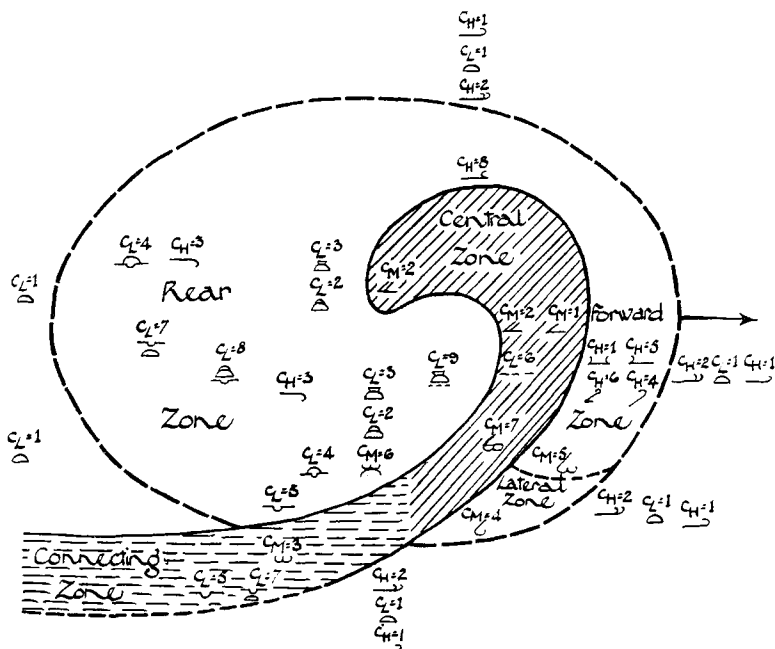
- C_L 1 Fair weather cumulus.
 C_L 2 Large cumulus without anvil.
 C_L 3 Cumulonimbus.
 C_L 4 Stratocumulus formed by the spreading out of cumulus.
 C_L 5 Layer of stratus or stratocumulus.
 C_L 6 Ragged low clouds of bad weather (or fractonimbus).
 C_L 7 Fair weather cumulus and stratocumulus.
 C_L 8 Large cumulus (or cumulonimbus) and stratocumulus.
 C_L 9 Large cumulus or cumulonimbus and ragged low clouds of bad weather.
 C_M 1 Typical altostratus (thin).
 C_M 2 Typical altostratus (thick) or nimbostratus, sun or moon invisible.
 C_M 3 Single layer of altocumulus or high stratocumulus.
 C_M 4 Altocumulus in isolated bands. Individually decreasing (often lenticular).
 C_M 5 Altocumulus in bands (increasing).
 C_M 6 Altocumulus formed from the spreading out of cumulus.
 C_M 7 Altocumulus associated with altostratus or altostratus with parts resembling altocumulus.
 C_M 8 Altocumulus castellatus (or altocumulus in ragged fragments).
 C_M 9 Altocumulus in several layers generally associated with fibrous veils and a chaotic appearance of the sky.
 C_H 1 Fine cirrus not increasing ; sparse.
 C_H 2 Fine cirrus not increasing ; abundant but not a continuous layer.
 C_H 3 Anvil cirrus (usually dense).
 C_H 4 Fine cirrus increasing ; usually in tufts.
 C_H 5 Cirrus or cirrostratus increasing ; still below 45° altitude.
 C_H 6 Cirrus or cirrostratus increasing and reaching above 45° altitude.
 C_H 7 Veil of cirrostratus covering the whole sky.
 C_H 8 Cirrostratus not increasing and not covering the whole sky.
 C_H 9 Cirrocumulus predominating, and a little cirrus.

For the purpose of reporting clouds for synoptic observation the following codes are used :—

CODE FOR FORM OF LOW CLOUD (C_L)

Code Figure	Form of Cloud
0	No low cloud
1	Fair weather Cu
2	Large Cu without anvil

SCHEMATIC DISTRIBUTION OF THE SKY AND CLOUDS ROUND A DEPRESSION



This diagram represents broadly the distribution of clouds in a depression arriving from the west in western Europe. There are considerable variations from the typical case. For example, it sometimes happens that the rear zone is much more extensive and may persist with secondary variations for several days over the same region.

NOTES

- (1) Fractocumulus may occur practically anywhere in the rear zone.
- (2) The symbols for high cloud are reproduced above in black. On charts they are in red.
- (3) The specification $C_M 8$ applies to the clouds in the forward and lateral zones and $C_M 9$ to the clouds in the central zone of a thunderstorm depression (in the British Isles usually spreading from the south in summer). They are not shown on this diagram of the distribution in a normal depression.

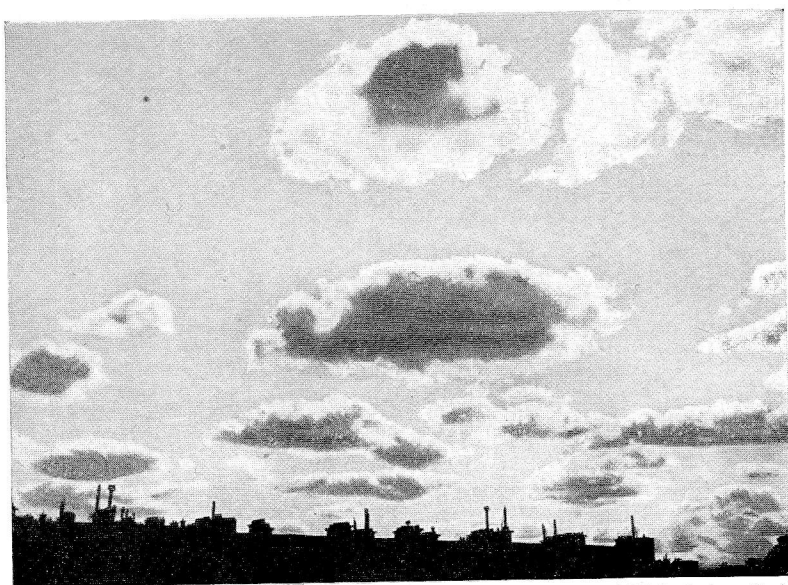


Photo by the Office National Météorologique, Paris

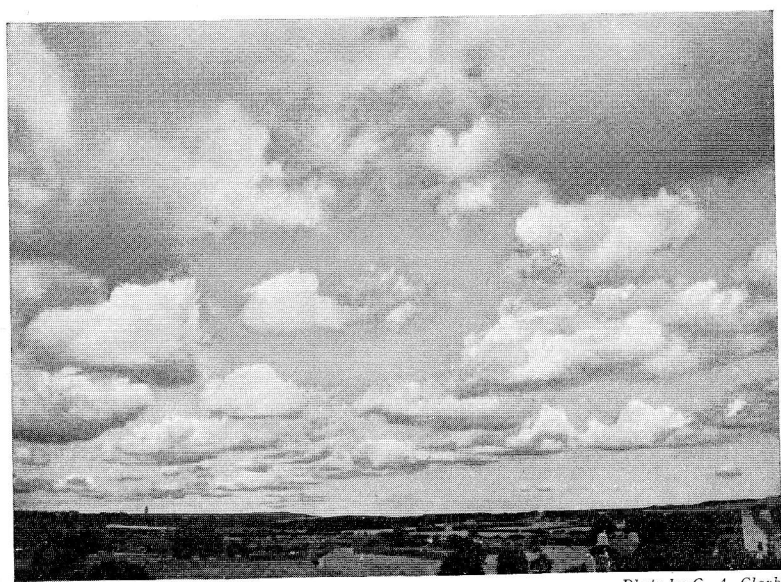


Photo by G. A. Clarke

CL1 ☼ Fair weather cumulus. The clouds look rather like cauliflowers. The bases tend to be flat and to be at a uniform level. They are scattered and have a flat and deflated appearance, even when convection is greatest in the early afternoon. Their horizontal extension is greater than the vertical. The words "Fair Weather" are not to be interpreted as a forecast; they refer to the weather at the time, and imply that there is no evidence in the sky of precipitation at the time in the neighbourhood.



Photo by the Office National Météorologique, Paris

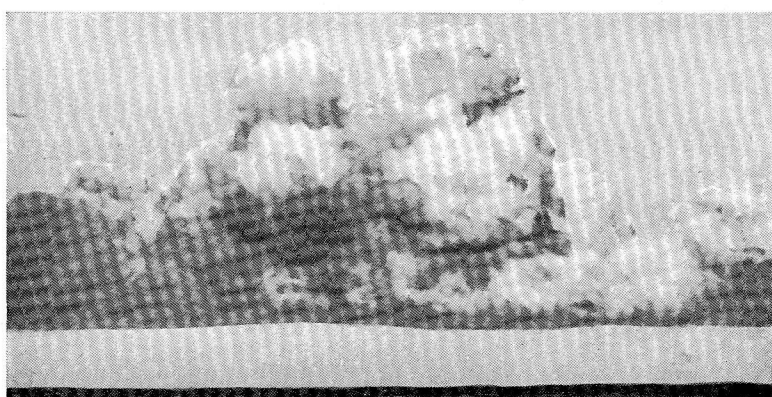


Photo by the Meteorologisch-Magnetisches Observatorium, Potsdam

C_L2  Large cumulus without anvil. The difference between these and the fair weather cumulus is that the tops of the clouds instead of remaining rounded (and apparently quiescent) begin to bulge upwards and "rising heads" appear. These can be seen clearly in both pictures. Their edges are still well defined and are not softening at the top into cirrus cloud. In the upper picture there is a patch of thick lenticular cirrostratus. This originated from the anvil of a cumulonimbus (see C_L 3). If this cumulonimbus were still in the sky, the code figure would be 3 and not 2, even though a large amount of cumulus without anvil were present.

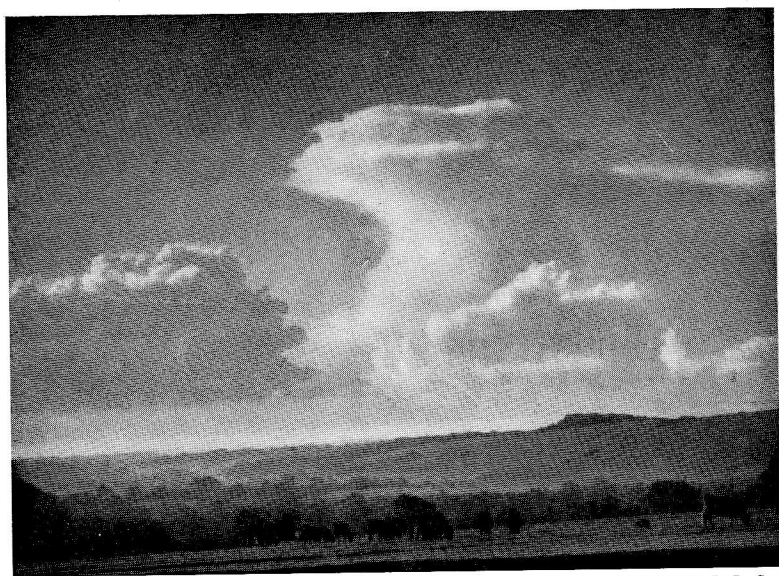


Photo by C. J. P. Cave

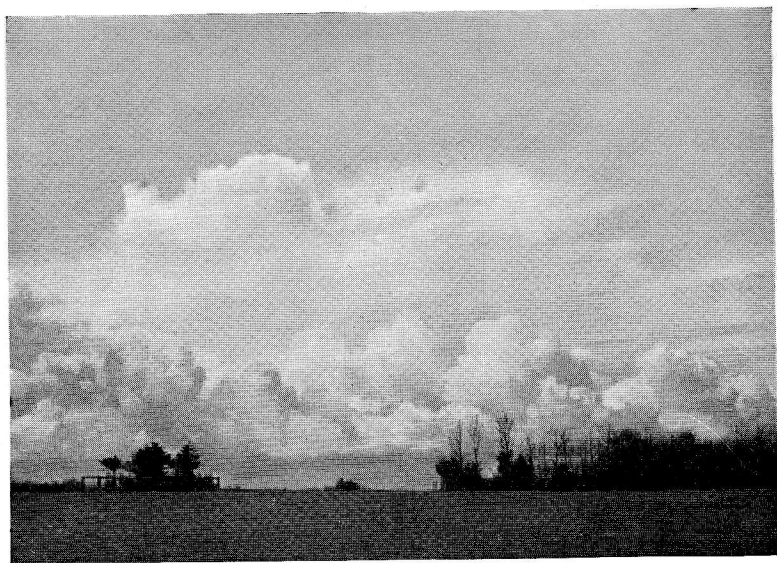
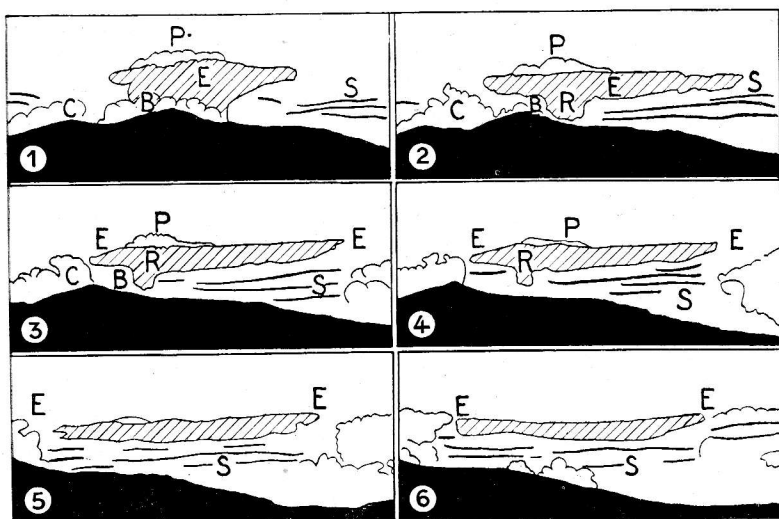


Photo by C. J. P. Cave

C_L3 ☼ Cumulonimbus. Seen at a distance the cumulonimbus is easily recognised by its veil of false cirrus so well shown in the lower photograph. From beneath, however, the clouds will appear heavy and lowering and heavy rain or hail will fall from them. The upper picture shows an anvil with cirrostratus blowing forward from the top of the cloud. (Do not confuse C_M 6 with anvil cloud. In C_M 6 the cloud which looks anvil shaped is lumpy like cumulus and not uniform like a mass of cirrus.)



Reproduced from the International Atlas of Clouds

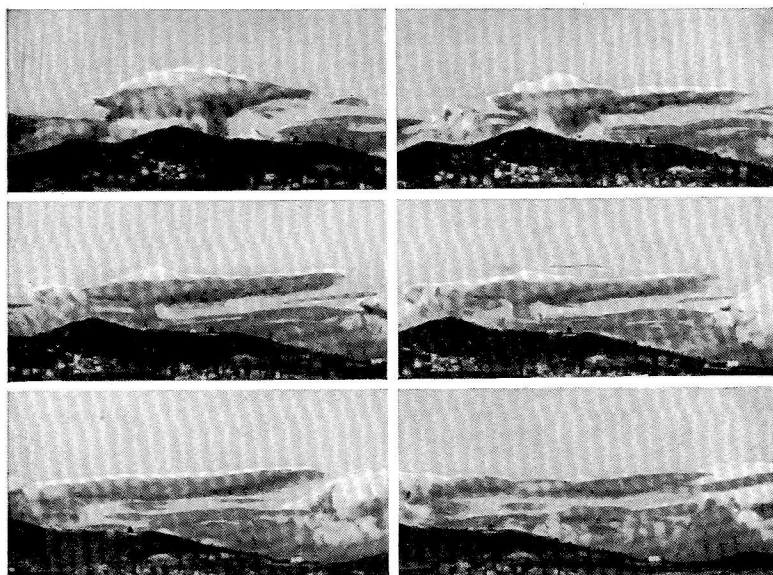


Photo by the Fundació Concepció Rabell, Barcelona

C_L 4 ☽ Stratocumulus formed by the spreading out of cumulus. This cloud is formed in two ways : (a) during the day when there is a stable layer or an inversion which the convective cumulus clouds reach and cannot penetrate ; (b) in the evening when convection weakens, with or without an inversion above the cumulus. It is most common in the evening.

"The time from the beginning to the end of the series shown is 20 minutes. 1. It is clear that the top of the cloud that is growing out is of the rounded cumulus type (B) without any cirriform parts. The spreading out has been at (E) and the head of the cumulus has penetrated the extension at (P). 2. (P) has developed a little, but (B) is decreasing and (E), which is increasing in extent, is beginning to separate off, so that the extreme base of the cloud (R) is now seen. 3. (P) grows smaller, (B) has completely settled down and is detached at (R), while (E) is still developing in extent. 4. (P) has completely settled down, (R) is melting away, (E) is completely independent. 5 and 6. There is no longer any trace of (P) or (R) while (E) is fully formed : notice the pendant shreds of cloud on the lower surface. On all the photographs other bands of stratocumulus may be seen in the distance which are being drawn out into stratus ; they probably originated in the same way."

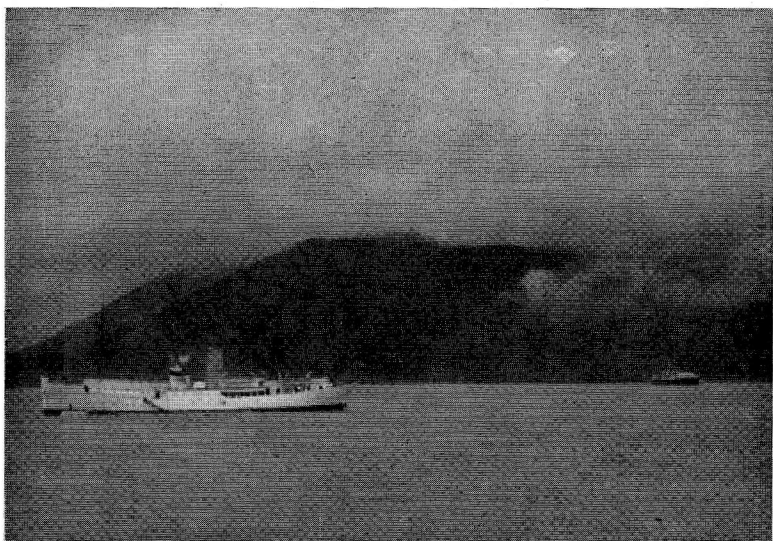


Photo by G. H. D. Evans

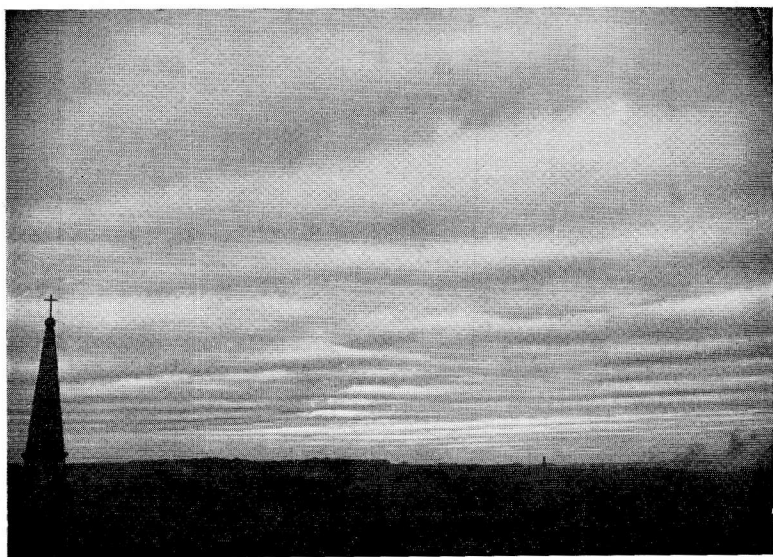


Photo by G. A. Clarke

C_L 5  Layer of stratus or stratocumulus. As will be seen from the pictures above, code figure 5 covers two very different clouds, the stratus of lifted fog and the stratocumulus which itself may present a great diversity of type. For example, stratocumulus may consist, as in the lower illustration, of wave-like lines of cloud with or without interstices; sometimes the "waves" can only just be distinguished, on other occasions the cloudsheets is broken up into cloudlets. Stratocumulus is often a dark cloud, particularly in winter, but it may be fairly light—usually when it is at a fairly high level. (If it is very high it is reported as C_M 3.) It should be noted that the cloud does not necessarily cover the whole sky.



Photo by G. A. Clarke



Photo by G. A. Clarke

C_L 6 --- Ragged low clouds of bad weather. These low clouds, collectively known as fractonimbus, often show up very dark against the relatively lighter background of altostratus or nimbostratus. The lower picture shows typical scud (fractostratus) below a background of nimbostratus; the upper picture shows, perhaps, a less typical example but nevertheless one in which the ragged low clouds are the predominant features.



Photo by G. A. Clarke



Photo by F. W. Baker

C_L 7 ☼ Fair weather cumulus and stratocumulus. The stratocumuli are at different levels and are independent. The sky is distinguished from C_L 6 or C_L 9 by the two factors: (a) that the upper of the two clouds is stratocumulus and not altostratus, nimbostratus or cumulonimbus; (b) that the lower of the two clouds is cumulus and not fractostratus or scud. In the photographs the tops of the cumulus do not reach up to the stratocumulus level. This shows that the sky is neither a C_L 4 sky nor a C_L 8.



Photo by C. J. P. Cave

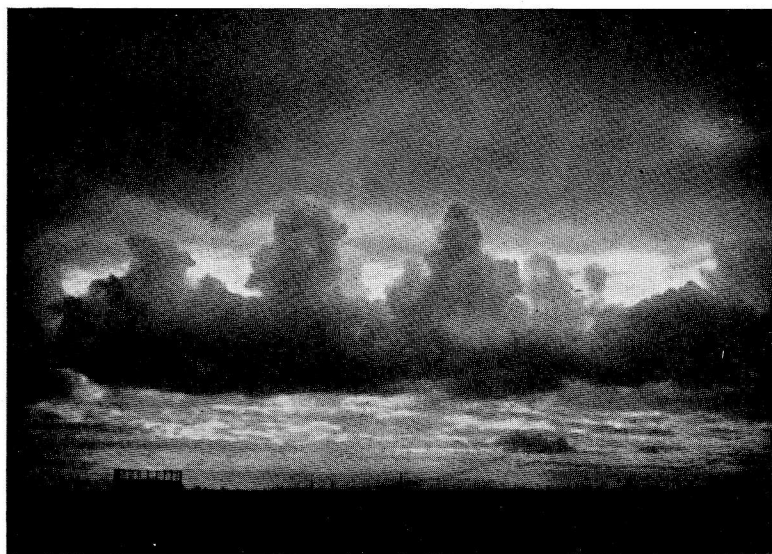


Photo by G. A. Clarke

C_L 8  Large cumulus (or cumulonimbus) and stratocumulus. In this type convection beneath the cloud has reached a greater development than in C_L 7 and the cumulus clouds reach right up to the stratocumulus layer.

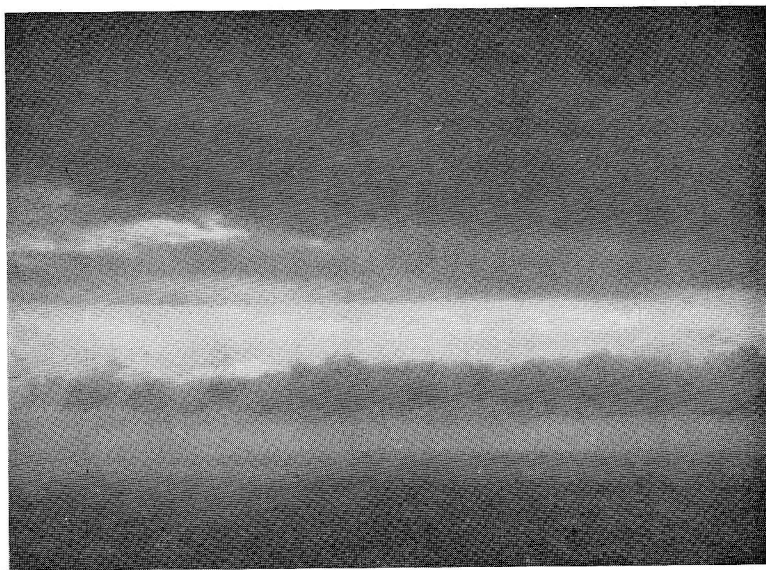


Photo by R. A. F., Detling



Photo by G. A. Clarke

C_L 9  Large cumulus (or cumulonimbus) and ragged clouds of bad weather. Beneath the base of large cumuliform cloud may often be seen scud clouds. The cumuliform cloud may be either due to intense local convection or to instability at a cold front. In the latter case, as is illustrated in the upper picture, the ragged low clouds may take the form of a roll cloud accompanying the squall. The roll may be separated or it may be joined to the cumulonimbus.

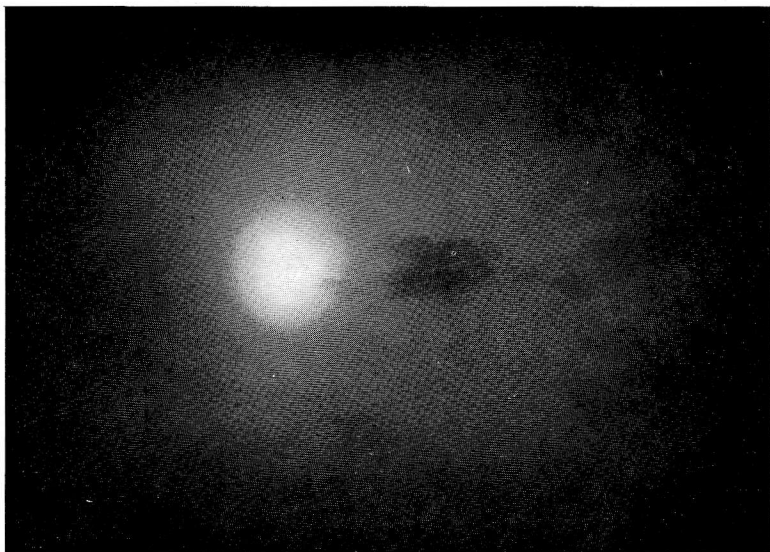


Photo by G. A. Clarke

C_M1 $\angle$ Typical altostratus (thin). This is a darkish veil usually covering the whole sky, though not always. It looks rather like a thinly fogged photographic plate. The sun or moon appears as though shining through ground glass and does not cast a shadow. Halo phenomena are not seen in altostratus. A sheet of this cloud resembles thick cirrostratus (see C_H 7) from which it is often derived.



Photo by G. A. Clarke

C_M2 $\angle$ Typical altostratus (thick) (sun and moon invisible) or nimbostratus. The sun and moon are generally hidden or are indicated only by the lighter colour of one part of the cloud. Typical thick altostratus can be formed either by a thickening of thin altostratus or by the fusing together of the cloudlets in a sheet of altocumulus. The picture illustrates an example rather on the thin side ; in many cases the lightness will be less evident or will not appear at all.

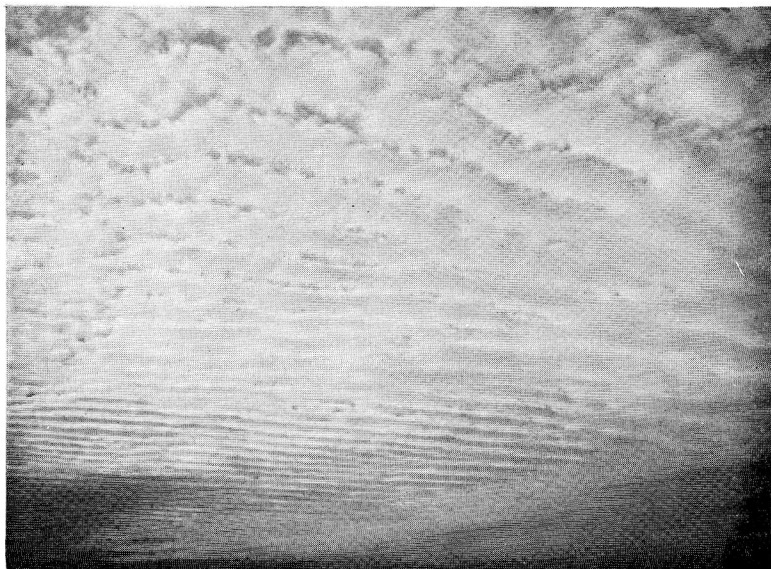


Photo by G. A. Clarke

C_M 3 ☽ Single layer of altocumulus or high stratocumulus. Altocumulus often looks like sheep's fleeces. This type generally forms a single layer; it is fairly regular, and of uniform thickness, the cloudlets always being separated by clear spaces or lighter gaps; the cloudlets are neither very large nor very dark. This layer is generally fairly persistent, it does not change or disappear quickly. Cases of altocumulus which are so dense that the waves do not show lighter parts should be reported as C_M 7.



Photo by G. A. Clarke

C_M 4 ☾ Altocumulus in isolated patches—often lenticular. The cloudlets may be as small as cirrocumulus, but lenticular altocumulus shows delicate colouring (irisation). Where this is so, the clouds are often scattered over the sky quite irregularly and may be at different levels. Though individually they may be changing, the amount of cloud over the whole sky generally remains about the same.

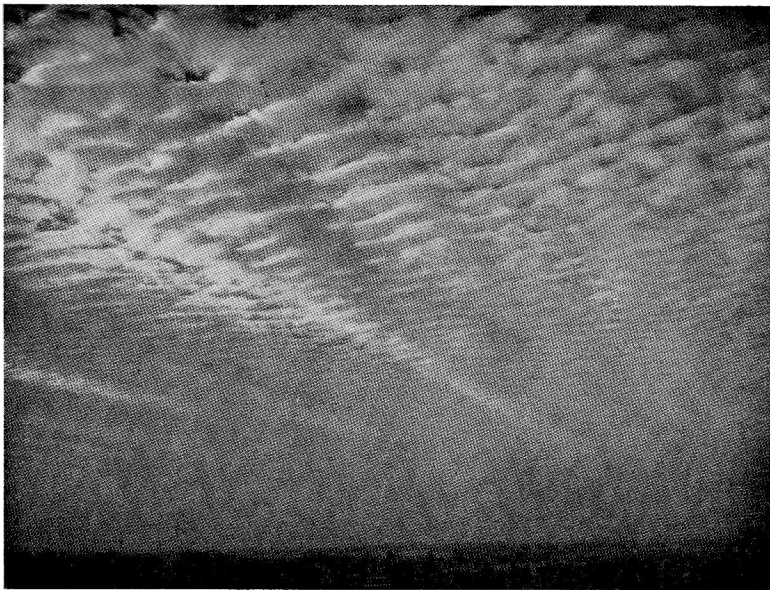


Photo by Lindenberg Observatory

C_M5 ☞ Altocumulus in bands (increasing). In this type either the bands are great elongated masses, sometimes appearing rather dark, often of a roughly lenticular shape, or the ordinary altocumulus waves are crossed by blue lanes, so that they appear like bands (with the waves across the bands). An essential feature of this type is that the sky becomes more and more covered. Often the layer thickens up as in the photograph or has another layer of cloud lower and darker forming beneath it.

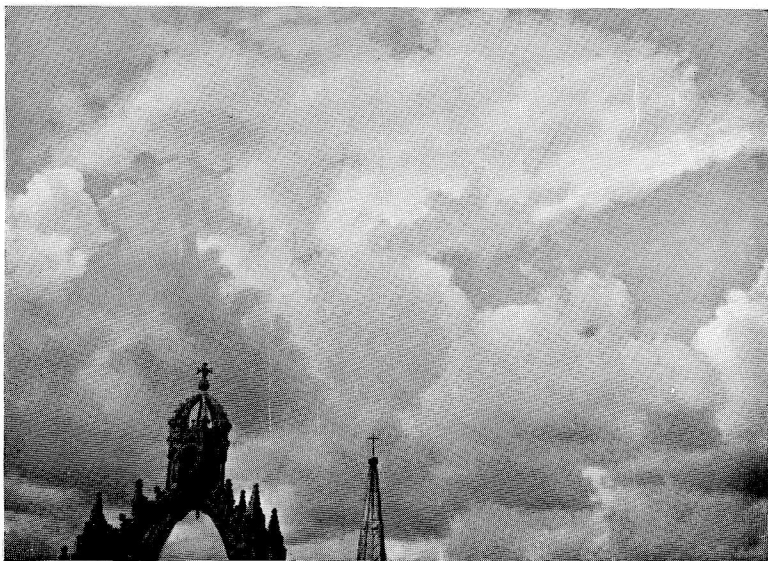


Photo by G. A. Clarke

C_M6 ☞ Altocumulus formed from the spreading out of cumulus. Cumulus clouds of sufficiently great vertical development may undergo an extension of their summits while their bases may gradually melt away. The process is similar to that of C_L 4 but at a higher level. The cloud which looks anvil-shaped must not be confused with C_L 3.

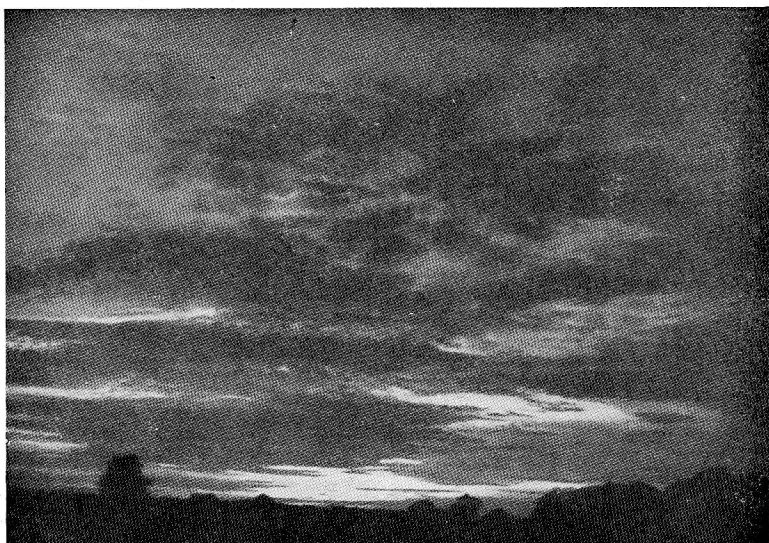


Photo by C. J. P. Cave

C_M7 ☞ Altocumulus associated with altostratus or altostratus with parts resembling altocumulus. Different types are comprised in this section. There may be two definite layers of altostratus and altocumulus or the altocumulus may be thickening into altostratus by the cloudlets fusing together or altostratus may break up into altocumulus. Cases of altocumulus, which are so dense that the waves do not show light parts (wrinkled altostratus), should be classed as C_M 7.



Photo by G. A. Clarke

C_M8 M Altocumulus castellatus (or altocumulus in ragged fragments). The character common to these types of altocumulus is vertical development, a turret or a dome shape. These clouds are often the precursors of thunderstorms. Altocumulus castellatus is composed of small cumuliform masses with more or less vertical development, but scattered tufts, white or grey, without definite shadows, and with the rounded parts very slightly domed, should also be included as C_M 8.



Photo by the Office National Meteorologique, Paris

C_M9 ☞ Altocumulus in several layers generally associated with fibrous veils and a chaotic appearance of the sky. The sky has a disordered, heavy and stagnant appearance. It is very complex with patches of medium cloud more or less fragmentary, superposed, often badly defined and giving all the transitional forms between low altocumulus and the fibrous veil.



Photo by the Fundació Concepció Rabell, Barcelona

C_H1  Fine cirrus not increasing; sparse. Wisps of cloud at a very high level; they may be scattered over a large part of the sky but they do not amount to very much; the amount does not increase noticeably either in time or in any particular direction.

The clouds do not collect into sheets and bands, and there is no tendency for the elements to fuse together into masses of cirrostratus. The cirrus cloud whose strands end in an upturned hook or tuft must not be included in this class.

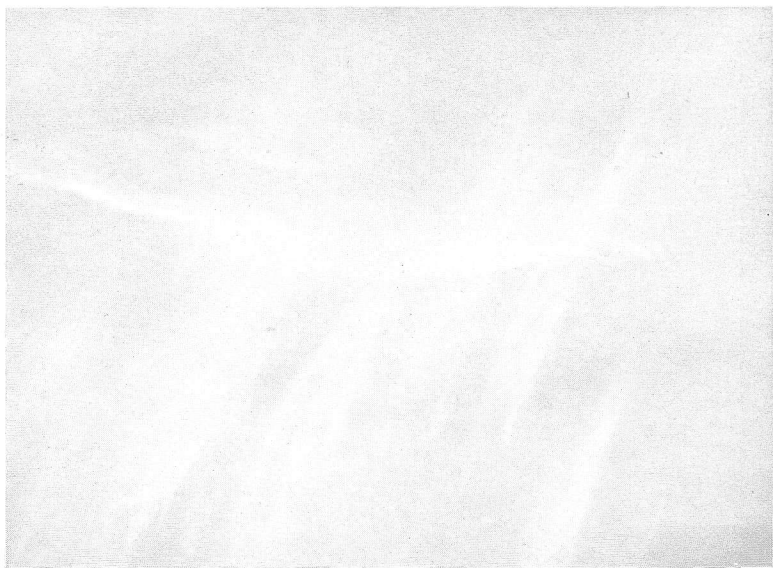


Photo by G. A. Clarke

C_H2  Fine cirrus not increasing; abundant but not a continuous layer. The definition of this type is the same as the preceding, with the exception that in this type the cirrus is more abundant over the whole sky, but without any tendency to increase in any particular direction.



Photo by G. A. Clarke

C_H3 — Anvil cirrus (usually dense). This cirrostratus is usually seen at the top of a thunder cloud—it looks like a dense white mass, and as the cloud develops the cirrus shoots upwards and outwards and has the appearance of an “explosion.” Frequently it is blown away in a stronger wind and makes the cloud look like a great anvil in the sky (see C_L 3). Sometimes the cirrus gets entirely separated from the thunder cloud and then appears as rather dense separate white masses.



Photo by the Fundació Concepció Rabell, Barcelona

C_H4 — Fine cirrus increasing; usually in tufts. This type of cirrus which is often in the form of streaks ending in a little upturned hook or in a small tuft, increases in amount both in time and in a certain direction. In this direction it reaches to the horizon where there is a tendency for the cloud elements to fuse together, but the clouds do not pass into cirrostratus.



Photo by G. A. Clarke

C_H 5 — Cirrus or cirrostratus increasing; still below 45° altitude; often in polar bands. Sheet of fibrous cirrus partly uniting into cirrostratus, especially towards the horizon in the direction where the cirrus strands tend to fuse together; the cirrus is often in a herring-bone formation or in great bands converging more or less to a point on the horizon. In this class is also included a sheet of cirrostratus which does not cover the sky and is below 45° altitude.

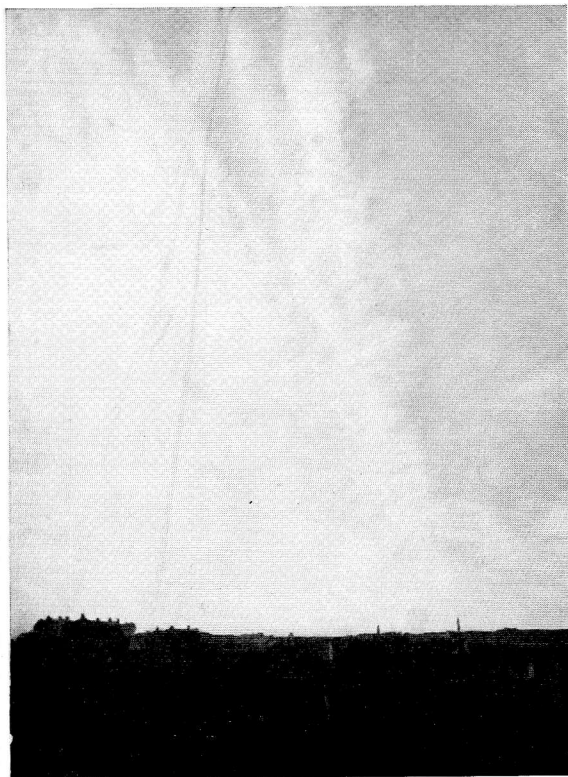


Photo by G. A. Clarke

C_H 6 $\curvearrowright$ Cirrus or cirrostratus increasing and reaching above 45° altitude; often in polar bands. The definition of this type is the same as the previous one, with the exception that the cloud reaches more than 45° above the horizon. (N.B.—Altitudes if not measured instrumentally are deceptive; it is common to over-estimate a point in the sky. A point at 30° altitude will appear to be about 45° altitude.)



Photo by G. A. Clarke

C_H 7 — Veil of cirrostratus covering the whole sky, either (a) a thin uniform nebulous veil, sometimes hardly visible, sometimes relatively dense, always without definite detail, but producing halo phenomena round the sun and moon ; or (b) a white fibrous sheet, with more or less clearly defined fibres, often like a sheet of fibrous cirrus from which indeed it may be derived.



Photo by G. A. Clarke

C_H 8 — Cirrostratus not increasing and not covering the whole sky. This is a case of veil or sheet cirrostratus reaching the horizon in one direction but leaving a segment of blue sky in the other direction ; this segment of blue sky does not grow smaller, otherwise it would be reported as C_H 5 or C_H 6. Generally the edge of the sheet is clear cut and does not tail off into scattered cirrus.



Photo by G. A. Clarke

C_H9  Cirrocumulus predominating, and a little cirrus. Cirrocumulus is a wavy type of "mackerel" sky with a delicate fine structure. Cirrocumulus is not to be confused with small altocumulus. There must be either evident connexion with cirrus or cirrostratus, or the cloud observed must result from a change in cirrus or cirrostratus.

Cirrocumulus may occur with any of the types 1 to 8.

CODE FOR FORM OF LOW CLOUD (C_L)—*continued*

Code Figure	Form of Cloud
3	Cb
4	Sc formed by the spreading out of Cu
5	Layer of St or Sc
6	Ragged low clouds of bad weather (fractonimbus)
7	Fair weather Cu and Sc
8	Large Cu (or Cb) and Sc
9	Large Cu (or Cb) and ragged low clouds of bad weather

CODE FOR FORM OF MEDIUM CLOUD (C_M)

Code Figure	Form of Cloud
0	No medium cloud
1	Typical As (thin)
2	Typical As (thick) or Ns. Sun or Moon invisible
3	Single layer of Ac or high Sc
4	Ac in isolated bands. Individually decreasing (often lenticular)
5	Ac in bands (increasing)
6	Ac formed from the spreading out of Cu
7	Ac associated with As or As with parts resembling Ac
8	Ac Castellatus (or Ac in ragged fragments)
9	Ac in several layers generally associated with fibrous veils and a chaotic appearance of the sky

CODE FOR FORM OF CIRRUS CLOUD (C_H)

Code Figure	Form of Cloud
0	No cirriform cloud
1	Fine Ci not increasing ; sparse
2	Fine Ci not increasing ; abundant but not a continuous layer
3	Anvil Ci (usually dense)
4	Fine Ci increasing ; usually in tufts
5	Ci or Cs increasing ; still below 45° altitude : often in polar bands
6	Ci or Cs increasing and reaching above 45° altitude ; often in polar bands
7	Veil of Cs covering the whole sky
8	Cs not increasing and not covering the whole sky
9	Cc predominating, and a little cirrus

Examples of each code figure are given between pp. 156-7 together with brief notes about the clouds shown in the photographs, and also the plotting symbol which represents the cloud on the synoptic working charts used by forecasters.

The detailed analysis of the individual clouds should follow and not precede the observations of the sky as a whole. If the observer gets used to this course he will find in a short time that the different types of sky, low, medium and high, corresponding with the code, will seem just as "live" as the typical cloud forms, and it will be just as easy to identify a type of sky as the form of a cloud.

To make an observation of cloud it is necessary to do more than survey the sky while walking to the instrument enclosure. The aspect of the sky is continually changing. It is relatively rare for the observer to see typical clouds of one type ; in most cases he will find he has difficulties at the time of observation if he has not taken the trouble to watch the evolution of the sky since the last observation. If, however, he has been able to keep it in view he will often be able to refer an indefinite type of sky or a particular cloud to a previous formation which was typical and easy to identify. Moreover, the specification of many of the code figures depends on evolution. If two figures seem to be equally applicable, the observer should in general select the higher figure rather than the lower, but he must remember that if cumulonimbus cloud is present the figure for C_L must be reported as either 3, 8 or 9.

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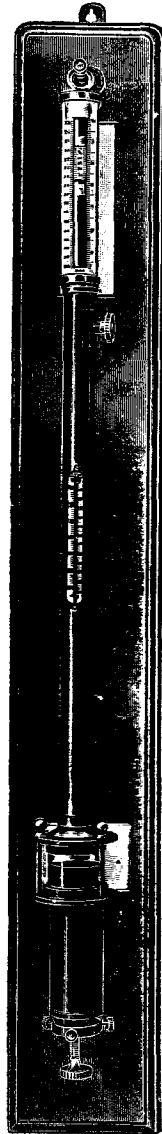
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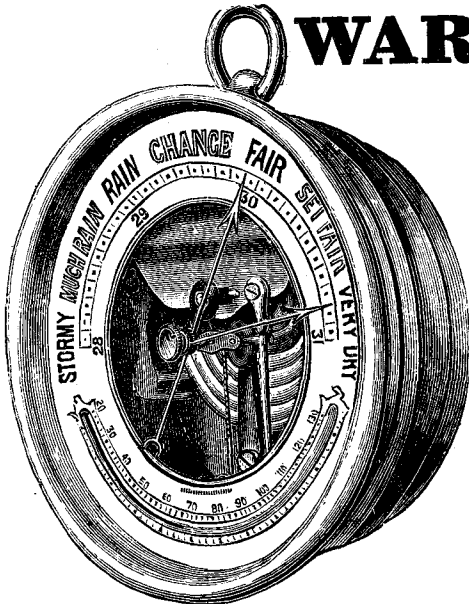
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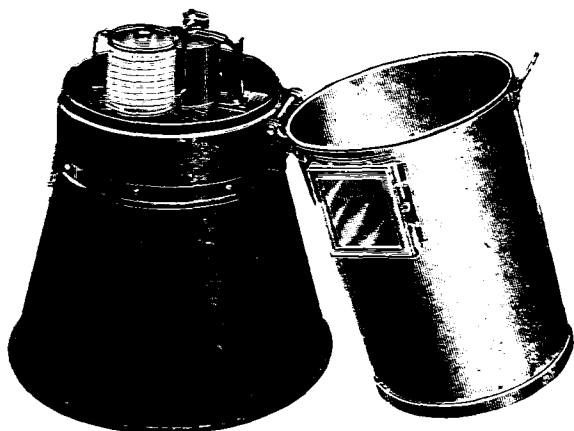
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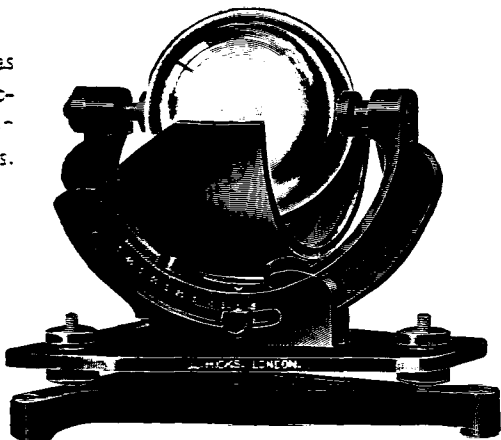
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