AEROGRAPHY

A MANUAL OF AEROGRAPHY

FOR THE

UNITED STATES NAVY

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PREFACE.

NAVY DEPARTMENT,
Washington, D. C., March 28, 1918.

This is the first edition of the Aerographer's Manual of the United States Navy, compiled and edited under the supervision of Lieut. Commander Alexander McAdie, U. S. N. R. F. The object of this book is to aid in the instruction and guidance of the personnel of the Aerography Division of the United States Naval Reserve Flying Corps. The department invites criticism and suggestions as to the form and substance of the book. Such criticisms should be sent to the Navy Department, Washington, D. C., Naval Operations, Aviation Division.

The following list gives the names of those who have taken an active part in the preparation of the Manual. The initials indicate specific contributions:

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Gift of
Navy dept.

CHAPTER I

DEFINITION OF UNITS AND SYMBOLS USED

CHAPTER I.

UNITS AND SYMBOLS.

In order to meet the requirements of the new meteorology now generally called "aerography," the adoption of a standard and finally an international standard set of recognized units is desirable if not indeed essential. In selecting this new notation, the units should be such that compilation of data will be simplified, that fewer mistakes will occur, and above all that definite and precise conceptions of the phenomena of the atmosphere shall be had, particularly of the various transformations of energy which are manifested in general and local disturbances.

1. **The centimeter-gram-second (C. G. S.) system.**—

(*a*) Centimeter (cm.) is the unit of length and the hundredth part of a meter. The meter is generally defined as the ten-millionth part of the meridian passing through Paris. Lengths and distances will be designated by l.

(*b*) Gram (gm.) is the unit of quantity of matter and is the thousandth part of the quantity of matter in a standard piece of platinum-iridium called the kilogram-prototype.

The kilogram, or standard of mass, is made as nearly as possible equal to the mass of a cubic decimeter of distilled water at maximum density 277K or 1014 on the Kelvin-Kilograde scale.[1] Weights will be designated by W_t.

(*c*) Second (sec.) is the unit of time and is the mean solar second, i. e., there are 86,400 such seconds in a mean solar day.

Time unit will be designated by s.

Derived from the three foregoing units are—

(*d*) Velocity, the rate of change in position of a body or the ratio of length to time, the conversion factor being $\frac{l}{s}$.

Velocity will be designated by *vel* or v and the unit is 1 centimeter per second.

(*e*) Momentum is the quantity of motion and is the product of mass and velocity, so that the conversion factor is $\frac{W_t l}{gs} = M$.

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[1] Kelvin-Kilograde, a name used it is believed for the first time in this work, to designate a scale starting from the absolute zero and having 1,000 for the temperature of melting ice under standard conditions This scale was suggested by Prof. A. McAdie and described in the Annals, Harvard College Observatory, vol. 73, part III, 1916. It was then called, for the lack of a better name, the New Absolute.

(*f*) Acceleration is the rate of change of the velocity of a body, expressed as 1 centimeter per second per second, and the conversion factor will be $\frac{l}{s} = v_s$.

(*g*) The unit of area will be expressed by l^2 or a, and the unit of volume as l^3 or v.

(*h*) The unit of density or the ratio of mass to volume is expressed by $\frac{W_t}{gl^3}$, or the Greek letter rho (ρ).

2. **Force.**—The unit of force is called the dyne, i. e., the force which will impart to the unit mass (a gram) an acceleration of 1 centimeter per second per second.

Force is measured by the rate of change of momentum, and the conversion factor is $\frac{W_t l}{gs^2}$, designated by F.

One pound in the old system's unit of force is 13,825 dynes, when gravity is not considered.

3. **Work.**—Work done by a force may result in change of velocity or change of form, the former being a change in kinetic energy and the latter a change in potential energy.

The unit of work is the erg, the conversion factor $\frac{W_t l^2}{gs^2}$ to be designated by W_k. To raise 1 kilogram 10 meters requires 1,000,000 ergs; 981×10^6 dynes is the value of a poundal when the work done is against gravity.

4. **Power.**—The unit of power is the watt, or 10,000,000 ergs per second.

In the old system the unit was a horsepower, or 550 foot-pounds per second. In the new system the equivalent value will be $30.48 \times 17{,}710 \times 13{,}825 \div 10^7 = 746$ watts per horsepower. A kilowatt, or 1,000 watts, is equal to $\frac{1{,}000}{746} = 1.34$ horsepower.

Power will be designated by the symbol p. Electrical engineers use the letter "P" to represent power and sometimes the letters KVA, meaning the product of the voltage and amperage divided by 1,000. In this manual the use of P is restricted to pressure.

5. **Pressure.**—Atmospheric pressure has been expressed in units of height of a column of mercury, in units of weight, and, finally, in units of force.

A megadyne atmosphere or the pressure equivalent to the force of 1,000,000 dynes per square centimeter is 0.987 of the standard sea-level pressure at latitude 45° and freezing temperature. It is the standard pressure at an elevation of 106 meters above sea level.

Unit of pressure. The "bar" or 1×10^{-6} of a standard atmosphere is the unit of pressure expressed in terms of force, or 1 dyne per square centimeter.

The millibar (*mb*) is the one-thousandth part of a bar; a kilobar (*kb*) is equal to a thousand bars, and is the practical unit of pressure for aerographic use.

In brief:

Millibar or $mb = 1 \times 10^{-9}$ standard atmosphere.
Bar or $b = 1 \times 10^{-6}$ standard atmosphere.
Kilobar or $kb = 1 \times 10^{-3}$ standard atmosphere.
Megabar or *mgb* is the standard atmospheric pressure.

Unfortunately, the term "millibar" has been inadvertently used by certain meteorologists for kilobar. The change is easily made by substituting *kb* for the symbol *mb* printed on maps previous to 1918.

Pressure will be designated by P.

6. **Temperature.**—For convenience in the rapid compilation of data and in notes relating to aerography, T will represent the general term of temperature on any scale. T_c will indicate temperatures Centigrade. T_f temperatures on the Fahrenheit scale, and T_k will designate temperatures on the Absolute scale devised by Lord Kelvin, and T_{kk} temperatures on the Kelvin-Kilograde scale.

THE MECHANICAL EQUIVALENT OF HEAT.

By experiment, it has been shown that the energy which can raise the temperature of a gram of water 1 degree could do the mechanical work of lifting, against the force of gravity, 1 gram of water 42,683.7 cm. This is called the mechanical equivalent of heat under standard gravity, i. e., at 45° latitude and at sea level, and is expressed by the symbol $\frac{1}{A}$. Conversely, the "heat equivalent of work" is expressed by A, its value being 0.00002343.

MEASUREMENTS OF HEAT.

Heat may be measured in dynamical or thermal units. In dynamical units, the conversion factor is $\frac{W_t l^2}{g s^2}$, or E, energy; i. e., the temperature of a body may be considered to be the average kinetic energy of translation of its molecules and is designated by mass times velocity squared.

In thermal units, it is necessary to determine the amount of heat required to raise unit mass of water 1 degree, the conversion factor being $W_t T$.

The heat unit is the gram-calorie or therm, or the quantity of heat, Q, which will raise the temperature of a gram of pure water 1 degree Centigrade.

Since the specific heat of water varies slightly at different temperatures, the value of the gram-calorie is properly one one-hundredth of the total heat required to raise the temperature of a gram of water from 273K to 373K or 1,000KK to 1,366KK.

7. **International symbols.**[1]—In addition to the foregoing units, the use of certain symbols was agreed upon by the congress at Vienna in 1873, and as subsequently modified are now in use as follows:

● Rain.
✱ Snow.
▲ Hail.
△ Sleet.
≡ Fog.
⌓ Dew.
⊔ Hoar frost.
⊠ Surrounding country more than half under snow.
V Frostwork (rough) forming.
⌐ Ice coating (smooth) forming.
⇸ Drifting snow.
← Floating ice crystals.
╱ Gale.
ℸ Thunderstorm.
ϟ Distant lightning.
✹ Duration of sunshine.
T Distant thunder.
∞ Haze.
⊕ Solar halo.
⦶ Solar corona.
◡ Lunar halo.
⋓ Lunar corona.
⌒ Rainbow.
⍙ Aurora.
‡ Sea breeze.

The intensity of a phenomenon is denoted by an exponent; 0, indicating slight; 2, great; and an absence of exponent, moderate intensity.

The time of occurrence is expressed in hours and tenths: morning and afternoon are indicated by A. and P., respectively; midnight and noon by 12 P. and 12 M., respectively, the hours being counted from 0 to 12, commencing at midnight. The continuance of a phenomenon is indicated by a dash (—).

Maximum and minimum values are denoted by heavy-faced type except for relative humidity, in which case only the minima are so indicated.

It is desirable that a 24-hour system be used as far as possible. The beginning of the day will correspond with 0, Greenwich mean civil time and the last hour marked 23.

8. **General geodetic data.**[2]—1 cm. equals 0.3937 inch, or 0.0328 feet. (1 mm. is roughly 0.04 inch.)

1 $cm.^2$ equals 0.155 square inch.

1 $cm.^3$ equals 0.061 cubic inch.

1 cm. per second equals 0.0224 mile per hour, or 0.0328 foot per second; 1 meter per second equals 2.24 miles per hour.

The equatorial radius of the earth is 6,378,388 ± 18 meters, or 3,963 miles.

The polar semi-diameter of the earth is 6,356,909 meters, or 3,950 miles.

The reciprocal of flattening is 1/297.4.

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[1] Taken from "Principles of Aerography," pp. 31.

[2] Taken from "Principles of Aerography," pp. 31-32.

The circumference of the equator is 40,076,000 meters, or 24,902 miles.

The perimeter of the meridian ellipse is 40,008,600 meters or 24,860 miles.

The area of the earth's surface is 510,044,000 square kilometers or 196,940,000 square miles.

The area of the ocean is approximately three quarters that of the whole earth's surface.

The mass of the earth is $5,984 \times 10^{24}$ kilograms, or 6×10^{21} tons.

The mass of the atmosphere is $5,263 \times 10^{15}$ kilograms, or 5.8×10^{15} tons.

The mass of the ocean is about 1.3×10^{24} kilograms, or 1.3×10^{18} tons.

The volume of the atmosphere is approximately $4,080 \times 10^{15}$ cubic meters; and since a cubic meter of dry air under standard conditions weighs 1.293 kilograms, the approximate weight of the atmosphere is $5,263 \times 10^{15}$ kilograms. This is 1/1,125,000 of the mass of the earth.

If the density of water under standard conditions is taken as 1, then—

The mean density of the earth is 5.52.
The mean density of the surface is 2.67.
The mean density of the ocean is 1.03.

The mean solar day is 24 hours, 3 minutes, 56 seconds, sidereal time. A sidereal day has 86,164 seconds, or 23 hours, 56 minutes, 4 seconds mean solar time.

A sidereal year has 365.26 mean solar days.

The mean distance from earth to sun is 149,500,000 kilometers, or 92,900,000 miles.

Solar parallax, 8,796 seconds; lunar parallax, 3,422.68 seconds.

Sun's diameter, 1,392,000 kilometers, or 865,000 miles.

The mean distance from earth to moon is 384,399 kilometers, or 238,854 miles, or 60.3 terrestrial radii.

The velocity of light is 299,870 kilometers, or 186,300 miles per second.

The time required for light to traverse the mean radius of the earth's orbit is 498.8 seconds.

9. Standard notation—

e	Base of natural logarithms, 2.718281828
π	3.14159265.
ϕ	Latitude.
λ	Longitude.
ρ	Density.
C_P	Specific heat of air at constant pressure.
C_V	Specific heat of air at constant volume.
π	Ratio of specific heat.
g	Acceleration of gravity at sea level.

g_0	Acceleration of gravity at a height of 106 meters above sea level. (The new pressure base.)
l	Distance or height in cms.
W_t	Weight in grams.
s	Time in seconds.
v	Velocity in cms. per second.
M	Momentum.
v_t	Acceleration.
M_s or F	Force in dynes.
W_k	Work in ergs.
p	Power in watts.
V	Volume.
T	Temperature (general).
T_k	Temperature on Absolute scale.
T_{kk}	Temperature on Kelvin-Kilograde scale.
A	Heat equivalent of work or 0.00002343.
$\frac{1}{A}$	Mechanical equivalent of heat or 42,683.7 gm. cm.
Q	Quantity of heat, the gram-calorie being the unit.
Q_1	Initial quantity of heat.
Q_2	Final quantity of heat.
Q_1-Q_2	Free heat.
E	Energy.
U	Inner energy.
K_1-K_2	Radiation energy.
S_1-S_2	Entropy (S being the general term).
P	Pressure.
b	Bar $= 1 \times 10^{-6}$ megadyne atmosphere.
mb	Millibar $= 1 \times 10^{-9}$ bar.
kb	Kilobar $= 1 \times 10^{-3}$ bar.
mgb	Megabar $= 1 \times 10^{6}$ bars, standard atmosphere.
a	Area.
N	Avogadro's constant $= 6.062 \times 10^{23}$.
H	Plancks's element of action.
μ	0.001 mm.
w	Wave length.
G_T	Temperature gradient.
G_P	Pressure gradient.
R	Gas characteristic.
ω	Angular velocity of earth's rotation.
r	Radius of earth.
XYZ	Coordinates for axes.

Conversion factors to be used in connection with aerography:

1 kilowatt-hour = 3,412.66 B. t. u.

1 h. p. = 746 watts.

1 h. p.-hour = 2,544.6 B. t. u.
1 B. t. u. = 777.5 foot-pounds.
1 B. t. u. = 0.252 calories.
1 large calorie = 1,000 therms.
1 calorie = 3.968 B. t. u.
1 calorie per kilogram = 1.8 B. t. u. per pound.
1 pound of air at 32° F. occupies about 12.4 cubic feet.
1 kg. of air at 273° A. occupies about 0.7741 cu. m.
1 pound of water at 212° F. occupies 0.0161 cubic feet.
1 kg. of water at 373° A. occupies about 8.95 cu. m.
1 pound of steam at 212° F. occupies 26.14 cubic feet.
1 kg. of steam at 373° A. occupies 164.1 cu. m.
1 pound of water at 212° F. contains 181.8 B. t. u.
1 kg. of water at 373° A. contains 400.72 B. t. u. or 100.98 calories.
1 pound of steam at 212° F. contains 1,150.4 B. t. u.
1 kg. of steam at 373° A. contains 2536.1 B. t. u. or 639.16 calories.
1 pound of ice requires 143.8 B. t. u. to change to water.
1 kg. of ice requires 317.02 B. t. u. or 79.89 calories to change to water.
1 cubic foot of water at 212° F. weighs 59.84 pounds.
1 cu. m. of water at 373° A. weighs 0.768 kg.
1 cubic foot of water at 62° F. weighs 62.2786 pounds.
1 cu. m. of water at 290° A. weighs 0.800 kg.
1 cubic foot of steam at 212° F. weighs 0.03826 pound.
1 cu. m. of steam at 373° A. weighs 0.000522 kg.
1 cubic foot of dry air at 32° F. weighs 568 grains.
1 cu. m. of dry air at 373° A. weighs 1.293 kg.
1 cubic meter of dry air at 0° C. weighs 1,293.05 grams.
Specific heat of water 1.
Specific heat of ice 0.489.
Specific heat of water vapor 0.453 at atmospheric temperatures.
Specific heat of air 0.241.

Values given above are laboratory values, obtained by using distilled water. Ordinary drinking water is heavier than distilled water, because of matter in solution. Salt water is also heavier. It may be remarked that the temperature of the freezing point in ordinary use, that is, 273 K, may not hold for the freezing of water in plant life. W. N. Shaw instances one plant where the freezing point is apparently 268 K. In other words, the change of water from the liquid to the solid state under natural conditions is somewhat different from the change as studied in a laboratory.

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1 kg. of air at 273° A. occupies about 0.7741 cu. m.
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1 kg. of water at 373° A. occupies about 3.96 cu. m.
1 pound of steam at 212° F. occupies 26.14 cubic feet.
1 kg. of steam at 373° A. occupies 1.641 cu. m.
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1 cubic foot of water at 212° F. weighs 59.84 pounds.
1 cu. m. of water at 373° A. weighs 0.9588 kg.
1 cubic foot of water at 62° F. weighs 62.356 pounds.
1 cu. m. of water at 290° A. weighs 0.999 kg.
1 cubic foot of steam at 212° F. weighs 0.03826 pound.
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1 cubic foot of dry air at 32° F. weighs 565 grains.
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A. P. L.

CHAPTER II.

FUNDAMENTAL EQUATIONS.

CHAPTER II.

The following formulæ are considered as fundamental in connection with the aerographer's work.

Pressure gradient.—As given by the "dynamic" definition the vertical pressure gradient

$$G_P = -\rho g \qquad (1)$$

and by the "geometric" definition as

$$G_P = -\frac{dP}{dl} \qquad (1a)$$

where ρ, g, P, l are in C. G. S. units

Gradient wind.

$$G_P = 2\omega\, v \sin\phi \qquad (2)$$

Here v is the velocity of the wind in cm. per sec. and the other symbols are of standard nomenclature.

Deflective force due to earth's rotation.—Deflecting force:

$$F = \text{mass} \times \text{acceleration}.$$

$$= \frac{W_t}{g} \times 2\,\omega\,\rho\, v \sin\phi \qquad (3)$$

ω = angular velocity of earth's rotation or

$$\frac{2\pi}{86164} = 0.00007292$$

v = velocity of air in meters per second.

sin ϕ = sin latitude (Boston 42° 13′ = 0.6719)
(New York 40° 43′ = 0.6524)
(Washington 38° 53′ = 0.6277)

ρ = density of air = 0.001293 gm. per cubic meter.

$F = \frac{1}{10}$ megabar (wind 10 meters per second).

With moderate pressure gradient at surface, gradient velocity is reached about 350 meters and gradient direction about 700 meters. In light anti-cyclonic winds, gradient velocity is not reached below 1,000 meters.

Relation of pressure (P) and altitude (l).—Let P'_2 and P'_1 be pressures at heights under consideration.

P_2, P_1 and T_{k2}, T_{k1} the pressure and temperatures at the stations $Sta._2$ and $Sta._1$ at the ground, then—

$$P_2' - P_1' = P_2 - P_1 - \left(\frac{T_{k1} - T_{k2}}{273}\right) \tag{4}$$

where the pressures are measured in kilobars.

Relation of velocity (v) to altitude (*l*).—Humphreys has shown that near the earth (0.2 to 8 m.) wind conditions are as follows:

(1) Actual velocity is very irregular,

(2) Average velocity increases rapidly with elevation,

(3) Rate of velocity increase, (*a*) decreases with average velocity; (*b*) decreases with elevation. And that above this layer the increase in velocity is regular enough to allow its computation by means of such formulas as Stevenson's, which is fairly accurate up to 16 m.

$$v_1 = v\sqrt{\frac{l_1 + 22}{l + 22}} \tag{5}$$

Where v_1 is the computed velocity at height l from the known velocity (v) at height l.

For elevations varying from 100 m. to 600 m. the following formulas give results which are quite accurate.

Douglas's formula:

$$\frac{v_1}{v} = \left(\frac{l_1}{l}\right)^{\frac{1}{4}} \tag{5a}$$

Where v_1 = velocity sought at height l_1 and v = velocity by anemometer at height l.

Shaw's formula:

$$v_1 = \frac{l + \text{constant}}{\text{constant}}\ v \tag{5b}$$

the constant depending upon surroundings and is found for each station.

Other interesting generalizations concerning the variations of wind with altitude have been obtained by Cesare Fabris, who carried on his observations with pilot balloons near Rome. He found that, in general—

(1) The air currents for the first 600 m. to 700 m. are greatly influenced by surface conditions, but that there is a rapid increase in velocity as the upper limit is approached,

(2) For a short distance of 100 m. above the first 600 to 700 meters there is a decrease of velocity with altitude,

(3) From 500 m. or 600 m. to 1,500 m. altitude the winds are irregular, but tending to increase in velocity,

(4) Above 1,500 m. to the stratosphere there is a constant increase in velocity with altitude.

In his studies of the upper atmosphere Engell suggested the theory that the volume of air passing a given vertical plane per unit of time is the same for all altitudes. From this it follows that

$$\rho v = \rho^1 v^1$$

where v and v_1 = the wind velocities and ρ and ρ_1 represent the densities of the air at the different heights.

In summing up the general relations of wind velocity to height, Humphreys shows that from 5 km. to 10 km. the temperature is nearly constant, so

$$\frac{\rho}{\rho'} = \frac{P}{P'}$$

but as

$$\frac{P}{P'} = \frac{l'}{l} \text{ (roughly)}$$

then

$$\frac{\rho}{\rho'} = \frac{l'}{l} \text{ (roughly)}$$

from the above—

$$\rho v = \rho' \ v'$$

so

$$\frac{\rho}{\rho'} = \frac{v'}{v}$$

therefore—

$$\frac{l'}{l} = \frac{v'}{v}, \qquad (6)$$

approximately, or the velocity of the wind through the levels in question is roughly proportional to the altitude.

Above the isothermal layer the temperature gradient decreases so the value of ρv falls off faster than the density, with increased height. This agrees with the mathematical deduction that the maximum velocity occurs slightly below this level, namely, 8 or 9 kilometers above the surface of the earth.

Relation of temperature (T) and altitude (l).—From extensive experiments carried out by different types of balloons and airplanes the following conclusion may be expressed, that the aviator may expect a decrease of six-tenths of a degree Centigrade for every increase in altitude of roughly 100 meters; i. e., the normal decrease; while the adiabatic rate of decrease of one degree Centigrade corresponds roughly to every increase of 100 meters elevation.

Relation between pressure, temperature, and altitude.—In a chart recently devised by Lieut. Commander Alexander McAdie, the airman has a quick way of obtaining the true altitude corrected for temperature, the correction for latitude and gravity change for altitude being neglected.

Reduction of barometric readings to sea level.—Laplace gives the following formula; only the symbols used here are of standard nomenclature and values:

$$l = \mathrm{R}\ (1+\alpha \mathrm{T_k})\ \frac{1}{1-0.00259\ \cos\ 2\phi}\left(1+\frac{l}{r}\right)\log\frac{\mathrm{P_0}}{\mathrm{P}} \qquad (7)$$

Where—

l = altitude of the station above the sea level.

ϕ = latitude.

r = mean terrestrial radius, 6, 378,388 meters.

α = the coefficient of expansion of air.

$\mathrm{T_k}$ = the equivalent mean temperature on the absolute scale of the air between the station and a place supposed to be situated in the same vertical at sea level.

P and $\mathrm{P_0}$ = the atmospheric pressures at the two points.

0.00259 = the constant for variation of gravity with latitude.

R = barometric constant, and equals

$$\frac{\rho_1}{\rho}\times\frac{\text{normal barometric height}=76\text{ cm}}{log_{10}e=0.43429}.$$

Where—

ρ_1 = density of mercury at 273 K.

ρ = density of air at 273 K and normal pressure.

$log_{10}e$ = modulus of common logarithms.

Whence R = 18,400 meters = 60,370 feet.

So that by substituting the values of these known constants and observed conditions, the reduction of the known pressure to that at sea level can be made.[1]

The equation of motion for the atmosphere.[1]—If the influence of vertical currents and of viscosity may be ignored we can write down the equations

$$\left(\frac{d}{ds}+v\frac{d}{dl}\right)v=-\frac{1}{\rho}\frac{dP}{dl} \qquad (8)$$

$$\frac{v^2}{r_L{}^1}=-\frac{1}{\rho}\times\frac{dP}{dl^1{}_L}-2\omega v\sin\phi \qquad (9)$$

Where P is the pressure, dl is an element of the path of the air, dl'_L is at right angles thereto and toward the left, ρ is the density of the air, and r_L' is the radius of curvature to the left of the path of the air.

The characteristic equation for air.[1]

$$P=\mathrm{R}\ \rho\ \mathrm{T_k} \qquad (10)$$

for pressure in kilobars, temperature in degrees Absolute (Kelvin scale) and density in grams per cubic centimeter:

For dry air R = 2,870.

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[1] Computer's Handbook, 1916.

For air saturated at 273 K with a vapor pressure of 6.10 Kb. R=2,876.

For air saturated at 283 K with a vapor pressure of 12.24 Kb. R=2,883.

Weight of vapor in the air.[1]

$$W_t = \rho\,\delta\,\frac{P}{P'}\,\frac{T'_k}{T_k} \tag{11}$$

Where W_t is the weight of vapor in a cubic meter of air.

$P'T'_k$ are the standard pressure and temperature of the atmosphere.

ρ = weight of one cubic meter of dry air under standard conditions of pressure and temperature and is equal to 1,292.8 grams per cubic meter.

δ = ratio of the density of water vapor to air at the same temperature and may be taken equal to 0.622.

P = pressure of water vapor in the air.

T_k = temperature of the Kelvin scale.

The computation of humidity.[1]

$$T - T_d = C(T - T') \tag{12}$$

Where—

T is the temperature of the dry bulb.

T′ is the temperature of the wet bulb.

T_d is the temperature of the dew point.

C is a factor which depends on the temperature of the dry bulb.

Glaisher's hygrometric tables, which are generally used in the British Isles, are especially prepared for this subject.

Density of air for various pressures.[2]

$$\rho = 348.3\left(\frac{P - \frac{3}{8}P'}{T_c}\right) \tag{13}$$

Where—

ρ is the density in grams per cubic meter.

P is the pressure of the air in kilobars.

P′ is the pressure of the water vapor present in the air in kilobars.

T_c is the absolute temperature on the Centigrade scale.

Variation of wind velocity with height.[2]—It has been found by experiment that the velocity of the wind increases with height and tends to gradually become parallel to the isobars in the lower levels.

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[1] Computer's Handbook.

[2] Air Navigation for Flight Officers. (Lieut. Commander A. E. Dixie, R. N.)

The veering of the wind with height may be roughly estimated in degrees from the following formula, where "V" is the veering and "H" the height, in meters:

$$V=\frac{30\times\frac{H}{1000}}{\frac{H}{1000}+2} \qquad (14)$$

Height.	Veering.
0	0°
1,000	10°
2,000	15°
3,000	18°
4,000	20°
5,000	21°
6,000	22½°
7,000	23½°
8,000	24°
9,000	24½°
10,000	25°
11,000	25½°
12,000	25¾°

Fluctuation and gustiness.[1]—The velocity of the wind is seldom uniform, but varies in gusts and lulls.

The difference between the average maximum velocity of the gusts and the average minimum velocity of the lulls is known as the "fluctuations of the wind."

The gustiness of the wind is found as follows:

$$\text{Gustiness}=\frac{\text{Fluctuations.}}{\text{Average velocity.}}$$

Let $v_{\max}$ be the maximum and v_m the minimum velocity.

$$\text{Then gustiness}=\frac{v_{\max}-v_m}{\frac{v_{\max}+v_m}{2}}$$

It has been found that the gustiness of the wind at any particular place for a given direction is practically constant.

A. B. L.

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[1] Air Navigation for Flight Officers. (Lieut. Commander A. E. Dixie, R. N.)

CHAPTER III.

THE WINDS.

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THE WINDS.[1]

Edmund Halley, the astronomer, in 1698 received from King William III command of a sailing ship, with directions to study variations of the compass. He made two memorable voyages and practically covered the Atlantic from 50° N. to 50° S. Besides the magnetic work much meteorological work was done, and our first knowledge of the general wind system of the Atlantic comes as a result of these voyages.

In 1856 another explorer, Capt. Charles Wilkes, of the United States Navy, read a paper before the American Association for the Advancement of Science, which was later published. It is in this work that we find included one of the earliest maps of the winds of the world. In 1875, through the joint agency of the Smithsonian Institution and Prof. J. H. Coffin, of Lafayette College, there was published a large volume on the Winds of the Globe. Several world maps of wind movement are given; and not only the annual direction but the directions for summer and winter months are charted. Köppen, of Hamburg, has given us the latest of these charts.

It is apparent that there are several mighty streams of air flowing around the world in certain latitudes. Some blow steadily and are more or less permanent, like the trades, the anti-trades, and the prevailing westerlies. Some are seasonal in character, like the monsoons. There are also well-marked minor circulations, known as sea breezes and valley winds; and, finally, there are the individual, localized winds accompanying the various storm types.

The permanent, or planetary, winds are controlled by the planetary pressure distribution; that is, they depend upon the general difference of temperature between equatorial and polar regions, and more especially upon the position and strength of the great planetary pressure belts. The seasonal winds can be correlated with movements of the hyperbars or infrabars (the so-called centers of action). The local winds can be traced to temporary disturbances of pressure.

The winds have been classified by Dove, Davis, and others as planetary, terrestial, continental, land and sea breeze, mountain and valley breeze, cyclonic, and certain accidental winds due to volcanic eruptions.

Trade winds.—These are the great northeast and southeast wind systems. The name is derived from the old English, to blow

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[1] Principles of Aerography, Chap. X. (A. McAdie.)

trade, meaning in one direction. On the pilot charts issued by the Hydrographic Office, founded upon the researches made and the data collected by Lieut. M. F. Maury, U. S. N., there is published the average condition of wind and weather for the given period. Thus if we look on the chart of the North Pacific Ocean for May we find that the northeast trades, force 4 to 5 (5 to 8 meters per second), extend to within about 5° of the American coast between the twenty-fifth and fifteenth parallels. They average 24 days in May over the Hawaiian Islands. On the other hand, the southeast trades, force 3 to 4 (3 to 5 meters per second), extend 1° to 5° north of the Equator, and are farthest north between longitudes 150° W. and 110° W.

Over the Atlantic during May we find that the northeast trades extend northward slightly beyond the Canary Islands, but west of the thirtieth meridian the northern limit of these winds is nearly along the twenty-fifth parallel. The southern limit is close to the Equator on the American side, but rises to latitude 12° N. at longitude 20° W. The force of the northeast trades is 4 to 5, increasing toward the south. Their direction is northerly off the African coast, but is northeast between the twentieth and thirtieth meridians. Farther westward the direction is more easterly, and north of the Lesser Antilles it is southeasterly, showing the anti-cyclonic circulation around the Azores hyperbar. The winds are generally east to northeast in the Caribbean Sea and east to southeast in the Gulf of Mexico. The southeast trades, force 3 to 4, extend from 1° to 30° above the Equator between the eighth and forty-second meridians.

Over the Indian Ocean during May the southeast trades prevail over the area between the Equator and latitude 30° S. Over the extreme northern and southern portions of this area the trades are broken by variable winds, and calms are frequent between the Equator and 10° S. The trades are steadiest between latitudes 10° S. and 25° S. Along the African coast, near the Equator, they follow the contour of the land and merge into the southwest monsoon.

If we follow the trades during winter months we shall find that over the North Pacific the northeast trades reach their most northern limit in the eastern part of the ocean at the twenty-ninth parallel, slightly southeast of the central area of the California high, and are strongest and steadiest south of this region. Between longitudes 145° W. and 155° E. their northern limit is close to the 25th parallel. They extend eastward to within 5° to 8° of the American coast and westward to Asiatic waters, where they merge into the northeast monsoon. They extend as far south as the Equator west of longitude 170° E. East of this longitude their southern limit gradually rises to the tenth parallel at longitude 125° W. The southeast trades extend north of the Equator between longitudes 85° W. and 180° W.

They reach their most northern limit, the sixth parallel, between longitudes 115° W. and 125° W. In the North Atlantic the northeast trades prevail between the fifth and twenty-fifth parallels. Near Brazil they extend as far south as the Equator, and near the African coast as far north as latitude 32° N. These winds are the typical northeast trades over the eastern part of the ocean and in the Caribbean Sea. In the central part of the ocean they become east-northeasterly. Southeast trade winds extend north of the Equator over the central part of the ocean to the fourth parallel.

In the South Atlantic the southeast trades prevail from the area of high pressure to latitude 5° S. on the eastern part of the ocean, and from latitude 15° S. to the Equator on the western. Over the greater part of this area they are well developed, blowing from the southeast from 50 to 60 per cent of the time, with a small percentage of calms and no gales, the average force being about 4. South of the area of high pressure "the brave west winds" prevail. They have increased slightly in intensity since the spring. The winds around the high show their anticyclonic movements very plainly, while those within the area are variable in direction and force. Over the Indian Ocean in winter the southeast trades occur between 10° S. and 30° S. east of the fiftieth meridian. Their average force is 3 to 4. West of Madagascar the winds are mostly northeasterly and southeasterly, while south of Madagascar they are easterly.

In discussing the planetary circulation it is assumed that in the upper levels there must be an overflow of air from the Equator to the poles. Recent soundings, however, do not confirm this view. And this variability in flow is shown in marked degree above the trades. The trades themselves are comparatively shallow streams, not extending above the 5-kilometer level. Above these the air movement is from west to east; and these winds are called the anti-trades, somewhat unfortunately since this term is applied to the winds farther north or south, better described as the prevailing westerlies. We shall use the term "countertrades" for the winds above the trades. The countertrades, then, are above the trades and extend approximately from 4 to 16 kilometers, or more than twice the depth of the surface trades. Still higher and above the countertrades flows the so-called upper easterly current, extending up to a height of 20 kilometers, and above this again, a westerly flow in the same direction as the countertrades, and approximately 5 kilometers in depth. Finally at a height of 30 kilometers there would seem to be another easterly current. Thus over the Tropics we find at least five wind systems. As we move to higher latitudes, the winds, possibly under the influence of the deflective tendency, due to the earth's rotation, change their direction through the south and become eventually west winds. These air streams are drier and heavier than the trades and descend to the surface in latitude 30° from the thermal Equator as warm, dry, southwest winds. In the United States the anti-trades are more commonly called the prevailing westerlies, winds which lack the steadiness of the trades, but which nevertheless are the controlling factors in determining the weather of the temperate zones.

In connection with the movement of the upper air it is of interest to note that the dust from the Krakatau eruption in 1883, a few degrees south of the equator, was carried from east to west around the world in about 15 days. The red sunsets and sunrises due to the fine dust and vapor particles appear progressively later from west to east and indicated an average movement of 113 kilometers per hour, 31 meters per second.

Monsoons.—The word "monsoon" is said to be of Arabic origin, meaning "season," and rightly applies to the winds of the Indian Ocean, for the general character of the season and the crop yield are closely connected with the duration and intensity of these winds. During the summer months the southwest monsoon force 3 to 5 (3 to 8 meters per second) dominates the ocean north of the equator. It overspreads the Arabian Sea early in June, and by the third week is in full force over the Bay of Bengal. Severe thunderstorms, thick, cloudy weather, and gales with occasional dangerous cyclones occur during the period immediately preceding the full force of the monsoon. In winter we have to deal with the northeast monsoon, force 3 to 4 (3 to 5 meters per second), which prevails over Indian waters and extends down the African coast to latitude 10° S. Northwesterly winds prevail in the Persian Gulf and the Gulf of Oman, and easterly winds in the Gulf of Aden. In the southern part of the Red Sea the winds are southeasterly, and in the northern part they are northwesterly. On the Asiatic coast the winds east of Chosen (Korea) are northeasterly; west of it they are northwesterly. Along the China coast immediately north of Shanghai to the fifth parallel they are northeasterly and are known as the northeast (winter) monsoon. The monsoon is in full force during January and blows with greatest strength and constancy between Macao and Chusan. It shows a marked tendency to follow the coast, and as it weakens at night and the wind becomes somewhat offshore, northbound sailing vessels may then make fair headway. The thick, rainy weather of the monsoon period renders navigation difficult off the coast of Taiwan (Formosa). A rising pressure foreruns an increase in the strength of the monsoon, and a falling pressure a decrease.

Local winds.—In nearly every land there are local names for special winds, based as a rule upon the warm or cold and wet or dry character of the wind. In mountainous countries, especially if the range is but a short distance from some large water surface, the air at times seems to rush through the valleys and canyons. This can nearly always be traced to the passage of some general disturbance. There is another class of day and night winds which are due primarily to differences of temperature in the valley and at the level of the mountain tops; also sometimes to differences in the heating of the east and the west sides of the range. These are the well-known mountain and valley winds, reversing their direction with the change from night to day. In all these wind systems the contour of the land plays an important part. Study of the topography shows that the drafts are localized and intensified by the lay of the land. Most of these winds are in the nature of forced drafts, in the sense that air masses, generally with moderate momentum, forced through restricted channels, such as mountain passes and valleys, are drafts. These are chiefly horizontal currents, while the regular mountain and valley winds are more often due to vertical currents.

It is not surprising, therefore, to find that the direction of the flow may be determined to some degree by the trend of the narrow air passage or valley. Thus, although the foehn wind in the Alps is primarily a south or southwest wind, it may appear in certain districts as a southeast wind, having had its direction of flow deflected by the trend of the valley. Furthermore, displacement at one place means motion at some other point of the circuit, and we may have an endless chain, as it were, in which the natural flow is masked. And just as in the case of the flow of water in rivers there may be established return currents at the sides of the main stream, or eddy currents at points where obstruction to the general flow is met, in the central part of a valley the flow of air or wind may be in one direction, while on the sides the flow may be in an opposite direction. An excellent way of studying the flow of air in mountainous countries is from a station on the summit. Close observation of the clouds above and the fogs below, as they form and dissipate, will show the existence of many unsuspected air streams.

Of all the special winds, the foehn is perhaps the best known, as it has been most studied and written about. The word is of German origin and possibly is connected with the Latin "favonius," a west wind of the spring; but if such were the original meaning it is not in accord with the conditions now existing, for the foehn is essentially a dry south wind. It blows on the northern slopes of the Alps and is most noticeable in those valleys which have a north-and-south trend; indeed, it is hardly noticeable in some valleys which extend east and west. For many years it was explained as originating in the deserts of Africa; but it is now known to be the southerly component of an indraft due to the passage of a cyclonic area over Western Europe. The word foehn is also used in a broader sense to designate any wind system where the air, moving into a cyclone, is forced over some range and thus cooled and dried; and then, descending on the farther slopes, is dynamically heated. Under such conditions evaporation is rapid and snow on the ground disappears quickly. In the Northern Hemisphere such winds in temperate latitudes are generally from the south, and in the Southern Hemisphere from the north. Thus we find foehn winds in Greenland, Iceland, Eastern Europe, as in Hungary (rotenturmwind), South America, Japan, Peru, and in fact in all parts of the world where mountains act as partial barriers to the flow of air and there is compression after expansion. Such a wind is the chinook (name of an Indian tribe dwelling on Puget Sound), a dry and relatively warm wind of Wyoming, Montana, Idaho, eastern Oregon, and parts of Colorado. A good illustration of the pressure distribution and resulting wind direction and temperature can be found on the weather map for January 23, 1907. The temperature rose quickly from about 255° A. to 275° A. and, as previously stated, the snow evaporated rapidly. The duration of the wind depends upon the movement of the low-pressure area to the north. Sometimes the high temperature will last 24 hours. Other warm, dry winds are the so-called "hot winds" of the Plains States, the summer winds of Texas, the "northers" of the Sacramento and San Joaquin valleys, and the "Santa Anas" of southern California. Some of these winds in the summer months pass over heated areas and are warmed to some degree by radiation from the earth. The sirocco of southern Italy and Greece is a warm south wind, generally dust-laden and therefore trying to man and beast. The leveche of Spain and the leste of the Maderia Islands are sirocco winds; the solano is an east wind on the east coast of Spain; the harmattan is a hot, dusty east wind of the winter months in the Gulf of Guinea; the simoon (from the Arabic word to poison, although there are no poisonous gases associated with it) is a hot, sand-laden wind felt in Palestine, Syria, and Arabia; the Khamsin of Egypt is a hot southeast wind which blows for about 50 days after the middle of March; the brickfielders are hot north winds of Southern Australia. There are many others having local names.

Cold waves and boreal winds.—The word "boreal," from "Boreas," the north wind of the Greeks, is used to designate a class of cold winds generally of cyclonic origin. There would seem to be some connection between the intensity of the depression and the temperature of the northwest quadrant. Being preceded by comparatively warm southerly winds, the contrast is marked and all the more noticeable. The air is not necessarily brought from high levels, and the compression is not sufficiently great to warm the air enough to affect materially its initial low temperature. The so-called cold waves of the United States are essentially boreal winds. Such, too, are the "buran" or "purga" of Russia, the "pamperos" of Argentina, the southerly "burster" of New Zealand, the "bora" of the Adriatic, and the "mistral" of the valley of the Rhone. The word "mistral" is derived from the Latin "magister," and the wind is therefore appropriately described as a master wind, or the wind which dominates. It has been known for some time that the winds of the Antarctic region were of higher velocity and lower temperature than elsewhere, and the records of the Australian Antarctic expedition of 1911–1914 confirms this. Thus gusts of wind having a velocity of nearly 90 meters per second (200 miles per hour) were recorded on the Robinson anemometers used. The record is subject to correction, and these figures may be reduced 20 per cent. Velocities of 80 meters per second and even higher were not infrequent, nor were winds of 45 meters per second (100 miles per hour) with a temperature of 240° A. (−28° F.) rare.

Charts for aeronauts and aviators.—The term "aeronaut" is used to designate the pilot of a balloon, while "aviator" is restricted to the pilot of a heavier-than-air flying machine. One of the first attempts to bring the results of the exploration of the air by kites, balloons, and other means into convenient form for the use of aviators and aeronauts is the volume by Rotch and Palmer,[1] issued in 1911. Charts of the relative heights, corresponding densities, and temperatures are given. The frequency of winds from various directions and their respective velocities at Blue Hill are shown. Thus the shallowness of easterly winds is made evident by comparison at different levels. The summer sea breeze has a depth of about 1,000 meters, while the easterly winds of cyclonic origin may have a depth of 2,000 meters. The winds of winter are of greater velocity than the winds of summer. In brief, west winds are most frequent. Near the ground they blow about 25 per cent of the time from south-southwest to west-southwest in summer, and about 33 per cent of the time from west to northwest in winter, with a velocity varying from 8 to 11 meters per second. At a height of 3,000 meters the frequency of the westerly winds increases to nearly twice that at the lower level, and there is a corresponding increase in velocity. Particular attention is paid to the problem of trans-Atlantic flight and the possibility of utilizing the northeast trade for the western voyage is considered. The height at which the southwest counter trade may be expected is uncertain. It has sometimes been found below 1,500 meters, and again has been absent at 10,000 meters.

Another excellent book is that of C. J. P. Cave, entitled "The Structure of the Atmosphere is Clear Weather," which gives the result of 200 observations of pilot balloons and "ballons-sondes." The direction and velocity of the wind at different levels are charted. Cardboard models show the distribution of wind with each kilometer

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[1] Charts of the Atmosphere for Aeronauts and Aviators.

of height. The arrowhead flies with the wind. The gradient wind is computed from the distribution of pressure. The velocity is calculated from the measured distance of two isobars between which the station lies by means of the formula.

$$G_p = 2\rho\omega\, v \sin\phi$$

where G_p is the gradient, ω the angular velocity of the earth, ϕ the latitude, v the velocity, and ρ the density of the air.

Five types of atmospheric structure are described: (1) Where the wind in the upper air is steady and there is no increase of velocity with height; (2) where the wind is steady, but increases in velocity much above the gradient value; (3) where the upper wind decreases in velocity; (4) where changes of direction or reversals occur; and (5) where the upper air blows away from centers of low pressure.

The strongest current is, as a rule, just below the stratosphere; and in view of the work of Dines and the suggestions of Shaw, the question is raised whether it would not be advantageous to refer variations in the different levels to the conditions in the 9-kilometer level instead of to the surface. Starting with a strong westerly wind under the stratosphere, Cave would then work downward, for almost without exception the west wind decreases in the lower levels, and the falling off may proceed continuously to such an extent that the direction of motion is reversed at some point in the intermediate layers, so that near the surface an easterly wind is shown instead of the westerly one of the upper levels.

The term "holes in the air" has been used by aviators to describe certain unstable conditions experienced when flying and which in their opinion are caused either by "holes" in the air, or by partial vacuums or "pockets." Such conditions are found on summer mornings and afternoons and near cumulus clouds, and are generally simply ascending currents of some momentum through which the flyer passes. Sometimes the aviator may skirt such a column of uprising air (and there are also descending currents), and part of the plane be within the current, while the rest may be without. In such cases there will be sudden tilting or inequality of pressure, and the aviator should be careful not to attempt to meet the changed conditions too quickly, for they are but temporary and instability will result when the machine is again free. Not only near cumuli, also near cross currents—that is, where one air stream is flowing in a different direction from an adjacent stream—there will be minor vortices and more or less of an air surge; and such a condition will cause instability of the airplane. As has been explained in preceding paragraphs, there is sometimes a marked stratification of the lower air, and under certain conditions marked turbulence. When such conditions are suspected it might be advisable to resort to preliminary tests by freezing pilot balloons or pilot planes.

A. McA.

1. Tables for the Computation of Humidity from the Readings of the Dry and Wet Thermometers on the Kelvin Scale of Absolute Temperature Based on Glaisher's Factors.

[From Computer's Handbook, Meteorological Office.]

Per cent of relative humidity.	Dry thermometer.									
	270°	271°	272°	273°	274°	275°	276°	277°	278°	279°
	WET THERMOMETER.									
	°	°	°	°	°	°	°	°	°	°
99	270.0	271.0	272.0	273.0	274.0	274.9	275.9	276.9	277.9	278.9
95	269.9	270.9	271.8	272.8	273.7	274.7	275.7	276.7	277.7	278.7
90	269.8	270.7	271.6	272.6	273.5	274.4	275.4	276.4	277.3	278.3
85	269.6	270.6	271.5	272.3	273.2	274.1	275.1	276.0	277.0	277.9
80	269.5	270.4	271.3	272.1	272.9	273.8	274.7	275.6	276.6	277.5
75	269.3	270.2	271.1	271.8	272.6	273.4	274.3	275.3	276.2	277.1
70	269.2	270.0	270.8	271.5	272.3	273.1	273.9	274.8	275.8	276.7
65	269.0	269.8	270.6	271.2	271.9	272.7	273.5	274.4	275.3	276.2
60	268.8	269.6	270.3	270.9	271.5	272.2	273.1	273.9	274.8	275.7
55	268.6	269.4	270.0	270.6	271.1	271.8	272.6	273.4	274.3	275.2
50	268.4	269.2	269.7	270.2	270.7	271.3	272.1	272.9	273.8	274.6
45	268.2	268.9	269.4	269.8	270.2	270.7	271.5	272.3	273.1	274.0
40	268.0	268.6	269.0	269.4	269.7	270.2	270.8	271.6	272.5	273.3
35	267.7	268.3	268.6	268.9	269.1	269.5	270.1	270.9	271.7	272.5
30	267.4	267.9	268.2	268.3	268.4	268.8	269.3	270.0	270.8	271.6
25	267.0	267.5	267.7	267.6	267.6	267.9	268.4	269.1	269.8	270.5
20	266.6	266.9	267.0	266.9	266.7	266.8	267.3	267.9	268.6	269.3
10	265.3	265.4	265.2	264.5	263.9	263.7	264.0	264.5	265.1	265.6
	VAPOR PRESSURE.									
	Kb.	*Kb.*	*Kb.*	*Kb.*	*Kb.*	*Kb.*	*Kb.*	*Kb.*	*Kb.*	*Kb.*
100	4.89	5.27	5.66	6.09	6.54	7.03	7.55	8.09	8.68	9.29
90	4.40	4.74	5.09	5.48	5.89	6.33	6.80	7.28	7.81	8.36
80	3.91	4.22	4.53	4.87	5.23	5.62	6.04	6.47	6.94	7.43
70	3.42	3.69	3.96	4.26	4.58	4.92	5.29	5.66	6.08	6.50
60	2.93	3.16	3.40	3.65	3.92	4.22	4.53	4.85	5.21	5.57
50	2.45	2.64	2.83	3.05	3.27	3.52	3.78	4.05	4.34	4.65
40	1.96	2.11	2.26	2.24	2.62	2.81	3.02	3.24	3.47	3.72
30	1.47	1.58	1.70	1.83	1.96	2.11	2.27	2.43	2.60	2.79
20	0.98	1.05	1.13	1.22	1.31	1.41	1.51	1.62	1.73	1.86
10	0.49	0.53	0.57	0.61	0.65	0.70	0.76	0.81	0.87	0.93

Per cent of relative humidity.	Dry thermometer.									
	280°	281°	282°	283°	284°	285°	286°	287°	288°	289°
	WET THERMOMETER.									
	°	°	°	°	°	°	°	°	°	°
99	279.9	280.9	281.9	282.9	283.9	284.9	285.9	286.9	287.9	288.9
95	279.7	280.6	281.6	282.6	283.6	284.6	285.6	286.6	287.6	288.6
90	279.3	280.3	281.3	282.2	283.2	284.2	285.2	286.2	287.1	288.1
85	278.9	279.9	280.9	281.8	282.8	283.8	284.7	285.7	286.7	287.7
80	278.5	279.5	280.4	281.4	282.4	283.3	284.3	285.2	286.2	287.2
75	278.1	279.0	280.0	280.9	281.9	282.8	283.8	284.7	285.7	286.6
70	277.6	278.6	279.5	280.5	281.4	282.3	283.3	284.2	285.1	286.1
65	277.2	278.1	279.0	279.9	280.8	281.8	282.7	283.6	284.5	285.5
60	276.7	277.6	278.5	279.4	280.3	281.2	282.1	283.0	283.9	284.8
55	276.1	277.0	277.9	278.8	279.7	280.6	281.5	282.3	283.2	284.2
50	275.5	276.4	277.3	278.2	279.0	279.9	280.8	281.6	282.5	283.4
45	274.8	275.7	276.6	277.5	278.3	279.2	280.0	280.9	281.7	282.6
40	274.1	275.0	275.8	276.7	277.5	278.3	279.2	280.0	280.8	281.7
35	273.3	274.1	275.0	275.8	276.6	277.4	278.2	279.0	279.9	280.7
30	272.4	273.2	274.0	274.8	275.6	276.4	277.2	277.9	278.7	279.6
25	271.3	272.1	272.9	273.7	274.4	275.2	275.9	276.7	277.4	278.2
20	270.0	270.8	271.6	272.3	273.0	273.7	274.4	275.2	275.9	276.7
10	266.4	267.0	267.6	268.2	268.9	269.5	270.1	270.7	271.3	272.0

1. TABLES FOR THE COMPUTATION OF HUMIDITY FROM THE READINGS OF THE DRY AND WET THERMOMETERS ON THE KELVIN SCALE OF ABSOLUTE TEMPERATURE BASED ON GLAISHER'S FACTORS—Continued.

Per cent of relative humidity.	Dry thermometer.									
	280°	281°	282°	283°	284°	285°	286°	287°	288°	289°
	VAPOR PRESSURE.									
	Kb.	Kb.	Kb.	Kb.	Kb.	Kb.	Kb.	Kb.	Kb.	Kb.
100	9.96	10.65	11.40	12.19	13.02	13.91	14.85	15.84	16.89	18.01
90	8.96	9.59	10.26	10.97	11.72	12.52	13.37	14.26	15.20	16.21
80	7.97	8.52	9.12	9.75	10.42	11.13	11.88	12.67	13.51	14.41
70	6.97	7.46	7.98	8.53	9.11	9.74	10.40	11.09	11.82	12.61
60	5.98	6.39	6.84	7.31	7.81	8.35	8.91	9.50	10.13	10.81
50	4.98	5.33	5.70	6.10	6.51	6.96	7.43	7.92	8.45	9.01
40	3.98	4.26	4.56	4.88	5.21	5.56	5.94	6.34	6.76	7.20
30	2.99	3.20	3.42	3.66	3.91	4.17	4.46	4.75	5.07	5.40
20	1.99	2.13	2.28	2.44	2.60	2.78	2.97	3.17	3.38	3.60
10	1.00	1.07	1.14	1.22	1.30	1.39	1.49	1.58	1.69	1.80

DRY THERMOMETER.

Per cent of relative humidity.	290°	291°	292°	293°	294°	295°	296°	297°	298°	299°
	WET THERMOMETER.									
	°	°	°	°	°	°	°	°	°	°
99	289.9	290.9	291.9	292.9	293.9	294.9	295.9	296.9	297.9	298.9
95	289.6	290.6	291.6	292.5	293.5	294.5	295.5	296.5	297.5	298.5
90	289.1	290.1	291.1	292.1	293.0	294.0	295.0	296.0	297.0	298.0
85	288.6	289.6	290.6	291.5	292.5	293.5	294.5	295.4	296.4	297.4
80	288.1	289.1	290.1	291.0	292.0	292.9	293.9	294.9	295.8	296.8
75	287.6	288.5	289.5	290.5	291.4	292.3	293.3	294.3	295.2	296.2
70	287.0	288.0	288.9	289.8	290.8	291.7	292.7	293.6	294.6	295.5
65	286.4	287.3	288.3	289.2	290.1	291.1	292.0	292.9	293.9	294.8
60	285.8	286.7	287.6	288.5	289.4	290.4	291.3	292.2	293.1	294.1
55	285.1	286.0	286.9	287.8	288.7	289.6	290.5	291.4	292.3	293.2
50	284.3	285.2	286.1	287.0	287.9	288.8	289.7	290.6	291.4	292.4
45	283.5	284.4	285.2	286.1	287.0	287.9	288.8	289.6	290.5	291.4
40	282.6	283.4	284.3	285.1	286.0	286.9	287.7	288.6	289.4	290.3
35	281.6	282.4	283.2	284.1	284.9	285.7	286.6	287.4	288.3	289.1
30	280.4	281.2	282.0	282.9	283.7	284.5	285.3	286.1	286.9	287.8
25	279.1	279.8	280.6	281.4	282.2	283.0	283.8	284.6	285.4	286.2
20	277.4	278.2	279.0	279.7	280.5	281.2	282.1	282.8	283.5	284.4
10	272.7	273.4	274.1	274.8	275.4	276.1	276.8	277.4	278.1	278.8
	VAPOR PRESSURE.									
	Kb.	Kb.	Kb.	Kb.	Kb.	Kb.	Kb.	Kb.	Kb.	Kb.
100	19.20	20.44	21.76	23.14	24.62	26.17	27.81	29.53	31.36	33.28
90	17.28	18.40	19.58	20.83	22.16	23.55	25.03	26.58	28.22	29.95
80	15.36	16.35	17.42	18.51	19.70	20.94	22.25	23.62	25.09	26.62
70	13.44	14.31	15.23	16.20	17.23	18.32	19.47	20.67	21.95	23.30
60	11.52	12.26	13.07	13.88	14.77	15.70	16.69	17.72	18.82	19.97
50	9.60	10.22	10.88	11.57	12.31	13.09	13.91	14.77	15.68	16.64
40	7.68	8.18	8.70	9.26	9.85	10.47	11.12	11.81	12.54	13.31
30	5.76	6.13	6.53	6.94	7.39	7.85	8.34	8.86	9.41	9.99
20	3.84	4.09	4.35	4.63	4.92	5.23	5.56	5.91	6.27	6.66
10	1.92	2.04	2.18	2.31	2.46	2.62	2.78	2.95	3.14	3.33

1. TABLES FOR THE COMPUTATION OF HUMIDITY FROM THE READINGS OF THE DRY AND WET THERMOMETERS ON THE KELVIN SCALE OF ABSOLUTE TEMPERATURE BASED ON GLAISHER'S FACTORS—Continued.

Per cent of relative humidity.	Dry thermometer.									
	300°	301°	302°	303°	304°	305°	306°	307°	308°	309°
	Wet thermometer.									
	°	°	°	°	°	°	°	°	°	°
99	299.0	300.9	301.9	302.9	303.9	304.9	305.9	306.9	307.9	308.9
95	299.5	300.5	301.5	302.5	303.5	304.5	305.4	306.4	307.4	308.4
90	298.9	299.9	300.9	301.9	302.9	303.9	304.9	305.8	306.8	307.8
85	298.4	299.4	300.3	301.3	302.3	303.3	304.2	305.2	306.2	307.2
80	297.8	298.7	299.7	300.7	301.7	302.6	303.6	304.6	305.5	306.5
75	297.1	298.1	299.1	300.0	301.0	301.9	302.9	303.9	304.8	305.8
70	296.5	297.4	298.4	299.3	300.3	301.2	302.2	303.1	304.1	305.0
65	295.8	296.7	297.6	298.6	299.5	300.5	301.4	302.3	303.3	304.2
60	295.0	295.9	296.8	297.7	298.7	299.6	300.6	301.5	302.4	303.3
55	294.2	295.1	296.0	296.9	297.8	298.7	299.7	300.6	301.5	302.4
50	293.3	294.2	295.1	296.0	296.9	297.8	298.7	299.6	300.5	301.4
45	292.3	293.2	294.1	295.0	295.9	296.8	297.7	298.5	299.4	300.3
40	291.2	292.1	293.0	293.9	294.8	295.6	296.5	297.4	298.2	299.1
35	290.0	290.9	291.7	292.6	293.5	294.3	295.2	296.1	296.9	297.8
30	288.6	289.5	290.3	291.2	292.0	292.9	293.7	294.6	295.4	296.2
25	287.0	287.9	288.7	289.5	290.4	291.2	292.0	292.8	293.6	294.5
20	285.2	286.0	286.8	287.6	288.4	289.2	290.0	290.8	291.5	292.3
10	279.6	280.3	281.0	281.7	282.4	283.2	283.9	284.6	285.4	286.1
	Vapor pressure.									
	Kb.	*Kb.*	*Kb.*	*Kb.*	*Kb.*	*Kb.*	*Kb.*	*Kb.*	*Kb.*	*Kb.*
100	35.29	37.42	39.65	42.01	44.49	47.09	49.83	52.69	55.71	58.88
90	31.76	33.68	35.69	37.81	40.04	42.38	44.85	47.42	50.14	52.99
80	28.23	29.94	31.72	33.61	35.59	37.67	39.86	42.15	44.57	47.10
70	24.70	26.19	27.76	29.41	31.14	32.96	34.88	36.88	39.00	41.22
60	21.17	22.45	23.79	25.21	26.69	28.25	29.90	31.61	33.43	35.33
50	17.65	18.71	19.83	21.01	22.25	23.55	24.92	26.35	27.86	29.44
40	14.12	14.97	15.86	16.80	17.80	18.84	19.93	21.08	22.28	23.55
30	10.59	11.23	11.90	12.60	13.35	14.13	14.95	15.81	16.71	17.66
20	7.06	7.48	7.93	8.40	8.90	9.42	9.97	10.54	11.14	11.78
10	3.53	3.74	3.97	4.20	4.45	4.71	4.98	5.27	5.57	5.89

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CHAPTER IV.

HOLES IN THE AIR.

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"HOLES IN THE AIR."

By Prof. W. J. Humphreys.

General statement.—Every aviator experiences in the course of his flights many seemingly abrupt drops, and numerous more or less severe jolts. The causes of the first—the sudden drops—he has grouped together and called "holes in the air," while to the latter he has given such names as "bumps," "dunts," etc. There are, of course, no holes, in the ordinary sense of the term, in the atmosphere—no vacuous regions—but the phrase "holes in the air" graphically expresses the fact that occasionally, at various places in the atmosphere, there are conditions which, so far as flying is concerned, are very like unto holes. Such conditions are indeed real and, because of both their general interest and practical importance, deserving of careful study.

Before taking up these actual conditions, however, it will be convenient first to show that no matter how suddenly an aviator may drop, it can not be because he has run into a vacuum. Suppose for a moment that there was a great hole in the quiet atmosphere, in the sense of a place devoid of air. Obviously the surrounding atmosphere would begin rushing into this space with the velocity given by the equation, $v = \sqrt{2gH}$, in which g is gravity acceleration, and H the virtual height of the atmosphere, approximately 8 kilometers. Hence, since v equals 400 meters per second, roughly, or nearly 900 miles per hour, even if such a hole existed it would be impossible for an aviator to get into it—he could not catch up with its closing walls. But, according to the claims of some, if there are no complete holes in the atmosphere, there are, at any rate, places where the density is much less than that of the surrounding air; so much less, indeed, that when an aeroplane runs into one of them it drops quite as though it were in a place devoid of all air and without support of any kind.

This, too, like the actual hole, is a pure fiction that has no warrant in barometric records. Indeed, such a condition could be established and maintained only by a gyration or whirl of the atmosphere, such that the centrifugal force would be sufficient to equal the difference in pressure, at the same level, between the regions of high and low density.

Let, for instance, the pressure gradient be uniform about a circular area and so great that the barometer reading varies from 0 at the center to 1013 Kb. at the radial distance 0.5 km.

On substituting these values in the gradient velocity equation, $f=2m\omega\, v \sin\phi+\frac{mv^2}{r}$, or, very closely, $f=\frac{mv^2}{r}$, and remembering that the density varies as the pressure, or, in this case, as r, that is from 0 where $r=0$ to .00129 where $r=0.5$ kilometers, it appears that the linear velocity of the wind in the tornadic whirl that would sustain such a gradient would be the same throughout, and approximately 280 meters per second (626 miles per hour). But such large and violent whirls are unknown; even tornadoes seldom reduce the pressure more than 10 per cent. Hence neither vacua nor even isolated and dangerous partial vacua occur in the atmosphere.

Along with these two impossibles, the vacuum and the half vacuum, should be consigned to oblivion that other picturesque fiction, the "pocket of noxious gas." Probably no other gases, certainly very few, have, at ordinary temperatures and pressures, the same density as atmospheric air. Therefore, a pocket of foreign gas in the atmosphere would almost certainly either bob up like a balloon, or sink like a stone in water; it could not float in mid-air. It is possible, of course, as will be explained a little later, to run into columns of rising air that may contain objectional gases and odors, but these columns are quite different from anything likely to be suggested by the expression "pocket of gas."

The above are some of the things that, fortunately, do not exist. The following, however, are some that do exist and produce effects such as actual vacua and partial vacua would produce—sudden drops, usually small but occasionally very considerable, and, though rarely, even disastrous falls.

Air fountains.—A mass of air rises or falls according as its density is less or greater, respectively, than that of the surrounding atmosphere, just as and for the same reason that a cork bobs up in water and a stone goes down.

Hence warm and therefore expanded and relatively light air is driven up whenever the surrounding air at the same level is colder, and as the atmosphere is heated mainly through contact with the surface of the earth, which in turn has been heated by sunshine, it follows that these convection currents or vertical uprushes of the atmosphere, are most numerous during calm summer afternoons.

The turbulence of some of these rising masses is evident from the numerous rolls and billows of the large cumulus clouds they produce, and it is obvious that the same sort of turbulence, probably on a smaller scale, occurs near the top of such columns as do not rise to the cloud level. Further, it is quite possible, when the air is exceptionally quiet, for a rising column to be rather sharply separated from the surrounding quiescent atmosphere, as is evident from the closely adhering long pillars of smoke occasionally seen to rise from chimneys.

The velocity of ascent of such fountains of air is at times surprisingly great. Measurements on pilot balloons and also measurements taken in manned balloons have shown vertical velocities, both up and down, of more than 3 meters per second. The soaring of large birds is a further proof of an upward velocity of the same order of magnitude, while the fact that in cumulus clouds water drops and hailstones often are not only temporarily supported, but even carried to higher levels, shows that uprushes of at least 8 to 10 or 12 meters per second not merely may but actually do occur.

There are, then, air fountains of considerable velocity whose sides at times and places may be almost as sharply separated from the surrounding atmosphere as are the sides of a fountain of water, and it is altogether possible for the swiftest of these to produce effects on an aeroplane more or less disconcerting to the pilot. The trouble may occur:

1. On grazing the column, with one wing of the machine in the rising and the other in the nonrising air; a condition that interferes with the lateral stability and produces a sudden shock both on entering the column and on leaving it.

2. On plunging squarely into the column; thus suddenly increasing the angle of attack, the pressure on the wings, and the angle of ascent.

3. On abruptly emerging from the column; thereby causing a sudden decrease in the angle of attack and also abruptly losing the supporting force of the rising mass of air.

4. As a result of rotation, if rapid, as it sometimes is, of the rising air.

That flying with one wing in the column and the other out must interfere with lateral stability and possibly cause a drop as though a hole had been encountered, is obvious, but the effects of plunging squarely into or out of the column require a little further consideration as does also the effect of rotation.

Let an aeroplane that is flying horizontally pass from quiescent air squarely into a rising column. The front of the machine will be lifted, as it enters the column, a little faster than the rear, and the angle of attack, that is, the angle which the plane of the wing, or plane of the wing chords, makes with the apparent wind direction, will be slightly increased. This, together with the rising air, will rapidly carry the machine to higher levels, which, of itself, is not important. If, however, the angle of attack is so changed by the pilot as to keep the machine, while in the rising column, at a constant level, and if, with this new adjustment the rising column is abruptly left, a rapid descent must begin. But even this is not necessarily harmful.

Probably the real danger under such circumstances arises from *over adjustments* by the aviator in his hasty attempt to correct for the abrupt changes. Such an adjustment might well cause a fall so sudden as strongly to suggest an actual hole in the air.

If the rising column is in fairly rapid rotation (tornadoes are excluded—they can be seen and must be avoided), as sometimes is the case, disturbances may be produced in several ways. If the column is entered on its approaching side, the head-on wind may so decrease the velocity of the plane with reference to the surrounding air that on emerging there necessarily must be a greater or less drop; as explained below under the caption "Wind layers." On the other hand, if entered on the receding side there will be a tendency to drop within the column, which may or may not be fully compensated by the vertical component of the wind. Finally, such a rotating column, especially, perhaps, if crossed near its outer boundary, may quickly change the orientation of the plane and therefore the action on it of the surrounding air.

None of these conditions, however, except when encountered near the surface of the earth is likely to involve any appreciable element of danger to the skillful aviator. But this does not justify ignoring them—no beginner is skillful, and all must start from and return to the surface.

Rising columns of the nature just described occur most frequently during clear summer days and over barren ground. They also occur, even to surprising altitudes, over roads, sandpits, and other places of similar contrast to the surrounding areas. Isolated hills, especially short or conical ones, should be avoided during warm still days, for on such occasions their sides are certain to be warmer than the adjacent atmosphere at the same level, and hence to act like so many chimneys in producing updrafts. Rising air columns occur less frequently and are less vigorous over water and over level green vegetation than elsewhere. They are also less frequent during the early forenoon than in the hotter portion of the day, and are practically absent before sunrise and at such times as the sky is wholly covered with clouds.

Air cataracts.—There are two kinds of air cataracts, the free air cataracts and the surface cataract. The former is the counterpart of the air fountain and is most likely to occur at the same time.

Indeed it is certain to occur over a small pond, lake, or clump of trees in the midst of a hot and rather barren region. These cooler spots localize the return or down branches of the convection currents, and generally should be avoided by the aviator when flying at low levels. Similarly, on calm, clear, summer days down currents nearly always obtain at short distances offshore, over rivers, and along the edges of forests. The free-air cataract, however, seldom is swift, except in connection with thunderstorms, and, therefore while it may render flying difficult or even impossible with a slow machine it seldom involves much danger.

The second, or surface cataract, is caused by the flow of a dense or, what comes to the same thing, a heavily laden surface layer of air up to and then over a precipice, much as a waterfall is formed. Such cataracts are most frequent among the barren mountains of high latitudes where the cold surface winds catch up and become weighted with great quantities of dry snow and, because of both this extra weight and their high density often rush down the lee sides of steep mountains with the roar and force of a hurricane. But the violence of such winds clearly is all on the lee side and of shallow depth. Hence, where such conditions prevail the aviator should keep well above the drifting snow or other aerial ballast, and, if possible, strictly avoid any attempt to land within the cataract itself.

Cloud currents.—It frequently happens that a stratum of broken or detached clouds, especially of the cumulus type, is a region of turbulent currents, however quiet the air at both lower and higher levels. In the case of cumuli, at least, the currents within the clouds are upward, and those in the open spaces, therefore, in general, downward, with, of course, in each case greater or less turbulence. Hence while passing through such a layer the aviator is likely to encounter comparatively rough flying, though, owing to the height, of very little danger.

Air cascades.—The term "air cascades" may, with some propriety, be applied to the wind as it sweeps down the lee of a hill or mountain. Ordinarily it does not come very near the ground, where indeed there frequently is a counter current, but remains at a considerable elevation. Other things being equal, it is always most pronounced when the wind is at right angles to the direction of the ridge and when the mountain is rather high and steep. The swift downward sweep of the air when the wind is strong may carry a passing aeroplane with it and lead observers, if not the pilot, to fancy that a hole has been encountered where, of course, there is nothing of the kind. Indeed, such cascades should be entirely harmless as long as the aviator keeps his machine well above the surface and therefore out of the treacherous eddies, presently to be discussed.

Wind layers.—For one reason or another it often happens that adjacent layers of air differ abruptly from each other in temperature, humidity, and density, and, therefore, as explained by Helmholtz, may and often do glide over each other in much the same manner that air flows over water and with the same general wave-producing effect. These air waves are "seen" only when the humidity at the interface is such that the slight difference in temperature between the crests and the troughs is sufficient to keep the one cloud-capped and the other free from condensation. In short, the humidity condition must be kept just right; clearly, then, though such clouds often occur in beautiful parallel rows, adjacent wind strata of different velocities and their consequent air billows must be of far more frequent occurrence.

Consider now the effect on an aeroplane as it passes from one such layer into another. For the sake of illustration let the propeller be at rest and the machine be making a straightaway glide to earth, and let it suddenly pass into a lower layer of air moving in the same horizontal direction as the machine and with the same velocity. This, of course, is an extreme case, but it is by no means an impossible one. Instantly on entering the lower layer, under the conditions just described, all dynamical support must cease, and with it all power of guidance. A fall, for at least a considerable distance, is absolutely inevitable, and, if near the earth, perhaps a disastrous one. To all intents and purposes a hole has been run into.

The reason for the fall will be understood when it is recalled that the pressure of any ordinary wind is very nearly proportional to the square of its velocity with respect to the thing against which it is blowing. Hence, for a given inclination of the wings, the lift on an aeroplane is approximately proportional to the square of the velocity of the machine with reference, *not* to the ground, but to the *air* in which it happens to be at the instant under consideration. If, then it glides, with propellers at rest, into a wind stratum that is blowing in the same horizontal direction and with the same velocity it is in exactly the condition it would be if dropped from the top of a monument in still air. It inevitably must fall unless inherent stability or skill of the pilot bring about a new glide after additional velocity had been acquired as the result of a considerable drop.

Of course, such an extreme case must be of rare occurrence, but cases less extreme are met with frequently. On passing into a current where the velocity of the wind is more nearly that of the aeroplane, and in the same direction, part of the supporting force is instantly lost and a corresponding drop or dive becomes at once inevitable. Ordinarily, however, this is a matter of small consequence for the relative speed necessary to support it is again soon acquired, especially if the engine is in full operation. Occasionally, though, the loss in support may be large and occur but a short distance above the ground and, therefore, be correspondingly dangerous.

If the new wind layer is against and not with the machine, an increase instead of a decrease in the sustaining force is the result, and but little occurs beyond a mere change in the horizontal speed with reference to the ground and a slowing up of the rate of descent.

All the above discussion of the effect of wind layers on aeroplanes is on the assumption that they flow in parallel directions. Ordinarily, however, they flow more or less across each other and therefore, as a rule, the aviator on passing out of one of them into the other has to contend with more than a disconcertingly abrupt change in the supporting force. That is to say, on crossing the interface between wind sheets, in addition to suffering a partial loss of support, he usually has to contend with the turmoil of a choppy aerial sea, in which "bumps" at least seem to abound everywhere.

Wind strata within ordinary flying levels are most frequent during weather changes, especially as fine weather is giving way to stormy. This, then, is a time to be on one's guard against the most troublesome of all "holes in the air," even to the extent of making test soundings for them with small pilot balloons. It is also well on such occasions to avoid making great changes in altitude, since wind strata, of whatever intensity, remain roughly parallel to the surface of the earth, and the greater the change in altitude the greater the risk of running into a treacherous "hole." Also to avoid the possibility of losing support when too low to dive, and for other good reasons, landings and launchings should be made, if practicable, squarely in the face of the *surface* wind.

Wind billows.—It was stated above that when one layer of air runs over another of different density billows are set up between them, as often shown by windrow clouds; however, the warning clouds are comparatively seldom present, and therefore even the cautious aviator may, with no evidence of danger before him, take the very level of the air billows themselves and, before getting safely above or below them encounter one or more sudden changes in wind velocity and direction due, in part, to the eddy-like or rolling motion within the waves, with chances in each case of being suddenly deprived of a large portion of the requisite sustaining force—of encountering a "hole in the air." There may be perfect safety in either layer, but, unless headed just right, there necessarily is some risk in going from one to the other. Hence, flying at the billow level, since it would necessitate frequent transitions of this nature, should be avoided.

When the billows are within 300 meters, say, or less of the earth (often the case during winter, owing to the prevalence then of cold surface air with warmer air above), they are apt to be very turbulent, just as and for much the same reason that waves in shallow water are turbulent.

For this reason, presumably, winter flying sometimes is surprisingly rough, the air is full of "bumps" and "holes." Fortunately, however, it is easy to determine by the aid of a suitable station barograph whether or not billows are prevalent in the low atmosphere, since they produce frequent (5 to 12 per hour, roughly) pressure changes, usually of 0.1 Kb. to 0.4 Kb. at the surface.

Wind gusts.—Near the surface of the earth the wind is always in a turmoil, owing to friction and to obstacles of all kinds that interfere with the free flow of the lower layers of the atmosphere, and thereby allow the next higher layers to plunge forward in irregular fits, swirls, and gusts, with all sorts of irregular velocities and in every which direction. Indeed, the actual velocity of the wind near the surface of the earth often and abruptly varies from second to second by more than the full average value, and the greater the average velocity, the greater, in approximately the same ratio, are the irregularities or differences in the successive momentary velocities.

Clearly, in a wind of this kind, if at all violent, the support to an aeroplane is correspondingly erratic and varies between such wide limits that the aviator finds himself in a veritable nest of ''holes'' out of which it is difficult to rise, at least with a slow machine, and sometimes dangerous to try. However, as the turmoil due to horizontal winds rapidly decreases with increase of elevation, and as the aviator's safety depends upon steady conditions, or upon the velocity of his machine with reference to the atmosphere and not with reference to the ground, it is obvious that the windier it is the higher in general the minimum level at which he should fly.

Wind eddies.—Just as eddies and whirls exist in every stream of water, from tiny rills to the great rivers, and even the ocean currents, wherever the banks are such as greatly to change the direction of flow and wherever there is a pocket of considerable depth and extent on either side, and as similar eddies, but with horizontal instead of vertical axes, occur at the bottom of streams where they flow over ledges that produce abrupt changes in the levels of the beds, so, too, and for the same general reasons, horizontal eddies occur in the atmosphere with rotation proportional, roughly, to the strength of the wind. These are most pronounced on the lee sides of cuts, cliffs, and steep mountains, but occur also, to a less extent, on the windward sides of such places.

The air at the top and botton of such whirls is moving in diametrically opposite directions—at the top with the parent or prevailing wind, at the bottom against it—and since they are close to the earth they may, therefore, as explained under ''wind layers,'' be the source of decided danger to aviators. There may be some danger also at the forward side of the eddy where the downward motion is greatest.

When the wind is blowing strongly landings should not be made, if at all avoidable, on the lee sides of and close to steep mountains, hills, bluffs, or even large buildings, for these are the favorite haunts, as just explained, of treacherous vortices. The whirl is best avoided by landing in an open place some distance from bluffs and large obstructions, or, if the obstruction is a hill, on the top of the hill itself. If, however, a landing to one side is necessary and the aviator has choice of sides, other things being equal, he should take the *windward* and not the *lee* side. Finally, if a landing close to the lee side is compulsory he should, if possible, head along the hill, and not toward or from it; along the axis of the eddy and not across it. Such a landing would be safe unless made in the down draft, since it would keep the machine in winds of nearly constant (zero) velocity with reference to its direction, whatever the side drift, provided the hill was of uniform height and slope and free from irregularities. But as hills seldom fulfill these conditions lee-side landings of all kinds should be avoided whenever there is any considerable wind.

Air torrents.—Just as water torrents are due to drainage down steep slopes, so, too, air torrents owe their origin to drainage down steep narrow valleys. Whenever the surface of the earth begins to cool through radiation or otherwise the air in contact with it becomes correspondingly chilled and, because of its increased density, flows away to the lowest level. Hence, when the weather is clear, there is certain to be air drainage down almost any steep valley during the late afternoon and most of the night. When several such valleys run into a common one, like so many tributaries to a river, and especially when the upper reaches contain snow and the whole section is devoid of forest, the aerial river is likely to become torrential in nature along the lower reaches of the drainage channel.

A flying machine attempting to land in the mouth of such a valley after the air drainage is well begun is in danger of going from relatively quiet air into an atmosphere that is moving with considerable velocity, at times amounting almost to a gale. If one must land at such a place, he should head up the valley so as to face the wind. If he heads down the valley and therefore runs with the wind, he will, on passing into the swift air, lose his support, or much of it, for reasons already explained, and correspondingly drop.

Air breakers.—The term "air breakers" is used here in analogy with water breakers as a general name for the rolling, dashing, and choppy winds that accompany thunderstorm conditions. They often are of such violence, up, down, and sideways in any and every direction, that an aeroplane in their grasp is likely to have as uncontrolled and disastrous a landing as would be the case in an actual "hole" of the worst kind.

Fortunately air breakers usually give abundant and noisy warnings, and hence the cautious aviator need seldom be and, as a matter of fact, seldom is caught in so dangerous a situation. However, more than one disaster is attributable to just such winds as these—to air breakers.

Classification.—The above 10 types of atmospheric conditions may conveniently be divided into two groups with respect to the method by which they force an aeroplane to drop.

1. **The vertical group.**—All those conditions of the atmosphere, such as air fountains, cataracts, cloud currents, cascades, breakers, and

eddies (forward side), that, in spite of full speed ahead with reference to the *air*, make it difficult or impossible for the aviator to maintain his level, belong to a common class and depend for their effect upon a vertical component, up or down, in the motion of the atmosphere itself. Whenever the aviator, without change of the angle of attack and with a full wind in his face finds his machine rapidly sinking, he may be sure that he has run into some sort of a down current. Ordinarily, however, assuming that he is not in the grasp of storm breakers, this condition, bad as it may seem, is of but little danger. The wind can not blow into the ground and therefore any down current however vigorous must somewhere become a horizontal current, in which the aviator may fly away or land as he chooses.

2. **The horizontal group.**—This group includes all those atmospheric conditions—wind layers, billows, eddies (central portion), torrents, and the like—that, in spite of full speed ahead with reference to the ground, abruptly deprive an aeroplane of a portion at least of its dynamical support. When this loss of support, due to a running of the wind more or less with the machine, is small and the elevation sufficient, there is but little danger; but, on the other hand, when the loss is relatively large, especially if near the ground, the chance of a fall is correspondingly great.

W. J. H.

CHAPTER V.

STORMS AND STORM TRACKS.

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Cyclones and Anticyclones.—On the daily weather maps of the Weather Bureau are regions marked "high" and "low" and bounded by a number of circular or oval lines. These lines, called isobars, connect places of equal barometric pressure. From these charts it is evident that there is a distinct relation between the distribution of pressure, the direction and force of the wind, the temperature, and weather generally. By glancing at a number of maps it will be noticed that there is almost always an area of low barometric pressure, called a "cyclone," having an oval form and generally moving in an easterly or northeasterly direction; or a region of high barometric pressure, called an "anticyclone," also oval in form and moving more slowly in the same direction. The winds in both cases tend to blow nearly parallel with the isobars, having the region of lowest pressure on the left hand. This relation is expressed in Buys-Ballot's law (for the Northern Hemisphere; Southern, opposite), "Stand with your back to the wind, and the barometer will be lower on your left than on your right."

Cyclone.—The weather in a cyclone is described in the following outline. In the extreme front of a cyclone there is a blue sky; then, with the barometer falling, cirro-stratus clouds appear (with probably a halo), which gradually becomes lower and denser and forms an overcast sky. The temperature rises and the air feels muggy and close. As the center of the area approaches, rain falls until the barometer begins to rise. The passage of the trough is often accompanied by a heavy shower or squall, known as the clearing shower. The air then cools, loses its mugginess, and soon patches of blue sky appear. The shift of wind is different in the right-hand portion of the "low" area than it is in the left-hand portion. In the right-hand portion the flow is S. to SE., and as the area moves along there is a gradual change to SW. and W., with increase in velocity. In the left-hand side the flow is S. to SE., then on to E., NE., N., and, finally, NW., when there is a decrease and the weather becomes fair. The change of direction, and consequently the accompanying weather, depends upon the area passing to the north or south of us.

Anticyclone.—In an anticyclone the weather is almost the opposite to that in a cyclone; the weather of a cyclone is unsettled, while that in a cyclone is settled and fair. In an anticyclone the sky is generally clear and the air calm, consequently the temperature relatively high during the day and low at night. In the winter there is often frost, frequently accompanied by fog. The wind directions are clockwise and slightly outwards; and, as the movement of a "high" is sluggish, often blows from the same quarter for comparatively long periods. (See table.)

There is sometimes a ridge of high pressure between two cyclones. When this occurs there is usually a short period of fine weather. The sun is hot during the day and there is great radiation at night.

Comparative table.

	Cyclone.	Anticyclone.
Diameter	One hundred to several hundred miles.	Several hundred to several thousand miles.
Barometric pressure	Varies 948 to little less than 1016 kbs., approximately.	Varies 1016 to 1033 kbs., approximately.
Winds	Spirally inflowing; counter clockwise.	Spirally outflowing; clockwise.
Wind velocity	Outside, moderate; center, strong to high; center, light.	Moderate with frequent calms.
Movement	Fast	Slow; sluggish.
Form	Nearly circular or oval	Nearly circular or oval.
Axis direction	N-S; NE-SW; NW-SE	N-S; NE-SW; NW-SE.
Heat distribution	Front, warm; rear, cool	Front, cool: rear, warm.
Moisture	Front, high humidity; rear, low humidity.	Front, low humidity: rear, high humidity.

Secondary storms are local storms generally forming within the southern quadrants (in the northern hemisphere, opposite in southern) of a larger cyclonic disturbance, and usually follow in the same general direction as the larger storm. Tornadoes, waterspouts, and thunderstorms are of this type.

THUNDERSTORMS.

The frequency of thunderstorms depends mainly upon the existence of conditions necessary to produce much local convection. The warmer the atmosphere the greater the convection and vapor content. Consequently, the frequency is greatest on the land during the heat of day (afternoons), the hottest months of the year (June, July, and August), and over the ocean at its hottest period. (The high specific heat of water results in its losing its heat considerably slower than the land and we have the best conditions for vertical convection in the early morning hours.)

Thunderstorms are relatively small atmospheric whirls. During their occurrence the wind at the surface is light or calm. There is considerable motion in the clouds above, however, which sometimes become violent; and as the clouds of this type are comparatively low, we surmise that the cyclonic motion is confined to the surface layer. Thunderstorm whirls may vary from approximately 1 to 10 kilometers in diameter. When the storm is of low altitude strong winds reach the surface. Often there are several storms over the same locality which follow one another along the same track. They follow the "path of least resistance," and consequently tend to confine themselves to low ground, valleys, etc. The areas affected by single storms are nearly always narrow and diversified, as traced by amount of rainfall, and it is not unusual to find storms taking parallel paths with nearly dry areas between. Thunderstorms average about 30 kilometers an hour in movement in low barometric areas, and at a higher rate in squally conditions accompanying supplementary depressions, or "secondaries."

There is also another type of thunderstorm to which Sir Napier Shaw gives the name of "line thunderstorms." In this type the area of simultaneous thunder disturbance extends along a "line" which may be 160 kilometers in length. This line moves parallel to itself, and usually takes a direction from northwest to southeast, with a velocity of about 80 kilometers per hour.

Tornado.—A type of secondary storm peculiar to the United States east of the Rocky Mountains, usually occurring in connection with a thunderstorm and attaining destructive velocity. The counter-clockwise winds accompanying a tornado range from 45 to 225 meters per second. The diameter averages about 300 meters; the length of its path is from 100 to 500 kilometers; and its movement about 11 meters per second.

The conditions most favorable to the formation of tornadoes are: Counter wind currents of widely different temperatures causing strong vertical convection. These conditions occur most frequently in spring and summer months and in the warm sectors bounding the Gulf of Mexico. During the formation there is great turbulence in the clouds. This turbulence results in the formation of a funnel-shaped cloud beneath the center of the clouds, which gradually drops toward the surface in a spirally moving column, reaching the ground or hovering just above it. When it does reach the surface it moves in a northeasterly direction, spreading destruction in its immediate path.

Tornadoes are the result of mechanical action. As stated before, we have winds, blowing in approximately opposite directions, and of widely different temperatures. There is also an "intermingling" and "overrunning" of counter currents, which results in an indraft feeding the upward current immediately preceding a thunderstorm, and produces a violent whirl. This whirl tends to draw the air under it into itself, and the continuance of this action results in a formation of a spirally rising column. The force of a tornado may be broken or its course altered by hills or mountains, but buildings, trees, etc., standing in its immediate path are destroyed without any effect upon its course.

Waterspouts.—A type of secondary storm which results in a geyser-like spiral column of water, reaching from the sea to the thundercloud wherein they are formed. They are caused by conditions similar to those preceding formation of tornadoes on land. They are of comparatively short duration, seldom holding their form for more than an hour; and on account of their limited area of action, can not be classed as destructive.

STORM TRACKS.

Storm tracks are made by the connection of continuous areas of lowest barometric pressure. Storm tracks over the Atlantic Ocean are shown on the monthly charts issued by the Hydrographic Office, United States Navy, Washington, D. C.; over the United States, in the publications of the United States Weather Bureau, Washington, D. C.

J. W. A. B.

CHAPTER VI.

PRESSURE.

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Historical data.—The nature of the atmosphere and of atmospheric phenomena have been matters of conjecture and study since ancient times. In spite of the importance of the subject little progress was made in the study until the seventeenth century, when Torricelli developed the first barometer and demonstrated that atmosphere had weight and exerted a certain hydrostatic pressure. Pascal showed that the atmospheric pressure decreased with elevation and could be detected even at such small differences in elevation as 50 meters. At the same time von Guericke demonstrated that the pressure rose and fell with differences in atmospheric conditions and that weather changes as well as differences in elevation could be detected by the use of the barometer.

While a study of the upper atmosphere progressed gradually from the eighteenth century on, it was not until the latter part of the nineteenth century that the exploration and systematic measurement of the various upper layers of atmosphere were begun.

Following the pioneer work of Rotch at Blue Hill Observatory and Teisserenc de Bort at Trappes, systematic investigations of the upper air were carried on at many of the leading meteorological stations throughout the world. We have to-day the results of these investigations, but as yet the upper air study is in its infancy.

Height of atmosphere.—Before proceeding with the question of pressure it is well to consider and keep in mind that the atmosphere has considerable thickness or height. Astronomers have estimated the height, based on observations of the paths of shooting stars or meteors, to be from 150 to 200 kilometers. Other estimates have been made from measurements of such atmospheric phenomena as the auroral arc and the twilight arch. In the case of the latter method the height is estimated to be 79 kilometers, or 50 miles, an estimate that is probably 25 per cent too much on account of the refraction of rays as they pass through the layers of air of different densities. Never having been able to observe the free surface of a gas we can not tell much about the limits of the atmosphere, but it is safe to say that it extends to much greater elevations than 30 kilometers.

Distribution of gases in the atmosphere.—While of minor importance in our study of the air as a medium of navigation, it may be well to have some idea of the gases in the atmosphere. While the early meteorologists assumed that the atmosphere was homogeneous and the gases were uniformly distributed according to temperature, pressure and density, later investigations proved that such was not the case, because the atmosphere is characterized by well marked circulations and continuous departure from any state of rest.

According to Hann,[1] the chief independent gases that are blended into a dry atmosphere at the surface of the earth, and their respective volume percentages, are as follows:

	Per cent.
Nitrogen	78.03
Oxygen	20.99
Argon	.94
Carbon dioxide	.03
Hydrogen	.01
Neon	.0013
Helium	.0004

Besides these gases and a few of minor importance such as krypton and xenon, there are many substances, chief among which is water vapor, that are found in varying amounts in the atmosphere. The percentage of water vapor present in the air varies according to the temperature as warmer air contains a greater weight of water vapor at saturation than air at a lower temperature. Because of the relation of water vapor to temperature the percentage volume decreases from the equator to the poles, while the percentage volume of the other gases in the surface atmosphere is substantially the same at all parts of the earth. Although the amount of water vapor even at the surface is only 1.2 per cent of the total volume of gas, it is extremely important in our consideration of pressure and later of temperature.

TABLE A.—*Percentage distribution of gases in the atmosphere.*

Height in kilometers.	Argon.	Nitrogen.	Water vapor.	Oxygen.	Carbon dioxide.	Hydrogen.	Helium.	Total pressure in kilobars.
140	....	0.01	....	....	....	99.15	0.84	0.0053
130	....	.04	....	....	....	99.00	.96	.0060
120	....	.19	....	....	....	98.74	1.07	.0069
110	....	.67	0.02	0.02	....	98.10	1.19	.0079
100	....	2.95	.05	.11	....	95.58	1.31	.0089
90	....	9.78	.10	.49	....	88.28	1.35	.0108
80	....	32.18	.17	1.85	....	64.70	1.10	.0164
70	0.03	61.83	.20	4.72	....	32.61	.61	.0365
60	.03	81.22	.15	7.69	....	10.68	.23	.1246
50	.12	86.78	.10	10.17	....	2.76	.07	.4373
40	.22	86.42	.06	12,61	....	.67	.02	2.4530
30	.35	84.26	.03	15.18	0.01	.16	.01	11.5055
20	.59	81.24	.02	18.10	.01	.04	....	54.6478
15	.77	79.52	.01	19.66	.02	.02	....	119.5347
11	.94	78.02	.01	20.99	.03	.01	....	223.9776
5	.94	77.89	.18	20.95	.03	.01	....	539.9460
0	.93	77.08	1.20	20.75	.03	.01	....	1,013.2320

From Physics of the Air. (Humphreys.)

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[1] Lehrbuch der Meterology, 3d edition.

The amount of water vapor (or absolute humidity) rapidly decreases under the influence of the lower temperatures with increase of elevation to a negligible amount at or below the level of 10 kilometers. By assuming, first, that the temperature decreases uniformly at the rate of 22 kk. (6 k.) per kilometer from 1040 kk. (284 k.) at the surface, to 800 kk. (218 k.) at 11 kilometers, and above this elevation, remains constant at 800 kk.; second, that vertical convection occurring in the region of constant temperature changes from the surface up to the region of constant temperature, which keeps the relative per cent of these several gases, with the exception of water vapor, constant; and, third, that above this elevation in the region of constant temperatures and little or no vertical convection, the several gases are distributed according to their respective molecular weights. Humphreys, in Physics of the Air [1] has computed by the aid of several barometric hypsometric formulas the approximate composition and barometric pressure of the atmosphere at various levels, as given in Table A. In studying this table, it must be kept in mind that the figures are supported by direct experimental observations only from the surface of the earth up to a level of about 30 kilometers, and that while above this level the values are based on sound logic, they are nevertheless less certain with increase in elevation. While the percentage of water vapor reaches a certain maximum at an elevation of 70 to 80 kilometers, the amount decreases with elevation, but less rapidly than do the heavier constituents, and more rapidly than the two lighter ones, hydrogen and helium.

Atmospheric circulation.—So far we have considered the atmosphere as having considerable thickness, and consisting of a mixture of gases that increase in density as we approach the earth. These gases have weight, and exert a downward pressure due to the pull of gravity, which decreases with elevation. If there were no temperature differences or winds to cause a difference in density, and if the pull of gravity were the same at all points on and above the earth's surface, the pressure would be the same at all points at the same elevation, and would decrease at a constant rate as we go to higher elevations. This is not the case, however, and the pressure varies at different points on the same level, is constantly changing at any point, and does not decrease at the same rate for any unit rise in elevation.

The existence of certain great air streams around the globe, such as the trade winds and monsoons, have been known for a considerable time, and many explanations of their causes as well as the causes of air movements in general, have been given. The precise explanations of these theories of air movements are problems in dynamics, so it is

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[1] Journal of The Franklin Institute, Sept., 1917.

sufficient to state here that there are three causes that help in the establishment of the major circulations of the globe, and, less directly, the minor circulations. These are (1) the unequal heating of the equatorial and polar regions (with gravity the prime factor in causing air motion); (2) the deflective forces due to the earth's rotation; and (3) the unequal absorption of heat by land and water surfaces, which determine largely the location of the hyperbars and infrabars, or "centers of action."[1]

The velocity of the earth's motion is greatest at the Equator and gradually diminishes toward the poles; so that a current of air flowing from a lower to a higher latitude is deflected to the eastward; conversely, a current of air flowing from a higher to a lower latitude is deflected to the westward, since the velocity of the earth's motion is not so great in the higher as it is in the lower latitude. Thus in the Northern Hemisphere a current of air flowing northward is deflected to the right and becomes a southwesterly wind, and a current flowing south is deflected to the right and becomes a northeasterly wind. In the Southern Hemisphere the converse is true, northerly winds and southerly winds are both deflected to the left. From this we see that when air currents flow toward areas of low pressure from high-pressure areas they are deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere by the earth's rotation, and instead of flowing directly toward the center of depression, will acquire a motion around it, but inclined inward toward the center. For this reason the wind circulation about an area of low pressure in the Northern Hemisphere will have a movement counterclockwise, while in the Southern Hemisphere, the movement will be clockwise. The movement around areas of high pressure will be outward and converse in direction.[2] Briefly stated, moving air is deflected to the right in the Northern Hemisphere, and to the left in the Southern. Components of gravity cause the deflection. With east and west motions the direction but not the velocity is affected. Air moving toward the pole has its eastward velocity increased, and air moving toward the Equator has its velocity diminished.

Distribution of pressure.—The distribution of pressure over the continents and oceans determines in large measure the path and frequency of smaller circulations. We find by a study of the pressure distribution over the globe that there are certain areas of high and low pressure to which can be traced periods of abnormal weather.

In the Pacific we find two areas where the pressure is in excess, so-called hyperbars, one west of California and extending southwest, and the other over the Southern Pacific west of Chile. Over the Atlantic there are two hyperbars, one in the region of the thirty-fifth

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[1] Principles of Aerography. (McAdie.)

[2] Seaman's Handbook. (W. N. Shaw.)

north parallel, with a small Bermuda extension, and one west of southern Africa. Another hyperbar is located over the Indian Ocean, and one in the vicinity of Australia. The land hyperbars are over western North America, southwestern Europe, and central Asia. There are certain reversals of these areas between summer and winter, as, for example, the North American hyperbar becomes an infrabar in summer, and the Australian hyperbar of July (the winter season) becomes an infrabar in January (the summer season). The more prominent infrabars, or areas of diminished pressure at the surface, are the Aleutian of the North Pacific, and the Icelandic of the North Atlantic. Thus in a general way we may place the winter hyperbars in the Northern Hemisphere between latitudes 20° and 40°, except over land areas where they extend farther north. In the Southern Hemisphere the hyperbars are more evenly aligned, and we find them like peaks in the belt of prevailing high pressure between latitudes 20° and 40°. The distribution of these "centers of action" has been found to be directly related to the character of the season. For example, on the Pacific slope typical wet winters occur when the North Pacific infrabar overlies the continent west of the line drawn from Calgary to San Francisco, and typical dry winters occur when the continental hyperbar extends westward to the coast, and the Aleutian infrabar moves to the northwest. In the summer, with the Aleutian infrabar practically disappearing, the continental hyperbar moving eastward, and the oceanic hyperbar moving northward, we have practically a rainless period over this same area.

The strength and location of these large "centers of action" determine the frequency and path of the individual disturbances. For example, individual "lows" move rapidly southward, when the continental "high" overlies Idaho, western Washington, and eastern Oregon. For the Atlantic coast, mild winters are usually associated with the presence of the Bermuda hyperbar, while low temperatures result from its continued absence.[1]

Ward, in his discussion of cyclonic and anticyclonic control of the weather in the United States,[2] shows that the spring and autumn transition periods are marked by a struggle between cyclonic and solar controls, and hence by striking convectional phenomena. As summer passes the sun's rays become more and more oblique, and the control of the weather passes gradually but irregularly from the sun back again to the cyclones, or "centers of action."

Pressure in the North Atlantic area.—As we are especially interested in the North Atlantic weather forces, since they affect the British Isles and the coast of France and Belgium, a résumé of the monthly distribution of pressure and winds over this particular part

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[1] Principles of Aerography. (McAdie.)

[2] Annals of the Association of the American Geog., vol. 4.

of the globe will be of interest. Over the North Atlantic area the transition from winter to summer shows very little change in the general distribution of pressure, but a strengthening of the pressure in the permanent "high" regions of the thirty-fifth parallel and a weakening of the slope to the Iceland and Greenland "low." The area that includes the British Isles and the coast of France and Belgium shows merely an equalizing of pressure from south to north and a gradual decline of intensity of the conditions rather than a change of general type.

In the winter a great high-pressure area extends from Mexico across the Atlantic to southern Europe and northern Africa. Above this is a region of low-pressure areas, with interruptions due to variations of pressure of a greater or less degree.

In the summer the high-pressure area of the Atlantic just north of the Tropic of Cancer becomes more pronounced and more isolated. The intensity of the low-pressure region farther north is very much reduced and there is a tendency for the "lows" to establish themselves over the continental areas as the mean temperature of the day increases. The area, including the British Isles and the coasts of France and Belgium, is influenced at different times by an eastern extension of the permanent Atlantic "high;" by the continental winter "high;" by an extension southeastward of the "high" in the vicinity of Greenland; and by the "high" which usually appears over Scandinavia. These influences are to some extent seasonal, but may be felt at any time during the year.

With weather having a general west to east movement, the British Isles, located as they are at the western margin of the high-pressure area, act as an outpost for weather forecasting on the French and Belgian coast.[1]

Cyclones and anticyclones.—It has been assumed that low-pressure areas are caused by the indraft and uplift of warm moist air, and conversely that high-pressure areas are due to descending cold dry air, but this assumption does not agree with observations; and recent study of the structure of cyclones and anticyclones shows an entirely different origin and circulation. Air flow is the result of dynamic rather than static conditions, and the surface temperatures are controlled by winds rather than the reverse.[2]

Various theories of the cause of cyclonic circulation have been advanced, most important of which are those of Hann and Bigelow. Hann denied the existence of a central, warm, uprising current, and held that the actual motion of the atmosphere is not the direct result of surface temperature, but, on the contrary, temperature may be the result of circulation. He, however, used as the prime mover the difference of temperature between the poles and the tropics to estab-

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[1] Forecasting the Weather. (Shaw.)

[2] Winds of Boston. (McAdie.)

lish the circulation. According to his theory, cyclones and anticyclones are caused by the irregular flow of the general winds. Air currents moving northward in consequence of temperature gradients are resolved into vortices in the higher latitudes, and the movement of these vortices is determined by the prevailing direction of the larger air streams.

Bigelow in his later theory recognizes the asymmetry of cyclonic flow and finds its origin in warm and cold currents arranged in ridges or streams of different densities driven into local circulation by gravity. This does away with warm centered cyclones and cold centered anticyclones, which do not exist except in the hurricane type of tropical storms. The cold and warm currents are likewise accounted for. In the United States the warm currents are thrown off by the Atlantic hyperbar, or region of permanent high pressure. Other warm currents are from the Gulf of Mexico. The warm currents in southeastern Asia can be traced to the Pacific hyperbar. The continents and oceans react upon the general circulation and greatly disturb and distort its free operation, so that finally southern currents prevail in certain regions and northerly currents in others.[1]

It is evident cyclonic and anticyclonic structure is very difficult to explain. Where lower air strata are warm, the upper strata are cold. The idea that pressure gradients are caused by temperature, and that they in turn cause the winds, is superseded by the idea that winds control the pressure distribution and that the pressure determines the temperature at different levels. It is known that in a cyclone, when we go some distance above ground, the air is colder even in summer than in an anticyclone in winter. Present theories do not coincide with known facts. They do not account for the prevalence of the westerly winds in the general circulation, and the upper air temperatures do not agree with those required, but are dependent upon pressure distribution. Dines and others have shown that the temperature of the upper air can be determined more accurately from the pressure values at a certain level, say 9 kilometers, than from any known seasonal surface distribution.

Barometric pressure and weather changes.—As has been pointed out, the changes of weather and the forces of the wind are closely related to the changes of pressure which accompany or cause them, and to the rapidity with which these changes take place.

In dealing with pressure we may consider it as being of two classes—periodic and nonperiodic. To the former belong the changes that depend on the time of day or year and are not strictly connected with changes of weather, and to the latter belong those that depend on the movement of areas of high and low pressure around the globe; in other words, are dependent on the movement of weather.

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[1] Winds of Boston. (McAdie.)

All changes in pressure are associated with the changes of temperature which take place at different hours of the day, or at the various seasons of the year, or arise at different places on the earth from various causes; among which may be mentioned position with respect to latitude, distribution of land and sea, greater or less abundance of cloud or rain, or quantity of vapor in the air.

When a difference of pressure is established air tends to flow from high pressure to low pressure, not directly but rather around the areas of high and low, with an inclination toward the center of the low. It must be kept in mind that pressure, as measured by the barometer, is determined by the entire height of the atmosphere and not by the lower layers alone. It can not be expected that the distribution of surface pressure can always be accounted for by the distribution of surface temperature. Generally speaking, especially in the Northern Hemisphere, in winter the barometer is higher over the land, which is then colder, than the sea; and in summer the barometer is lower over the continents and higher over the sea, since the land is then relatively hot and the sea relatively cold.

The pressure is relatively lower over the equatorial region and over the temperate regions. Over the sea areas just north of the Tropic of Cancer and south of the Tropic of Capricorn the pressure is always high, as has been shown before. Periodic changes of pressure occur over such wind tracks as the trades and monsoons.

Of the periodic changes the diurnal variation in pressure, although small, must be considered. This diurnal variation consists of a double oscillation with two periods of increase and two of decrease of presssure within 24 hours; the barometer rising from about 4 a. m. till about 10 a. m.; then falling until about 4 p. m., and again rising until about 10 p. m., when it once more falls until about 4 a. m. The forenoon maximum is commonly, but not invariably, higher than the afternoon maximum; and the former usually occurs before rather than after 10 a. m., while the latter tends to be later rather than earlier than 10 p. m. The afternoon minimum is, with rare exceptions, lower than the morning minimum and occurs after rather than before 4 p. m.[1] At sea the diurnal variation attains its greatest magnitude within the Tropics and gradually diminishes in higher latitudes to a hardly perceptible quantity in the Arctic region.

The extent of the oscillations depends to a great extent on the range of daily temperature and the times of maximum and minimum are influenced by the times of sunrise and sunset. The daily range in tropical seas is between 2.4 and 2.7 kilobars, the maximum rise above the mean being somewhat less than the maximum fall below it. In the British Isles, according to Shaw, the range of diurnal change of

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[1] Barometer Manual. (Sir Napier Shaw.)

pressure is only about 0.2 to 0.7 kilobars, so that, except in very calm settled weather, the daily oscillations can seldom be recognized in the hourly readings of a barometer during any given day, though they may become quite apparent in the means of such a period as a month.

There is also an annual variation of pressure which is very evident in the Tropics both on land and on sea, following the apparent motion of the sun north and south of the equator and being associated with modifications of the trade winds and such periodic winds as the monsoons. As the annual variation takes place gradually it is not important in the forecasting of daily and sudden changes of weather.

The nonperiodic changes in pressure, or those immediately associated with weather changes, under ordinary conditions vary with latitude, being smallest near the equator and increasing as we recede from it.

Within the Tropics the ordinary fluctuations of the barometer, including the diurnal variation, seldom exceed 10 to 14 kilobars except in event of one of those revolving storms known as hurricanes, cyclones, or typhoons according to the part of the globe where they occur, when the barometer usually falls much lower, and in the lowest and most dangerous part of the depression may be as much as 75 kilobars (more than 2 inches). Records taken from a large number of observations in the equatorial regions covering a considerable number of years show a range of pressure of only 14 kilobars (0.413 inch) from the highest reading 1020.6 kilobars (30.138 inches) observed in July to the lowest 1006.6 kilobars (29.725 inches) observed in December.

The average range of pressure increases with latitude until it reaches its maximum in the Northern Hemisphere between the sixtieth and sixty-fifth parallels, and then decreases to the pole. In the British Isles, according to Shaw, the average range in the course of a month is about 58 kilobars (1.7 inches) for January and 30 kilobars (0.9 inch) for July. At the Royal Observatory at Greenwich the highest corrected barometric reading was 1048.8 kilobars (30.972 inches) and the lowest 957.4 kilobars (28.272 inches) a range of 91.4 kilobars (2.70 inches). Such extremes are rather exceptional, as the pressure has seldom gone above 1040 kilobars (30.8 inches) or below 965 kilobars (28.5 inches).

The following table taken from the Barometer Manual, by Sir Napier Shaw, shows the mean range of barometric pressure that can be expected under ordinary conditions and excluding exceptional storms of great severity, during the months of January and July at different latitudes of the Northern Hemisphere. These figures are compiled from data secured from all available authorities, January and July being considered typical winter and summer months, respectively.

Mean range of barometric pressure.

[In kilobars and in inches.]

Latitude.	January.	July.	January.	July.
	Kilobars.	*Kilobars.*	*Inches.*	*Inches.*
Equator to Tropic of Cancer	7 -13.5	7 -10	0.20-0.40	0.20-0.30
Tropic of Cancer to 30° north	13.5-22	10 -13.5	.40- .65	.30- .40
30° north to 40° north	22 -42	13.5-20	.65-1.25	.40- .60
40° north to 50° north	42 -51	20 -27	1.25-1.50	.60- .80
50° north to 60° north	51 -61	27 -34	1.50-1.80	.80-1.00
60° north to 65° north	61 -58	34	1.80-1.70	1.00

For the smaller ranges the assumption that the variations of the height of the barometer are of nearly equal amount on each side of the mean reading is sufficiently exact for practical purposes.

An examination of the pressure records at the Greenwich, England, station show that in January, the typical winter month, when the fluctuations are greatest, the pressure falls below the mean about five-eighths of the whole range and above the mean three-eighths of the range; while in July, the typical summer month, when the fluctuations are least, the rise and fall in the range is very nearly divided. Thus, with an average barometric reading in the English Channel of 1014 kilobars, we should have in winter with a range of 51 kilobars, a fall of 32 kilobars and a rise of 19 kilobars as representing the lowest and highest barometric reading that may be expected. Keeping this range in mind we can by the observation of the rise and fall of the barometer and the change of direction and force of the wind keep in touch with abnormal as well as normal disturbances.

The approach and passage of cyclonic depressions or of anticyclonic rises give us our most marked changes of weather.

When the pressure in any area is below that of the surrounding region, a cyclonic circulation is formed and the air currents will be found to have a motion around it, but inclined inward toward the center, instead of, as might be expected, directly into the center of the depression.

On the other hand, when the pressure is high in any area and decreases in the region surrounding it an anticyclone is developed and the air acquires a motion around it but inclined outward. As has been pointed out, the circulation of air is counter-clockwise around low-pressure areas and clockwise around high-pressure areas in the northern hemisphere.

The steeper the pressure gradients, that is, the more rapid the changes in pressure the more rapid will be the changes in weather conditions.

C. N. K.

CHAPTER VII.

TEMPERATURE.

CHAPTER VII.

TEMPERATURE.

The temperature of a body is determined by the average kinetic energy of translation of the molecules of the body. Thus, if we have a gas inclosed in a cylinder and we compress it by thrusting the piston in, there will be an increased kinetic energy of the molecules, which our senses observe as a rise in temperature. If the gas expands and thrusts out the piston, it has done work, the average kinetic energy of the molecules decreases, and we have a lowering of temperature. Thus, if the average kinetic energy of translation is varied, so is the temperature.

The detection of gain or loss of heat, or temperature, is accomplished in several ways, such as change of volume, change of state, change of electromotive force, and change of electrical resistance. All of these, according to circumstances, afford convenient means of comparing temperatures of different objects.

The mercury thermometer and the alcohol thermometer, the latter adapted to low temperatures, are based on change of volume, and the fact that the expansion of the vessel is not the same as that of the fluid which it contains, under equal changes of temperatures. The principle of differential expansion is also used in the thermographs or instruments for the continuous mechanical registration of temperature. Important among these instruments are those containing a Bourdon tube, which consists of a curved closed tube of oval cross section, completely filled with a suitable liquid. The unequal expansion between the tube and the liquid changes the volume and that in turn changes the curvature of the tube. Hence by making one end of the tube fast and connecting the other with a tracing point, it at once becomes possible to obtain on a moving record sheet a complete record of the temperature changes. In other instruments use is made of the unequal expansion of the two sides of a bimetallic strip.

The variation of electrical resistance with change of temperature and electromotive force at a thermo-junction both provide means of measuring temperature changes very accurately.[1] Exceptionally low temperatures down to near absolute zero and exceptionally high ones have been registered by these latter means.

Change of volume and the state of matter as a means of detecting temperatures was made use of in developing the absolute temperature system. Examination of the expansion and contraction of gases

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[1] Humphrey's "Physics of the Air," Journal of the Franklin Inst., Aug., 1917.

shows that if any permanent gas, for example, hydrogen or nitrogen, were to go on contracting at the same rate with cooling as it does at ordinary temperatures, it would have no volume and would cease to exert any pressure at a temperature of about 459.4 below zero Fahrenheit, or 273.02 centigrade. This temperature is nearly identical with the temperature computed by Lord Kelvin as being the minimum below which it is impossible to reduce a body, and the temperature to which a substance must be reduced in order to get the full equivalent in work of heat supplied to it. This temperature is known as absolute zero. Two temperature scales, the (Kelvin) absolute and the Kelvin kilograde have been developed with this temperature as their zero point.

Temperature scales.—We have to-day four temperature scales in common use. The earliest of these in use, but now nearly obsolete in scientific work, is the Fahrenheit. This scale is graduated into 180 equal divisions between the freezing and boiling point of distilled water under the pressure of an absolute atmosphere, with the freezing point 32 divisions above the zero point of the scale. The zero point represents the lowest temperature of a mixture of ice and salt.

The scale in common use on the Continent of Europe is the Centigrade, and is graduated into 100 equal divisions between the freezing and boiling points of water, under an absolute atmosphere, with the freezing point as zero.

The absolute scale has the same scale divisions as the Centigrade but with the absolute zero as its zero point. The freezing point of water is therefore 273, with the boiling point of water as 373.

The most recent scale devised is the Kelvin-Kilograde, which has for its zero point the absolute zero and the freezing point, under a pressure of an absolute atmosphere (a thousand kilobars), 1,000. With this scale of divisions, the boiling point of pure water under a pressure of a thousand kilobars is 1,366. This scale has the advantage of having smaller and more suitable scale divisions, no minus signs, and no confusion regarding zero and freezing points.

The Kelvin-Kilograde, Centigrade, and Fahrenheit units have the corresponding values of 1: 3. 66 : 2. 04, respectively.

Temperature of the atmosphere.—Temperature has often been defined as the thermal condition of a body which determines the inner change of heat between it and other bodies. This interchange of heat occurs in one or more of three ways: By conduction, by convection, or by radiation. Heat imparted by conduction is transferred from particle to particle, and involves contact with, or near approach to, a warmer body. Of the different forms of matter, solids, especially metals, are the best conductors, while liquids are better conductors than gases. Changes in the temperature of the earth's surface, which becomes heated during the day and cool during the night, are communicated to the layers of air in contact with and immediately above it, by conduction. Heat is being constantly transmitted by convection from one locality to another through the agency of winds and ocean currents. Heat is communicated between bodies freely exposed to each other by means of radiation. The communication of heat by radiation proceeds not from one particle to another but through the ether. Radiant heat is a form of energy which proceeds in straight lines in all directions from a hot body.

The atmosphere derives its heat, directly or indirectly, almost entirely from the sun. The actual temperature of the atmosphere depends not so much upon the direct rays of the sun as upon the conduction and radiation from the surface of the earth heated by the sun's rays. The air is not heated directly by sunshine, but the surface of the earth is first heated by the sun's rays, and the air is warmed by contact with the earth, or by radiation and convection.

Soils of different character and water have a considerable effect on the distribution of atmospheric temperature. Cultivated land absorbs and radiates heat more readily than grass land or wooded tracts.

The sun's rays have their greatest effect in the Tropics where they fall perpendicularly, or nearly so, on the earth's surface. The affect decreases as we travel toward the poles and the rays strike more obliquely. It might be mentioned that hillsides surrounding bodies of water often derive a great deal of heat by reflection of the sun's rays from the water surface. Likewise the temperature of valleys is often raised by reflection and radiation from surrounding mountain sides.

Diurnal variation.—In contrast to the warming effect due to solar radiation and reflection is the cooling of the earth's surface. During the day and night the earth is parting with the heat received from the sun. The heat received from the sun during the day is, as a rule, greater than that which the earth parts with, but toward the end of the day when the sun's rays fall more obliquely on the surface, these conditions are reversed, and the loss is greater than the gain. As a result the atmosphere above is cooled and the temperature continues to fall until sunrise. The lowest temperature usually comes at about the time of sunrise and the highest at from 2 to 4.30 p. m. depending upon the season of the year. The maximum occurs early in winter and late in summer. The average temperature for the day occurs at about 9 a. m. and 8 p. m. The rise during the morning and early afternoon is sharp, the curve being convex; while the drop during the afternoon and night is long and slow, giving a concave curve.

When the atmosphere is cloudy or overcast the temperature amplitude is less than when it is clear. Likewise the cooling of the earth's surface and the air resting upon it is not so great when the air is in motion as when there is a calm.[1]

Annual variation.—A review of the temperature records for different stations in the Northern Hemisphere shows that the average minimum temperature occurs near the end of January, and the average maximum temperature during the last part of July. The annual variation in temperature varies slightly with elevation, latitude, and with the immediate surroundings of the station.

Fall of temperature per kilometer, or the approximate temperature gradient for each month of the year, by Dines.

[In Kelvin kilograde scale.]

	0–1 Km.	1–2 Km.	2–3 Km.	3–4 Km.	4–5 Km.	5–6 Km.	6–7 Km.	7–8 Km.	8–9 Km.	9–10 Km.	10–11 Km.	11–12 Km.	12–13 Km.	13–14 Km.	Mean 0–9 Km.
January	18.3	14.6	14.6	21.9	25.6	25.6	21.9	25.6	21.9	14.6	10.9	.....	3.7	.....	21.2
February	18.3	18.3	14.6	21.9	25.6	21.9	25.6	25.6	21.9	10.9	10.9	−3.7	3.7	.....	21.5
March	14.6	21.9	14.6	21.9	25.6	21.9	25.6	25.6	21.9	14.6	10.9	−7.3	.....	.....	21.5
April	21.9	21.9	18.3	21.9	25.6	21.9	25.6	25.6	21.9	14.6	10.9	−3.7	−3.7	.....	22.7
May	21.9	21.9	18.3	21.9	21.9	25.6	25.6	21.9	25.6	18.3	14.6	−3.7	−3.7	.....	22.7
June	21.9	21.9	18.3	21.9	21.9	25.6	25.6	25.6	25.6	21.9	14.6	−3.7	−3.7	.....	23.1
July	21.9	18.3	18.3	21.9	21.9	21.9	29.3	21.9	25.6	29.3	14.6	.....	−3.7	3.7	22.3
August	21.9	14.6	18.3	21.9	21.9	25.6	25.6	25.6	29.3	25.6	14.6	3.7	.....	.....	22.7
September	18.3	10.9	18.3	21.9	21.9	25.6	25.6	21.9	29.3	25.6	18.3	3.7	3.7	.....	21.5
October	14.6	18.3	18.3	21.9	21.9	25.6	21.9	25.6	25.6	25.6	14.6	3.7	3.7	3.7	21.5
November	18.3	10.9	18.3	21.9	21.9	21.9	29.3	21.9	25.6	18.3	14.6	3.7	3.7	3.7	21.2
December	18.3	10.9	18.3	21.9	21.9	25.6	25.6	21.9	25.6	14.6	10.9	3.7	3.7	3.7	21.2
Average	19.4	17.6	17.6	21.9	23.1	24.2	25.6	24.2	24.9	19.4	12.8	−0.4	0.7	1.1	22.3

It is evident that the gradient in free air under usual conditions is approximately 6° C. (22.3 Kk) per kilometer. By a study of thermodynamics we find that if the atmosphere were dry its temperature would decrease at an adiabatic rate of 9.8° C. (36.6 Kk) per 1,000 meters.

If an isolated volume of air rises or falls with its temperature changing at the adiabatic rate and the temperature of the surrounding air also changes at the adiabatic rate, there will be no tendency to continue the movement. If the temperature gradient of the surrounding air is less than adiabatic the isolated mass will tend to return to its initial level. If the local temperature gradient is steeper than adiabatic, the air will continue to rise or fall.

When the temperature of the atmosphere decreases rapidly with increasing altitude vertical currents will occur. When we have inversion of temperature aloft, as we frequently do above cloud layers, and the temperature increases with increase of altitude, vertical movement practically ceases as far up as the inversion extends.

Within 3½ kilometers of the earth's surface the rate of change of temperature vertically is very irregular. It may be more or less than 9.8° C. (36 Kk) per kilometer, or there may even be a rise in temperature with height.

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[1] Seaman's Handbook, M. O. 215, 1915.

Influence of water vapor on temperature gradient.—The presence of water vapor in the atmosphere has a great effect on temperature gradients. The adiabatic and actual gradients up to the point of vapor condensation are, generally speaking, the same. From this point to the freezing point, however, the temperature of a rising column of air will (due to the release of heat of vaporization) decrease only about half as rapidly as before condensation. Owing to the large amount of water vapor in the atmosphere, at or near the point of condensation, it has been found that the actual temperature gradient follows more closely the condensation gradient than that of dry air. Therefore we actually have a slower decrease in temperature with increase in altitude than would be expected under adiabatic conditions.

Stratosphere and troposphere.—One of the most important findings in the study of the temperature of the upper air has been the discovery that the temperature ceases to fall above a certain height. Above this level the temperature has been found to remain stationary or even to rise. Soundings have also shown that this level at which the temperature gradient ceases or reverses varies with the season and the latitude. DeBort, who discovered this phenomenon, called the upper inversion layer the *stratosphere* and the lower levels where convection did occur, the *troposphere*. He found the average height at which the stratosphere began to be 11 kilometers. He also found that the height varied in high pressure and low pressure areas from an average of 12.5 kilometers in the former to an average of 10 kilometers in the latter. At the 10-kilometer level the difference in pressure between an average high and an average low would be approximately 10 kilobars, while the difference at sea level is about 70 kilobars.

Temperatures in the stratosphere and troposphere for the different months (compiled from the results of various ascents made under the auspices of the International Commission for Scientific Aeronautics, by G. Nadler).

[In Kelvin kilograde scale.]

Kilometers.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
14	790	794	801	809	812	816	812	809	801	**794**	**790**	**786**
13	**790**	794	801	809	812	816	812	809	**801**	798	794	790
12	794	798	801	805	809	812	812	**809**	809	801	798	794
11	794	**794**	**794**	**801**	**805**	**809**	**812**	812	809	805	801	798
10	805	805	805	812	820	823	827	827	827	820	816	809
9	820	816	820	827	838	845	856	853	853	845	834	823
8	842	838	842	849	864	871	882	882	882	871	860	849
7	867	864	867	875	886	897	904	908	904	897	882	871
6	889	889	893	900	911	922	933	933	930	919	911	897
5	914	911	914	922	927	949	955	977	955	944	933	922
4	940	927	940	949	959	970	977	*981*	977	966	955	944
3	962	959	962	970	981	*992*	*1,000*	1,004	*992*	*988*	977	966
2	977	973	977	*988*	*1,000*	1,010	1,017	1,021	1,010	1,006	*996*	984
1	*992*	*992*	*1,000*	1,010	1,021	1,032	1,036	1,036	1,028	1,021	1,006	*996*
Ground	1,010	1,010	1,014	1,032	1,043	1,054	1,058	1,058	1,047	1,036	1,024	1,014

The temperatures in bold face indicate the lowest reached and the apparent beginning of the stratosphere or isothermal layer.

The temperatures in italics show the freezing temperature, which descends to sea level in latitude 63° north and south, but which at the Equator, is more than 5 kilometers above sea level.

The accompanying table, which is a review of the results of various upper air soundings made over the globe under the auspices of the International Commission for Scientific Aeronautics, gives a very good idea of the temperatures that can be expected at different levels and also the changes of temperature with seasons at the different levels. However, the height of the stratosphere over the Equator has been found to be much greater than over the temperate regions, and also the lowest temperatures in the upper air have been recorded above the Equator. From the soundings made at Batavia, Java, and other points on the Equator it was found that the mean height of the stratosphere is just under 17 kilometers with an average temperature of 187 A.

The important features of the stratosphere are: 1. The great elevation and lowered temperature over the tropical region. 2. That the height varies with the seasons and the pressure distribution.

Cause of stratosphere.—While there are many explanations for the existence of the stratosphere, radiation seems to be the basis for most of the explanations. According to Gold, radiation seems to have a heating effect above a level where the pressure is 250 kilobars, while below that level it has a cooling effect. He assumes that convective temperature equilibrium exists, and that there is the usual decrease of water vapor with elevation. Braak contends that the very low temperatures in the upper limits of the troposphere in tropical regions must have some connection with the rising air currents of the general circulation which disturb the distribution of temperature as determined by radiation and absorption and shift the troposphere to greater heights. The base of the cirrus clouds, according to Braak, represents fairly well the height of the hypothetical dividing surface between the cooling and heating effect of radiation for moist air.[1]

C. N. K.

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[1] "Principles of Aerography," McAdie.

CHAPTER VIII.

WATER VAPOR.

The accompanying table, which is a [illegible] of the results of various upper-air soundings made over the globe under the auspices of the International Commission for Scientific Aeronautics, gives a very good idea of the temperatures [illegible] to be expected at different levels, and also the changes of temperature [illegible] at the different levels. However, the height of the stratosphere over the Equator has been found to be much greater than over the temperate regions, and also the lowest temperatures in the upper air have been recorded above the Equator [illegible] Batavia, Java, and other [illegible] mean height of the strato- [illegible] average temperature of [illegible]

The principal features [illegible] are 1. The great [illegible] tropical region. 2. [illegible] the seasons and the [illegible] distribution [illegible]

CHAPTER VIII.

WATER VAPOR.[1]

The vapor of water is one of the most important constituents of the atmosphere, although the total amount present is small. It exists in various forms, as invisible vapor, condensed vapor, liquid and solid.

Thus we have vapor masses which can not be differentiated by the eye from the surrounding air and can only be detected by their effect upon the needle of an electrometer. Again, the vapor is visible, as in the clouds, mists, and fogs, and finally as precipitated or crystallized water in dew, glaze, rain, hail, frost, and rime.

At the earth's surface water vapor, according to Humphrey's, supplies 1.2 per cent of the total number of gas molecules present.[2]

The so-called tension of water vapor or pressure per unit area is therefore small compared with the pressure of the other gases or the combined aerostatic pressure. The ratio, if expressed in millimeters, would be about 4/760 at a temperature of 1000 kk. (freezing) and 27/1000 at 1100 kk. under conditions of saturation. If the pressure is to be expressed in units of force, then the following ratio may be used: Saturation vapor pressure at temperature 1000 kk. will be 6 kilobars, while the aerostatic pressure is 1016 kilobars.

A better way, however, is to define absolute humidity as the mass of water vapor per unit volume, preferably, in grams per cubic meter of space.

We then begin to clearly comprehend that the air and the water vapor exist independently of each other, and furthermore that as temperature falls the weight of dry air per unit volume increases, because of greater density, while the weight of water vapor decreases.

Relative humidity is simply the percentage of the absolute humidity existing at any given time. It is the ratio of the actual pressure of the vapor to the saturation pressure for the given temperature. Or again it may be defined as the weight of the water vapor per unit volume present to the weight when a condition of saturation prevails, saturation being 100 per cent. Thus, in the example given above if the saturation weight is expressed in force units as 6 kilobars then 3 kilobars would represent 50 per cent relative humidity.

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[1] Principles of Aerography, McAdie.

[2] Physics of the Air, Journ. Franklin Inst., Sept., 1917, p. 389.

Unless the temperature be given, a statement of relative humidity has no especial value as it is plain that a percentage of a force or weight which varies with temperature, applies only to the given value. Thus, in many climatological publications, tables of relative humidity are given, for comparative purposes, but such tables defeat their own purpose, unless in each instance the temperature is stated.

When the actual and sensible temperatures are the same, we have the temperature of saturation. When the sensible or wet bulb reads lower than the actual or dry bulb, the temperature indicated by the wet bulb is known as the temperature of evaporation.

The temperature of saturation is usually called the dew point. The term ''saturation deficit'' is the complement of the relative humidity or the weight per unit volume needed to equal the saturation weight.

The various physical processes connected with the distribution of water vapor are evaporation, condensation and precipitation.

Water vapor may be recorded by direct observation of the increase in weight of a hygroscopic material properly exposed, such as pumice coated with chemically pure sulphuric acid, phosphorus-pentoxide or other substances.

The usual method of determining humidity, however, is by means of a psychrometer (the word means to measure the chilliness, or fall in temperature due to evaporation) which is a combination dry and wet bulb thermometer.

Glaisher's hygrometric tables, which are used in Great Britain and most English speaking countries, are based on the determination of the dew point or temperature of saturation. In these tables there is given the temperature of the dry bulb or what is commonly called the *actual* temperature, the temperature of the wet bulb commonly called the *sensible* temperature, and the temperature of saturation commonly called the *dew-point*.

The formula used is—

$$Ta - Td = C(Ta - Tw)$$

in which—

Ta = actual temperature,
Tw = evaporation temperature,
Td = saturation temperature;

and C = the Glaisher factor as determined from many observations.

The value of C at 1000 kk (273 k) is approximately 3.3; at 1010 kk (276 k) is 2.4; at 1025 kk (280 k) is 2.2; and at 1045 kk (285K) is 2.0; at 1100 kk (300K) is 1.7.

In countries other than those mentioned above, formulæ based on Regnault's experiments are used—the most general form of the equation being—

$$e'' = e' - CP\ (Ta - Tw)$$

Where—

e'' = vapor pressure at saturation.
e' = vapor pressure at evaporation.
C = a constant.
P = aerostatic pressure = 1,000 Kb.

The values of C vary with the rapidity with which the wet bulb is slung or whirled. In other words, the evaporation is a function of the volume of air passing over the evaporating surface. At ordinary pressures the value of CP is 0.66. If a ventilated psychrometer is used the value of C is about 0.00066. When the temperature of the wet bulb is below the freezing point different values of C are used, depending upon the condition of the coating of the wet bulb whether it is ice or subcooled water. If the bulb is covered with water and there is no air motion, the value of C is 0.0012. If the bulb is covered with water and a moderate movement of the air prevails, the value is 0.0008, and if well ventilated the value rises to 0.0006. If the bulb has a coating of ice, and there is no air movement, the value of C is 0.0011; in light wind, it is 0.0007, and in strong wind, 0.0006.

If Assmann's aspiration psychrometer is used, the value of the constant is 0.00066. In the United States the tables used are those compiled by Marvin from Ferrel's formula—

$$e = e' - 0.000367\ P(T - T_1)\left(1 + \frac{T - T_1}{1{,}571}\right)$$

The psychrometer is whirled and the air movement is therefore about that of a strong wind. No device, however, has been introduced to record the approximate velocity, except at Blue Hill observatory.

The following remarks are taken from "Psychrometer Tables for Obtaining the Vapor Pressure, Relative Humidity and Temperature of the Dew Point, from readings of the wet and dry bulb thermometers," by C. F. Marvin, W. B. 235, Government Printing Office, 1913:

The weight of aqueous vapor (*absolute humidity*).—The weight of a cubic foot of aqueous vapor at different temperatures and percentages of saturation is sometimes called the absolute humidity.

Saturated aqueous vapor is but little more than half as heavy as the same volume of dry air under like conditions of temperature and pressure. In all ordinary computations it is assumed that the expansion and contraction of partially saturated aqueous vapor is in accordance with the same laws as apply to air and ordinary gases, which do not easily condense to the liquid state.

The adopted density of saturated aqueous vapor is not determined directly from experiment, but is deduced theoretically from the observed fact that two volumes of hydrogen and one of oxygen combine to produce two volumes of water vapor.

The weights of unit volumes of hydrogen, oxygen, and dry air are accurately known, from which the specific gravity of aqueous vapor is found to be 0.6221.

If English units of temperature, pressure and weight are used, we find the weight of a cubic foot of saturated aqueous vapor in grains is:

$$W=11.7449\frac{F'}{1+0.002037\,(t-32}$$

In reducing psychrometric observations, regard should be had to the atmospheric pressure at the time, and results deduced from the tables based on a pressure nearest that observed. Interpolation for intermediate pressures need not be made, and when the pressure is not observed, an approximate value, known to be appropriate to the particular elevation of the point of observation, may be employed.

The psychrometric observations made at Weather Bureau stations will be reduced by means of the tables based on an air pressure which is numerically nearest the average or normal station pressure.

The temperatures t and t' of the wet and dry bulb thermometers will be read, and the difference $t-t'$ computed to the nearest tenth of a degree. It is desired that the dew-point especially be taken out to the nearest whole degree, and the tables have been expanded with a view to obviating difficult interpolations. In some cases, however, double interpolations must be considered but the proper result can often be obtained by simple inspection. When the air is very dry, however, a careful calculation is necessary.

An examination of the dew-point tables especially will show that diagonal lines exist, inclining downward, and to the right, along which the tabulated values of the dew-points are constant or change very little. As a result of this circumstance, when the observed values of air temperature and $t-t'$ fall even roughly midway between the values given in the arguments of the table, double interpolation will, in general not be required, as the correct result will be obtained by dropping both intermediate fractions, even where they exceed half the interval—that is, take out the dew-point corresponding to the arguments next lower than the air temperature and $t-t'$ observed.

When one of the observed quantities is quite near a tabulated value, the latter will be used, and the interpolation, if any is required, based on the other quantity only.

When the air is very dry the successive values in the table differ so much that carefully calculated interpolations will often be required.

The following example of the use of the tables illustrates how the foregoing principles are applied:

Example.—Air pressure 27.0 inches.

Air temperature, $t=75.0°$ F.

Depression of the wet bulb $(t-t')=5.5°$.

In this case the table for 27 inches air pressure should be used, and we find, opposite 75° in column 5.5°, dew-point=67° F.

Opposite 67°, under the column headed vapor pressure, we find vapor pressure, $e=0.661$.

Finally, on page 9, opposite 75°, in column 5.5°, we find relative humidity=77 per cent.

TABLE I.—*Temperature of dew-point in degrees Fahrenheit.*

[Pressure=27.0 inches.]

Air temperature. *t*	Vapor pressure. *e*	Depression of wet-bulb thermometer (*i*—*t*).														
		.2	.4	.6	.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
0	0.0383	− 1	− 2	− 4	− 5	− 7	− 8	−10	−12	−15	−17	−20	−23	−28	−33	−42
+ 1	403	± 0	− 1	− 3	− 4	− 5	− 7	− 9	−11	−13	−15	−17	−20	−24	−29	−34
2	423	+ 1	± 0	− 2	− 3	− 4	− 6	− 7	− 9	−11	−13	−15	−18	−21	−25	−29
3	444	2	+ 1	− 1	− 2	− 3	− 4	− 6	− 7	− 9	−11	−13	−16	−18	−22	−26
4	467	3	2	+ 1	− 1	− 2	− 3	− 4	− 6	− 8	− 9	−11	−14	−16	−19	−22
5	.0491	4	3	2	+ 1	− 1	− 2	− 3	− 5	− 6	− 8	−10	−12	−14	−16	−19
6	515	5	4	3	2	+ 1	− 1	− 2	− 3	− 5	− 6	− 8	−10	−12	−14	−17
7	542	6	5	4	3	2	+ 1	− 1	− 2	− 3	− 5	− 6	− 8	−10	−12	−14
8	570	7	6	5	4	3	2	+ 1	− 1	− 2	− 3	− 5	− 6	− 8	−10	−12
9	600	8	7	6	5	4	3	2	+ 1	− 1	− 2	− 3	− 5	− 6	− 8	−10
10	.0631	9	8	7	6	5	4	3	2	+ 1	± 0	− 2	− 3	− 4	− 6	− 8
11	665	10	9	9	8	7	6	5	4	2	+ 1	± 0	− 2	− 3	− 4	− 6
12	699	11	10	10	9	8	7	6	5	4	3	+ 1	± 0	− 1	− 3	− 4
13	735	12	11	11	10	9	8	7	6	5	4	3	+ 2	± 0	− 1	− 2
14	772	13	13	12	11	10	9	8	8	7	6	4	3	+ 2	+ 1	− 2
15	.0810	14	14	13	12	11	10	10	9	8	7	6	5	4	2	+ 1
16	850	15	15	14	13	12	12	11	10	9	8	7	6	5	4	3
17	891	16	16	15	14	13	13	12	11	10	9	9	8	7	6	5
18	933	17	17	16	15	15	14	13	12	11	11	10	9	8	7	6
19	.0979	18	18	17	16	16	15	14	13	13	12	11	10	9	8	8
20	.1026	19	19	18	17	17	16	15	15	14	13	12	11	11	10	9

TABLE II.—*Temperature of dew-point in degrees Fahrenheit.*

[Pressure=27.0 inches.]

Air temperature. *t*	Depression of wet-bulb thermometer (*t*—*t′*).														
	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0
0	−58														
+1	−44														
2	−36	−47													
3	−30	−37	−50												
4	−26	−31	−39	−52											
5	−23	−27	−32	−40	−56										
6	−20	−23	−27	−33	−42	−60									
7	−17	−20	−23	−28	−34	−44									
8	−14	−17	−20	−24	−28	−34	−45								
9	−12	−14	−17	−20	−24	−29	−34	−45							
10	−10	−12	−14	−17	−20	−24	−28	−35	−46						
11	− 8	−10	−12	−14	−17	−20	−24	−28	−35	−46					
12	− 6	− 7	− 9	−11	−14	−16	−19	−23	−28	−34	−45				
13	− 4	− 5	− 7	− 9	−11	−13	−16	−19	−23	−27	−33	−44			
14	− 2	− 3	− 5	− 7	− 9	−11	−13	−16	−18	−22	−26	−32	−42	−60	
15	± 0	− 2	− 3	− 5	− 6	− 8	−10	−12	−15	−18	−21	−26	−31	−40	−57
16	+ 2	± 0	− 1	− 3	− 4	− 6	− 7	− 9	−12	−14	−17	−20	−24	−30	−38
17	3	+ 2	+ 1	− 1	− 2	− 3	− 5	− 7	− 9	−11	−13	−16	−19	−23	−28
18	5	4	3	+ 1	± 0	− 1	− 3	− 4	− 6	− 8	−10	−13	−15	−18	−22
19	6	5	4	3	+ 2	± 0	− 1	− 2	− 4	− 6	− 7	− 9	−12	−14	−17
20	8	7	6	5	4	+ 2	+ 1	± 0	− 2	− 3	− 5	− 7	− 9	−11	−13

t	(*t*—*t′*)				
	6.2	6.4	6.6	6.8	7.0
16	−51				
17	−35	−48			
18	−27	−32	−43		
19	−21	−25	−30	−39	−56
20	−16	−19	−23	−29	−36

TABLE III.—*Temperature of dew-point in degrees Fahrenheit.*

[Pressure=27.0 inches.]

Air temperature. *t*	Vapor pressure. *e*	Depression of wet-bulb thermometer (*t*−*t*′).															
		.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
20	0.103	19	17	15	13	11	9	6	4	± 0	− 3	− 8	−13	−21	−36		
21	.108	20	18	16	14	12	10	8	5	+ 2	− 1	− 5	−10	−17	−26	−50	
22	.113	21	19	17	15	14	12	9	7	4	+ 1	− 3	− 7	−13	−20	−33	
23	.118	22	20	18	17	15	13	11	9	6	3	− 1	− 4	− 9	−16	−25	−47
24	.124	23	21	20	18	16	14	12	10	8	5	+ 2	− 2	− 6	−12	−19	−31
25	0.130	24	22	21	19	17	16	14	12	9	7	4	± 0	− 3	− 8	−14	−23
26	.136	25	23	22	20	19	17	15	13	11	9	6	+ 3	− 1	− 5	−10	−17
27	.143	26	24	23	22	20	18	16	14	12	10	8	5	+ 1	− 2	− 7	−13
28	.150	27	25	24	23	21	20	18	16	14	12	10	7	4	± 0	− 4	− 9
29	.157	28	27	25	24	22	21	19	17	15	13	11	9	6	+ 3	− 1	− 5
30	0.164	29	28	26	25	24	22	20	19	17	15	13	11	8	5	+ 2	− 2
31	.172	30	29	27	26	25	23	22	20	18	17	14	12	10	7	4	+ 1
32	.180	31	30	28	27	26	24	23	21	20	18	16	14	12	9	7	3
33	.187	32	31	30	28	27	26	24	23	21	20	18	16	14	11	9	6
34	.195	33	32	31	29	28	27	26	24	3	21	19	17	15	13	11	8
35	0.203	34	33	32	30	29	28	27	25	24	22	21	19	17	15	13	10
36	.211	35	34	33	31	30	29	28	27	25	24	22	20	19	17	14	12
37	.219	36	35	34	32	31	30	29	28	26	25	24	22	20	18	16	14
38	.228	37	36	35	33	32	31	30	29	27	26	25	23	22	20	18	16
39	.237	38	37	36	35	33	32	31	30	29	27	26	25	23	22	20	18
40	0.247	39	38	37	36	34	33	32	31	30	29	27	26	24	23	21	20
41	.256	40	39	38	37	36	34	33	32	31	30	28	27	26	24	23	21
42	.266	41	40	39	38	37	36	34	33	32	31	29	28	27	26	24	23
43	.277	42	41	40	39	38	37	36	34	33	32	31	29	28	27	25	24
44	.287	43	42	41	40	39	38	37	35	34	33	32	31	29	28	27	25
45	0.298	44	43	42	41	40	39	38	37	35	34	33	32	31	29	28	27
46	.310	45	44	43	42	41	40	39	38	37	35	34	33	32	31	29	28
47	.322	46	45	44	43	42	41	40	39	38	37	35	34	33	32	30	29
48	.334	47	46	45	44	43	42	41	40	39	38	37	35	34	33	32	30
49	.347	48	47	46	45	44	43	42	41	40	39	38	37	35	34	33	32
50	0.360	49	48	47	46	45	44	43	42	41	40	39	38	37	36	34	33
51	.373	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	34
52	.387	51	50	49	48	47	47	46	45	44	43	42	40	39	38	37	36
53	.402	52	51	50	50	49	48	47	46	45	44	43	42	40	39	38	37
54	.417	53	52	51	51	50	49	48	47	46	45	44	43	42	41	39	38
55	0.432	54	53	52	52	51	50	49	48	47	46	45	44	43	42	41	40
56	.448	55	54	54	53	52	51	50	49	48	47	46	45	44	43	42	41
57	.465	56	55	55	54	53	52	51	50	49	48	47	46	45	44	43	42
58	.482	57	56	56	55	54	53	52	51	50	49	48	47	46	45	44	43
59	.499	58	57	57	56	55	54	53	52	51	50	50	49	48	47	46	45
60	0.517	59	58	58	57	56	55	54	53	53	52	51	50	49	48	47	46
61	.536	60	59	59	58	57	56	55	54	54	53	52	51	50	49	48	47
62	.555	61	60	60	59	58	57	56	56	55	54	53	52	51	50	49	48
63	.575	62	61	61	60	59	58	57	57	56	55	54	53	52	51	50	49
64	.595	63	62	62	61	60	59	59	58	57	56	55	54	53	53	52	51
65	0.616	64	64	63	62	61	60	60	59	58	57	56	55	54	54	53	52
66	.638	65	65	64	63	62	61	61	60	59	58	57	57	56	55	54	53
67	.661	66	66	65	64	63	62	62	61	60	59	58	58	57	56	55	54
68	.684	67	67	66	65	64	64	63	62	61	60	60	59	58	57	56	55
69	.707	68	68	67	66	65	65	64	63	62	62	61	60	59	58	57	56
70	0.732	69	69	68	67	66	66	65	64	63	63	62	61	60	59	58	58
71	.757	70	70	69	68	67	67	66	65	64	64	63	62	61	60	60	59
72	.783	71	71	70	69	68	68	67	66	65	65	64	63	62	62	61	60
73	.810	72	72	71	70	69	69	68	67	66	66	65	64	63	63	62	61
74	.838	73	73	72	71	71	70	69	68	68	67	66	65	64	64	63	62
75	0.866	74	74	73	72	72	71	70	69	69	68	67	66	66	65	64	63
76	.896	75	75	74	73	73	72	71	70	70	69	68	67	67	66	65	64
77	.926	76	76	75	74	74	73	72	72	71	70	69	69	68	67	66	65
78	.957	77	77	76	75	75	74	73	73	72	71	70	70	69	68	67	67
79	0.989	78	78	77	76	76	75	74	74	73	72	71	71	70	69	68	68
80	1.022	79	79	78	77	77	76	75	75	74	73	72	72	71	70	70	69

TABLE IV.—*Temperature of dew-point in degrees Fahrenheit.*

[Pressure=27.0 inches.]

Air temp. t	Vapor press. e	Depression of wet-bulb thermometer $(t-t')$.															
		8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0
25	0.130	−41															
26	.136	−28															
27	.143	−20	−36														
28	.150	−15	−25	−48													
29	.157	−11	−18	−30													
30	0.164	−7	−13	−21	−39												
31	.172	−3	−8	−15	−25	−52											
32	.180	±0	−4	−10	−18	−30											
33	.187	+3	−1	−6	−12	−20	−36										
34	.195	5	+2	−2	−7	−14	−24	−47									
35	0.203	8	4	+1	−3	−9	−16	−28									
36	.211	10	7	4	±0	−5	−10	−18	−33								
37	.219	12	9	6	+3	−1	−6	−12	−21	−41							
38	.228	14	11	9	6	+2	−2	−7	−14	−24	−51						
39	.237	16	13	11	8	5	+1	−3	−8	−16	−27						
40	0.247	18	15	13	11	8	5	+1	−4	−10	−17	−32					
41	.256	19	17	15	13	10	7	4	±0	−5	−11	−20	−36				
42	.266	21	19	17	15	13	10	7	+3	−1	−6	−12	−22	−44			
43	.277	22	21	19	17	15	12	10	7	+3	−1	−6	−14	−24	−55		
44	.287	24	22	20	18	16	14	12	9	6	+2	−2	−7	−15	−27		
45	0.298	25	24	22	20	18	16	14	11	9	6	+2	−3	−8	−16	−30	
46	.310	26	25	23	22	20	18	16	13	11	8	5	+1	−3	−9	−18	−33
47	.322	28	26	25	23	22	20	18	15	13	11	8	5	+1	−4	−10	−19
48	.334	29	28	26	25	23	21	20	17	15	13	10	8	4	±0	−5	−11
49	.347	30	29	28	26	25	23	21	19	17	15	13	10	7	+4	−1	−5
50	0.360	32	30	29	28	26	25	23	21	19	17	15	13	10	7	+3	−1
51	.373	33	32	30	29	28	26	25	23	21	19	17	15	12	10	6	+3
52	.387	34	33	32	30	29	28	26	24	23	21	19	17	15	12	9	6
53	.402	36	34	33	32	30	29	28	26	24	23	21	19	17	14	12	9
54	.417	37	36	34	33	32	30	29	28	26	24	23	21	19	17	14	12
55	0.432	38	37	36	34	33	32	30	29	28	26	24	23	21	19	17	14
56	.448	40	38	37	36	34	33	32	30	29	28	26	24	23	21	19	17
57	.465	41	40	39	37	36	35	33	32	31	29	28	26	24	23	21	19
58	.482	42	41	40	39	37	36	35	33	32	31	29	28	26	24	23	21
59	.499	43	42	41	40	39	38	36	35	33	32	31	29	28	26	24	23
60	0.517	45	44	43	41	40	39	38	36	35	33	32	31	29	28	26	25
61	.536	46	45	44	43	42	40	39	38	36	35	34	32	31	29	28	26
62	.555	47	46	45	44	43	42	41	39	38	37	35	34	32	31	30	28
63	.575	48	47	46	45	44	43	42	41	40	38	37	36	34	32	31	30
64	.595	50	49	48	46	45	44	43	42	41	40	38	37	36	34	33	31
65	0.616	51	50	49	48	47	46	45	43	42	41	40	38	37	36	34	33
66	.638	52	51	50	49	48	47	46	45	44	42	41	40	39	37	36	35
67	.661	53	52	51	50	49	48	47	46	45	44	43	42	40	39	38	36
68	.684	54	53	53	52	51	50	49	47	46	45	44	43	42	41	39	38
69	.707	56	55	54	53	52	51	50	49	48	47	46	44	43	42	41	39
70	0.732	57	56	55	54	53	52	51	50	49	48	47	46	45	44	42	41
71	.757	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	42
72	.783	59	58	57	56	55	55	54	53	52	51	50	49	47	46	45	44
73	.810	60	59	58	58	57	56	55	54	53	52	51	50	49	48	47	46
74	.838	61	60	60	59	58	57	56	55	54	53	52	51	50	49	48	47
75	0.866	62	62	61	60	59	58	57	56	55	54	53	53	52	50	49	48
76	.896	64	63	62	61	60	59	58	57	57	56	55	54	53	52	51	50
77	.926	65	64	63	62	61	60	60	59	58	57	56	55	54	53	52	51
78	.957	66	65	64	63	63	62	61	60	59	58	57	56	55	54	53	52
79	989	67	66	65	64	64	63	62	61	60	59	58	58	57	56	55	54
80	1.022	68	67	66	66	65	64	63	62	62	61	60	59	58	57	56	55

TABLE V.—*Temperature of dew-point in degrees Fahrenheit.*

[Pressure = 27.0 inches.]

Air temp. *t*	Depression of wet-bulb thermometer (*t*—*t*′).															
	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0
47	−37															
48	−20	−42														
49	−12	−22	−47													
50	− 6	−13	−24	−56												
51	− 2	− 7	−14	−26												
52	+ 2	− 2	− 8	−16	−29											
53	6	+ 2	− 3	− 8	−17	−32										
54	9	6	+ 1	− 3	− 9	−18	−35									
55	12	9	5	+ 1	− 4	−10	−19	−39								
56	14	12	9	5	+ 1	− 4	−11	−20	−44							
57	16	14	11	8	5	± 0	− 5	−12	−22	−49						
58	19	16	14	11	8	+ 5	± 0	− 5	−12	−23	−57					
59	21	19	16	14	11	8	+ 4	± 0	− 5	−12	−24					
60	23	21	19	16	14	11	8	+ 4	± 0	− 6	−13	−25				
61	25	23	21	19	16	14	11	8	+ 4	± 0	− 6	−14	−26			
62	26	25	23	21	19	16	14	11	8	+ 4	− 1	− 6	−14	−27		
63	28	27	25	23	21	19	17	14	11	8	+ 4	− 1	− 6	−14	−28	
64	30	28	27	25	23	21	19	17	14	11	8	+ 4	− 1	− 6	−15	−29
65	31	30	28	27	25	23	21	19	17	14	11	8	+ 4	− 1	− 6	−15
66	33	32	30	29	27	25	23	21	19	17	14	11	8	+ 4	− 1	− 6
67	35	33	32	30	29	27	25	24	22	19	17	14	11	8	+ 4	− 1
68	36	35	34	32	31	29	27	26	24	22	20	17	14	12	8	+ 4
69	38	37	35	34	32	31	29	27	26	24	22	20	17	15	12	9
70	40	38	37	35	34	32	31	29	28	26	24	22	20	18	15	12
71	41	40	39	37	36	34	33	31	30	28	26	24	22	20	18	15
72	43	42	40	39	38	36	34	33	31	30	28	26	24	23	20	18
73	44	43	42	40	39	38	36	35	33	32	30	28	27	25	23	21
74	46	45	43	42	41	39	38	37	35	34	32	30	29	27	25	23
75	47	46	45	44	42	41	40	38	37	35	34	32	31	29	27	25
76	49	48	46	45	44	43	41	40	39	37	36	34	32	31	29	27
77	50	49	48	47	46	44	43	42	40	39	38	36	34	33	31	30
78	51	50	49	48	47	46	45	43	42	41	39	38	36	35	33	32
79	53	52	51	50	49	47	46	45	44	42	41	40	38	37	35	34
80	54	53	52	51	50	49	48	46	45	44	43	42	40	39	37	36

t	Depression of wet-bulb thermometer (*t*—*t*′).															
	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5	32.0
65	−29															
66	−15	−30														
67	− 6	−15	−30												4	
68	± 0	− 6	−15	−30												
69	+ 5	± 0	− 6	−15	−30											
70	9	+ 5	± 0	+ 6	−14	−30										
71	12	9	+ 5	± 0	− 6	−14	−29									
72	15	12	9	+ 5	± 0	− 5	−14	−28								
73	18	16	13	10	+ 6	+ 1	− 5	−13	−27							
74	21	19	16	13	10	6	+ 1	− 4	−12	−26						
75	23	21	19	16	13	10	6	+ 2	− 4	−12	−25					
76	26	24	22	19	16	14	11	7	+ 2	− 4	−11	−24				
77	28	26	24	22	20	17	14	11	7	+ 3	− 3	−11	−23			
78	30	28	26	24	22	20	17	14	11	8	+ 3	− 2	−10	−21		
79	32	30	28	27	25	23	20	18	15	12	8	+ 4	− 2	− 9	−20	−54
80	34	32	31	29	27	25	23	21	18	15	12	9	+ 4	− 1	− 8	−18

CLOUD CLASSIFICATION.

International system of cloud classification, and definitions proposed by Hildebrandsson and Abercromby and adopted by the International Meteorological Congress in 1894 and the average height of the various types at different locations and during different times of year follow:

Average height in meters.

Latitude.	Potsdam, 1896–97, 52° N.		Blue Hill, 1890–91 and 1896–97, 42½°.		Toronto, 1896–97, 43.6°.		Washington, 1896–97, 39°.		Allahabad (India), 1896–97, 25½°.	Manila, 1896–97, 15°.
	Summer.	Winter.	Summer.	Winter.	Summer.	Winter.	Summer.	Winter.		
	Meters.	*Meters.*	*Meters.*	*Meters.*	*Meters.*	*Meters.*	*Meters.*	*Meters.*	*Meters.*	*Meters.*
Cirrus	9,100	8,100	9,500	8,600	10,900	10,000	10,400	9,500	12,400	10,900
Cirro-stratus	8,100	7,600	10,100	8,900	8,900	8,500	10,600	9,500	13,200	11,400
Cirro-cumulus	5,900	5,400	6,700	6,200	8,900	8,300	8,800	7,400	11,400	6,600
Alto-stratus	3,300	3,000	6,300	4,600	4,200	4,200	5,800	4,800	....	4,300
Alto-cumulus	3,600	3,300	3,800	3,700	3,500	2,500	5,000	3,800	5,800	5,300
Strato-cumulus	2,200	1,400	1,200	1,600	2,000	1,500	2,900	2,400	3,500	2,000
Cumulus (S.)	2,100	1,700	2,900	1,600	....	....	3,100	2,900	....	....
Cumulus (B.)	1,400	1,000	1,800	1,500	1,700	1,300	1,200	1,200	1,400	1,700
Cumulo-nimbus (S.)	4,700	4,000	9,000	....	....	....	5,000	3,700	....	....
Cumulo-nimbus (B.)	(3,800)	2,100	1,600	....	....	....	1,000	....	2,100	....
Nimbus	1,800	1,300	1,200	700	....	....	1,900	1,800	2,000	1,500

S. and B. refer to the summits and bases, respectively, of the clouds specified.

Clouds—1. *Cirrus* (*Ci.*).—Isolated feathery clouds of fine fibrous texture generally of a white color, frequently arranged in bands which spread like the meridians on a celestial globe over a part of the sky and converge in perspective toward one or two opposite points of the horizon. In the formation of such bands Ci. S. and Ci. Cu. often take part.

2. *Cirro-stratus* (*Ci. S.*).—Fine whitish veil, sometimes quite diffuse, giving a whitish appearance to the sky, and called by many "cirrus haze," sometimes of more or less distinct structure, exhibiting tangled fibers. The veil often produces halos around the sun and moon.

3. *Cirro-cumulus* (*Ci. Cu.*).—Fleecy cloud: Small white balls and wisps without shadows, or with very faint shadows, which are arranged in groups and often in rows.

4. *Alto-cumulus* (*A. Cu.*).—Dense fleecy cloud: Larger whitish or grayish balls with shaded portions grouped in flocks or rows, frequently so close together that their edges meet. The different balls are generally large and more compact (passing into S. Cu.) toward the center of the group, and more delicate and wispy (passing into Ci. Cu.) on its edges. They are very frequently arranged in lines in one or two directions. The term "cumulus cirrus" is given up because it causes confusion.

5. *Alto-stratus* (*A. S.*).—Thick veil of a gray or bluish color exhibiting in the vicinity of the sun and moon a brighter portion, which,

without causing halos, may produce coronas. This form shows gradual transitions to cirro-stratus, but according to the measurements made at Upsala it has only half the altitude. The term "stratus-cirrus" is abandoned because it gives rise to confusion.

6. *Strato-cumulus* (*S. Cu.*).—Large balls or rolls of dark cloud which frequently cover the whole sky, especially in winter, and give it at times an undulated appearance. The stratum of strato-cumulus is not usually very thick and blue sky often appears in the breaks through it. Between this form and the alto-cumulus all possible gradations are found. It is distinguished from nimbus by the ball-like or rolled form, and because it does not tend to bring rain.

7. *Nimbus* (*N.*).—Rain clouds: Dense masses of dark, formless clouds with ragged edges, from which generally continuous rain or snow is falling. Through the breaks in these clouds is almost always seen a high sheet of cirro-stratus or alto-stratus. If the mass of nimbus is torn up into small patches, or if low fragments of cloud are floating much below a great nimbus, they may be called "fracto-nimbus," the "scud" of the sailors.

8. *Cumulus* (*Cu.*).—Wool pack clouds. Thick clouds whose summits are domes with protuberances but whose bases are flat. These clouds appear to form in a diurnal ascensional movement, which is almost always apparent. When the cloud is opposite the sun the surfaces which are usually seen by the observer are more brilliant than the edges of the protuberances. When the illumination comes from the side this cloud shows a strong actual shadow; on the sunny side of the sky, however, it appears dark with bright edges. The true cumulus shows a sharp border above and below. It is often torn by strong winds, and the detached parts present continual changes ("fracto-cumulus").

9. *Cumulo-nimbus* (*Cu. N.*).—Thundercloud or shower cloud. Heavy masses of cloud, rising like mountains, towers, or anvils, generally surrounded at the top by a veil or screen of fibrous texture ("false cirrus") and below by nimbus-like masses of cloud. From their base generally fall local showers of rain or snow and sometimes hail or sleet. The upper edges are either of compact cumulus-like outline and form massive summits, surrounded by delicate false cirrus, or the edges themselves are drawn out into cirrus-like filaments. This last form is most common in spring showers. The front of thunderstorm clouds of wide extent sometimes shows a great arch stretching across a portion of the sky, which is uniformly lighter in color.

10. *Stratus* (*S.*).—Lifted fog in a horizontal stratum. When this stratum is torn by the wind or by mountain summits into irregular fragments, the clouds may be called "fracto-stratus."

The committee also adopted the following instructions for recording clouds:

1. The kind of cloud designated by the international letters of the cloud name, which may be more exactly defined by giving the number of the picture in the atlas most nearly representing the observed form.

2. *The direction from which the clouds come.*—If the observer remains completely at rest during a few seconds, the motion of the clouds may easily be studied by noting their relative position to a steeple or other tall object, such as a mast, in an open space.

If the motion of the cloud is very slow, for such an observation one's head must be supported. Clouds should be observed in this way only near the zenith, for if they are too far away from it the perspective may cause errors. In this case nephoscopes should be used and the rules followed which apply to the particular instrument employed.

3. *Radiant point of the upper clouds.*—These clouds often appear in the form of fine parallel bands, which by an effect of perspective seem to come from one point of the horizon. The radiant point is that point where these bands or their direction prolonged meet the horizon. The position of this point on the horizon should be recorded in the same way as the wind direction, N., NNE., and so on.

4. *Undulatory clouds.*—If often happens that the clouds show regular parallel and equidistant striæ, like the waves on the surface of water. This is the case for the greater part of the cirro-cumulus, strato-cumulus (roll-cumulus), and similar forms. It is important to note the direction of these striæ. When there are apparently two distinct systems, as are to be seen in clouds separated into balls by streaks in two directions, the directions of the two systems should be noted. As far as possible observations should be made on streaks near the zenith to avoid effects of perspective.

5. *Density and position of cirrus banks.*—The upper clouds frequently take the form of a tangled web, or of a more or less dense veil, which, rising above the horizon, resembles a thin white or grayish bank. As this cloud form has an intimate relation to barometric depressions, it is important to note:

(*a*) the density; 0, meaning very thin and irregular; 1, meaning thin but regular; 2, meaning rather dense; 3, meaning dense; 4, meaning very dense and of dark color;

(*b*) the direction in which the veil or bank appears densest.

Remarks.—All interesting details should be noted, for example:

1. On summer days all low clouds generally assume particular forms more or less resembling cumulus. In this case there should be put under "Remarks," "Stratus or nimbus cumuliformis."

2. It sometimes happens that a cumulus has a mammillated lower surface. This appearance should be described by the name of "mammato-cumulus."

3. It should always be noted whether the clouds appear stationary or whether they have a very great velocity.

Clayton, in the Discussion of the Cloud Observations, says that—

By following the changes in nomenclature since Howard, it seems clear that there has been a gradual evolution, during which differences and distinctions not recognized by Howard have been established, and errors due to perspective, as in the case of the cumulo-stratus, have been corrected. Thus distinctions between high and low cirro-stratus and between high and low cirro-cumulus have been established, and the lower forms called alto-stratus and alto-cumulus, respectively. The stratus has been separated into fog and low sheet clouds, and two distinct forms of rain cloud are recognized. These distinctions have been a gradual growth, and Abercromby says: "At Prof. Hildebrandsson's suggestion we examined the nomenclature used by different officers, and arranged the names systematically; and we found that the differences did not seem irreconcilable. Eventually, we agreed that 10 terms, all compounded of

Howard's four fundamental types—cirrus, stratus, cumulus, nimbus—would fully meet the requirements of practical meterorology, with the least disturbance of existing systems." [1] Hildebrandsson further says that the 10 cloud forms described were already recognized in the nomenclature used in Portugal. Hence the international cloud nomenclature adopted at Munich represents the greatest progress in cloud nomenclature which observers are yet ready to accept for general use, and no official bureau should hesitate to accept it for fear that the system is merely temporary and will soon be changed. Progressive development will undoubtedly continue, but changes of names in general use will, in all probability, be slow. A more detailed nomenclature is, however, needed for the use of specialists.

Distribution of the various types of clouds.—Bigelow shows graphically the distribution of the several clouds. Under the name of each type he gives the mean height in meters for the year and the number of observations. There is also plotted for the several types the curve of frequency, with heights as ordinates and the number of observations at the respective heights as abscissas. The curves follow the mean line of the plotted points very closely. Under the assumption that the observed frequency corresponds with the actual frequency of cirrus formation at the given height, a discussion of these curves would give a good explanation of the physical processes operative in cloud formation for the whole year.

There is a wide range in the heights of certain clouds. The mean height of the low clouds is probably 2,000 meters. The three low cloud strata are shallow (not exceeding 3,000 meters in depth), except the cumulo-nimbus, or thunder head, which may develop a height of 13,000 meters. All the clouds except stratus and cumulo-nimbus show a tendency to three maxima of height and thickness, one in midsummer and the other two in February and November. The minima occur in March and September. A similar relation is found to exist in the isothermal limits.

Cirrus bands have been explained as due to differences in velocity or in direction of contiguous upper-air currents. These currents nearly always move from west to east, and the higher part of the current may move more rapidly than the lower. Thus the upper part of any cloud formation might move in advance of the base, causing a band or bar extending from west to east.

WAVE MOTIONS IN THE AIR SHOWN BY CLOUD UNDULATIONS.

Cloud billows, or undulations, have a different origin from cirrus bands, though it is not always easy to distinguish between the two. According to Clayton, bands are usually isolated or widely separated and are of unequal length, while undulations are close, parallel rows or striations of nearly equal length. The undulations were comparatively little observed until Helmholtz called attention to them as illustrating wave motions in the air, of the same nature as ocean

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[1] Quarterly Journal of the Royal Meterological Society, Apr., 1887, p. 155.

waves. These undulations are visible in clouds at all altitudes. They are illustrated in the strato-cumulus by long parallel rows, which are parallel in fact as well as in appearance, and lie in approximately the same direction in all parts of the sky. This can be seen by laying a ruler across the center of the mirror of the nephoscope parallel with the undulations. Abercromby had a different opinion, but he clearly made no critical observations in this way. The undulations are illustrated in the cumulus level by long parallel lines formed by individual cumuli like a file of soldiers, and the lines appear to converge toward the horizon as the effect of perspective. The undulations appear to be most frequent in the alto-cumulus level, and are easily distinguished by the parallel rolls in the alto-cumulus and by striations in the alto-stratus, like the furrows in plowed ground. In the cirrus level they are usually distinguished as short, parallel threads or as small bands forming one broad band at right angles to their length. Sometimes they seem like furrows in the cirro-stratus.

The direction of length of the undulations is decidedly most frequent from north to south, which is at right angles to the most frequent direction of cirrus bands. It leads at once to the inference that cloud undulation is the phenomenon to which the popular name of "polar bands" was applied in Europe, but not to cirrus bands, as many meteorologists have supposed and have thus been led to introduce a wrong usage of the term. The tendency for the undulations to lie at right angles to their motion is very distinct, and is in contrast with the cirrus bands.

Since the crest of a wave usually lies at right angles to the wind which originates and drives it forward, it follows that the results of observation agree very well with Helmholtz's explanation of the cloud undulations; namely, that the clouds are the visible crests of real atmospheric waves formed between currents of air of a different density and having a different velocity or direction. The undulations would probably always lie at right angles to the upper current were it not that the lower current is also in motion, and that the observed cloud direction is a compound of the two.

The value of clouds in forecasting weather changes.—The cloud is not, as might be expected at first thought, a good exponent of air motion; and as yet cloud maps have not been used advantageously by professional forecasters except in connection with storms of the West Indian hurricane type, or the typhoon, or baguio, of the China Sea. Thus Father Viñes, at Havana, showed how certain types of cirrus accompanied or rather preceded storms of great violence but small diameter, while a different type was found to accompany storms of large diameter and moderate violence. Likewise at Manila, Zi-ka-wei, and other observatories on the Asiatic coast, the appearance and motion of the upper clouds have been carefully studied for forecasting purposes.

In general, cirrus clouds, except of a certain type, do not positively indicate coming rain, being, in fact, somewhat less frequently followed by rain than the average probability of rain. But they are closely controlled in their movements by temperature gradients, and they may serve an isolated observer as a guide to coming changes of temperature. In general, slowly moving cirrus clouds indicate slight changes in temperature, and, except when moving from a direction between south and west, they indicate, as a rule, slowly rising temperature during the succeeding 12 and 24 hours. Rapidly moving cirrus indicate the probability of decided changes of temperature, and, from any direction, a probability of a fall of temperature by the end of 24 hours. The probability of a fall, however, and the amount of fall, are much greater and earlier when the cirrus are observed to be moving rapidly from a direction between south and west. When cirrus are observed to be moving from the southwest, there is a strong probability of a fall of temperature during the succeeding 24 hours. This probably rises to 83 per cent in winter and is over 70 per cent at all times of the year for cirrus moving rapidly from the southwest. When cirrus are observed to be moving from the northwest, the probability is that there will be a rise of temperature during the succeeding 12 hours. The probability is 64 per cent for winter and 76 per cent during the entire year for cirrus moving rapidly from the northwest.

With the appearance of cirro-stratus there is a probability of rain during the succeeding 24 hours of about 80 per cent. This probability increases to nearly 90 per cent with the appearance of alto-stratus, which is as great as can usually be derived from a knowledge of the conditions prevailing over the country as given on a weather map. Cirro-cumulus are most frequently followed by fair weather, while alto-cumulus indicate a probability of rain.

There are two directions in which observations of the direction and of the relative velocity of upper clouds might be of use. The rapid movement of cirrus from the west or the southwest along the northern boundary of the United States will no doubt indicate the approach of a cold wave before its approach is indicated by the weather map, and will thus enable northwestern stations to be warned. The movement of cirrus from the south, observed at any of the Atlantic coast stations, with a dense bank of clouds to the south of the observer, would strongly indicate a severe storm off the coast and might enable the observer to determine the position of its center. This conclusion is derived from the individual observations at Blue Hill and from the fact of circulation of air in cyclones with deep barometric depressions. The prevalence of rapidly moving cirrus over a wide area indicates rapid storm movement and rapid and marked changes of weather and temperature. Slowly moving cirrus indicate sluggish storm movements and slight changes of temperature and are the usual accompaniment of droughts.

The direction of cirrus movement prevailing in advance of and around the storm center must, in the majority of cases, furnish a clew to the future movements of the storm, since it is found that the storm tends to move in the mean direction of the cirrus found for the storm as a whole.

A. McA.

CHAPTER IX.

RADIATION.

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The source of radiant energy.—The earth is, relatively speaking, an insignificant unit in the solar system. Furthermore, the solar system itself is an insignificant unit in the stellar universe. Astronomers tell us that the solar system is moving rapidly toward the constellation Hercules; but no appreciable effect upon the earth's atmosphere is known to result, nor is the amount of energy received from the stars sufficient to produce any observable effect. Efforts have been and are being made to measure the scattered radiation of the sky; but as yet there are no positive results. With the radiant energy of the sun, however, it is different; and here we have to deal with a prime mover. The mean distance of the sun from the earth is 149,500,000 kilometers, or 92,900,000 miles. The solar parallax is 8.796 seconds and the sun's diameter 1,392,000 kilometers, or 865,000 miles. The velocity of light is 299,870 kilometers per second (186,300 miles), and the time required to traverse the mean radius of the earth's orbit is 498.8 seconds. The visible spectrum comprises light waves ranging in wave length from 0.7 μ (0.0007 mm.), the red end, to 0.4 μ (0.0004 mm.), the violet end. At only a few aerological observatories are records of the intensity of solar radiation maintained. Perhaps one of the most serviceable records is that made at Davos, in the Swiss Alps, where continuous records have been obtained by C. Dorno. At this mountain station a continuous photographic record of the length of the ultra-violet spectrum (that is, the value of the shortest waves which penetrate the atmosphere) shows that the winter sun has great heating effect, but apparently does not attain a maximum in the other end of the spectrum. The spring sun has the greatest heat, with somewhat greater amount of ultra-violet radiation; the summer sun, much heat and strongest ultra-violet; and the autumn sun, much heat and much ultra-violet. Gockel thinks that herein lies the explanation of the "glacier burn," that is, an intense ultra-violet radiation. One point of interest is that the ultra-violet radiation undergoes more variation than the heat; and varies greatly with the season, so that a single day in summer may equal a winter month's total.

The intensity of solar radiation is measured by the heat produced when a given surface exposed at right angles to the beam entirely absorbs the radiant energy. The mean value of the so-called "solar constant of radiation" has been fixed by Abbot at 1.932 calories per square centimeter per minute. This value differs materially from former values, especially the generally accepted value of 3 calories as given in many textbooks. If the solar constant were indeed constant, the earth would receive in a year something like one million million million million calories. In popular terms this would be sufficient heat to melt a layer of ice 33 meters thick over the entire surface of the earth annually, or to evaporate 1.66×10^{33} kilograms of water, provided there were no atmosphere, no absorption, and no reflection.

Variation in sunshine.—At any given point there must, of course, be variation as the sun changes longitude. Thus on January 1, when the longitude is 1°, the ratio is 1.03; on March 1, longitude 59°, 1.02; on July 1, longitude 179°, 0.96; on September 1, longitude 240°, 0.98; and on December 1, longitude 330°, 1.03. Thus in winter the value is larger than in summer. The duration of sunshine can be determined for any given latitude from the hour angle converted into mean solar time and then multiplied by 2. Considering northerly declination positive, and southerly declination negative, we have for example in latitude 42° N. the following values:

Duration of sunshine.

Declination of the sun.	Length of day.		Declination of the sun.	Length of day.	
	Hours.	Minutes.		Hours.	Minutes.
−23° 27′	9	7	5°	12	45
−20°	9	37	10°	13	22
−15°	10	18	15°	14	1
−10°	10	56	20°	14	43
−5°	11	33	23° 27′	15	14
0°	12	9			

The greatest possible duration for other latitudes is:

Latitude.	0°	20°	40°	60°	66°	90°
	H. m.	*H. m.*	*H. m.*	*H. m.*	*H.*	
Maximum insolation	12 7	13 20	15 1	18 52	24	6 months

If the unit of insolation be the amount received in a day at the Equator on March 21, then for given latitudes values will vary in the following ratios:

Dates.	Latitude.					
	0°	20°	40°	60°	North Pole.	South Pole.
March 21	1.00	0.93	0.76	0.50		
June 21	.98	1.04	1.10	1.09	1.20	
Sept. 23	.88	.94	.70	.30		
Dec. 21	.94	.68	.35			1.28

The orbit which the sun appears to make around the earth, but which in reality is made by the earth around the sun, is not a circle but an ellipse inclined to the plane of the equator. The speed of the earth is not constant; and instead of traveling equal distances in equal times, the distance traveled is such as to make the areas swept over by the line joining earth and sun equal in equal times. So when the sun is nearest, the earth travels fastest. As we have said, the sun appears to travel in a plane which makes an angle of 23° with the plane of the equator.

There may be other causes of variation in the intensity of solar radiation—changes which may be of solar origin and not periodic. Thus the monthly mean values of the solar constant from 1905 to 1912 have been compared with the so-called "Wolff sunspot numbers" for the same months, and it seems likely that increased values of the solar constant attend increased sunspot numbers. In the report of the Astrophysical Observatory for 1913 it is stated that there is an increase of radiation, at the earth's mean distance from the sun, of 0.07 calorie per square centimeter per minute with an increased spottedness of the sun, represented by 100 Wolff sunspot numbers.

Simultaneous observations at Mount Wilson and at Bassour, Algeria, indicate that fluctuations in solar-constant values found in California in earlier years may now be explained not as local phenomena but as due to causes outside of the earth; and thus we may conclude that the sun is a variable star, having not only a periodicity connected with the periodicity of sunspots, but also an irregular, nonperiodic variation, sometimes running its course in a week or 10 days, again in longer periods, and ranging over irregular fluctuations of from 2 to 10 per cent of the total. It has also been shown by Abbot, Fowle, Kimball, and others that great volcanic eruptions materially decrease the apparent solar radiation, or rather that atmospheric transmissibility undergoes marked changes with consequent diminution of temperature. Marked changes occurred in 1884–1886 (probably connected with Krakatau) and again in 1903–4.

Measurement of solar radiation.—By using a Callendar pyrheliometer and an eclipsing screen, the total radiation can be obtained in two components, one representing direct solar radiation and the other the diffuse sky radiation. The total radiation per square centimeter of horizontal surface with the clearest sky varies, according to Kimball, for the particular point of observation (near Washington), from 250 calories a day (December 20) to 765 calories (June 10). In general the radiation received on clear days during the first half of the year exceeds that of the second half by 8 per cent, probably due to the increased water-vapor content of the atmosphere during the latter period.

The total radiation received with the clearest sky in midday per square centimeter of horizontal surface varies from 45 calories in December to 90 in June. When clouds are near the sun but do not obscure it, the momentary maximum rates are increased by about 0.15 calorie.

The diffuse sky radiation received on a horizontal surface at noon averages about 25 per cent of that from the sun.

Expressed in units of work, 1 calorie per minute per cm.^{2} represents 697 watts per m.^{2}; 90 calories per hour ($1\frac{1}{2}$ per minute) represent 1 kilowatt per m.^{2}

The radiation received on a square meter of horizontal surface on a clear day in midsummer is, therefore, equivalent to 5 kilowatt hours.

Some recent measurements are: American University, Washington, D. C., on December 24, 1914, with the sun at zenith distance 62.5°, an intensity of 1.48 calories per minute per square centimeter; and on February 28, 1915, with the sun at zenith distance 57.5 ° the intensity was 1.50 calories. At Santa Fe, N. Mex., elevation 2,133 meters, and in an arid region, a maximum of 1.64 calories was recorded with a zenith distance of 55°. In brief, at sea level, in summer and at midday, there reaches the earth each second 0.0225 calorie per square centimeter; and of this 0.0096 calorie is scattered or absorbed and 0.006 calorie reradiated from the atmosphere. The amount of energy varies inversely as the square of the distance from the sun, with the angle of incidence of the rays, and according to duration.

It is possible that there is in the upper atmosphere a layer of cosmical dust which is strongly radioactive. Simpson has recently pointed out that the measurements of Vegard and Stormer on the aurora indicate true radioactive radiation penetrating the atmosphere and producing the same results as if the atmosphere were being bombarded from the outside by the α radiation, which is now being studied in so many physical laboratories. Experiments on ionization made in balloons in 1914 show the existence of a strong radiation. This may help explain the nature of the aurora. The average height of the bottom edge of the aurora as determined by 1,920 measurements in Norway is 108 kilometers, and no aurora lower than 85 kilometers was noticed. It would seem that the cosmic rays producing the aurora are in two groups with different penetrating power. The diffuse arcs, the drapery, and more intense displays seem to be of the same physical nature.

A. McA.

CHAPTER X.

ATMOSPHERIC ELECTRICITY.

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THE ELECTRICITY OF THE AIR AND EARTH.

It is now generally accepted that the normal potential gradient[1] over the whole globe is positive; that is, the whole surface of the earth, except regions of disturbance, has a negative charge of electricity. This charge undergoes daily and yearly variations and is not constant.

For years it was thought that pure air was an insulator, but from experiments carried on in 1900 and 1901 by Elster and Geitel in Germany, and Wilson in England, it was found that pure air is not an insulator, but that it always contains a number of ions[2] which give to it the power of conducting electricity in a manner similar to that of an electrolyte.

Negative electricity is dissipated more rapidly than positive in the lower atmosphere, as there are more positive than negative ions in the air near the surface, which is a consequence of the former being attracted downward and the latter being repelled upward by the negative charges on the earth.

One of the primary laws of electricity in speaking of negative and positive charges is that like charges repel and unlike charges attract.

As no dissipation would be possible without ions, and no ions could be produced without the action of some ionizer possessing the necessary energy, it is believed that there are three main ionizers at work in the atmosphere, namely, an X-ray-like radiation, radio-active matter in the ground, and radio-active emanation acting in the atmosphere.

Radio-active properties are exhibited to some extent in all minerals. A supply of electricity is given to the air, in various amounts, by some substance present in rocks. Many radio-active substances not only

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[1] The potential gradient means the difference of electrical potential between two points 1 meter apart vertically, the ground surrounding them being supposed to be a level horizontal plane. The value of this gradient when measured near the ground depends entirely on the surface of the earth, a potential gradient of 100 volts per meter representing an electrical charge of 10^{-13} coulombs per square centimeter of surface.

[2] An ion is any minute material particle which carries an electrical charge. Generally an ion is an atom or a molecule of atmospheric gas carrying an elemental charge of electricity. Two ions, one positive and one negative, are produced by the breaking up of a neutral molecule into two charged atoms or two charged molecules of smaller dimensions. Ionization is the process of the formation of ions by the splitting up of neutral molecules.

(Definitions quoted from George C. Simpson. Quart. Journ. Roy. Met. Soc., Oct., 1905.)

give off electric charges, but also a gaseous material called "emanation," which has itself this same property of manufacturing ions.[1]

Positive electricity flows from places of high to places of low potential. This being the case, the electricity in the atmosphere will naturally move in accordance with this law. Thus positive charges will flow from the air to the earth and negative charges in the opposite direction. This flow constitutes an electric current which is known as the air-earth current.

THE ELECTRICITY OF RAIN, THUNDER AND LIGHTNING.

It has been found that rain is nearly always electrically charged, about 80 per cent of all rain carrying positive electricity. From observations carried on by Dr. G. C. Simpson, of the Indian meteorological department, it was found that light rain carried the greatest charges, with the exception of the thunder rain, which was always found to be more highly charged than rain unaccompanied by thunder.

In a thunderstorm the heavy rain which occurs at the beginning of a storm has a high positive charge, and the steady uniform precipitation following being also highly charged, but with negative electricity.

Thunderstorms are almost always accompanied by strong ascending air currents which tend to break up the drops falling through them. As the drops break up they become positively charged while the surrounding air particles receive a negative charge. The air thus charged is carried up by the ascending current and away from the positively charged drops into contact with cloud particles, which thus acquire a considerable negative charge. These clouds provide the negatively charged rain of the latter part of the storm.

Drops when electrically charged combine more rapidly than when uncharged, and in this way the process of recombination goes on rapidly, the drops quickly increasing in size until they again break up with another separation of electricity, the positive remaining on the drops and the negative on the air particles. The air, which is full of free negative ions, has been carried up, leaving the positively charged drops behind.

The electrical separation within a thunderstorm cloud is such as to place a heavily charged positive layer (the lower portion of the cloud) between the earth and a much higher heavily charged negative layer (the upper portion of the cloud.)[2] Discharges of lightning may take place from the intermediate or positively charged layer to either the negative portion above or to the earth.

The uprushing air, by its sustaining influence and turbulence, forms at times a practically continuous sheet or stream of water, heavily charged and at high potential, and also layers and streaks

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[1] C. D. Stewart: Atmospheric Electricity, Quart. Journ. Roy. Met. Soc., October, 1917.

[2] W. J. Humphreys "The Thunderstorm: Its Phenomena."

of highly ionized air. Electrically speaking, heavily charged conducting sheets and rods, either of coalesced drops or of ionized air, are formed over and over so long as the storm lasts, momentarily placed here and there within the mass of the storm cloud which is positively charged. This makes a heavily surface-charged vertical conductor in a strongly volume-charged horizontal layer or region, above and below which there are steep potential gradients to negatively charged parallel surfaces.

The conductor will be at the same potential throughout, and therefore the maxima of potential gradients normal to it will be at its ends, where if these gradients are steep enough, and the longer the conductor the steeper the gradients, brush discharges will take place. The brush discharge and the line of its most vigorous ionization necessarily will be directed along the potential gradient or toward the surface of the opposite charge. But this very ionization automatically increases the length of the conductor, and as the length of the conductor grows, so, too, does the steepness of the potential gradient at its forward or terminal end, and as the steepness of this gradient grows the more vigorous the discharge, always assuming that there is an abundant electrical supply. Therefore, an electric spark once started within a thunderstorm cloud has a good chance by making its own conductor as it goes, of growing into a tremendous lightning flash. When the electrical supply is small, then lightning will be feeble and soon dissipated.[1]

Lightning may be divided into three main classes according to the form of discharge: Forked, sheet, or globe lightning.

Forked lightning is a zigzag line of fire similar to the discharge of a Leyden jar. The electric current flows along the path of least resistance. The path, owing to the variations in the atmospheric structure, is very irregular and the consequence is seen in the zigzag path. The duration of the lightning discharge is probably much less than the hundred-thousandth part of a second.

Sheet lightning consists of flashes of light which illuminate the clouds and which are often not accompanied by thunder. They may be ordinary flashes of forked lightning invisible to the observer, owing either to distance or to their passing from cloud to cloud without reaching the earth.

Globe lightning is a mysterious phenomenon stated to consist of a ball of fire moving slowly through the air, sometimes accompanied by a violent explosion.

Under normal air pressure it has been estimated that the electromotive force necessary to produce a spark a mile long is over 3,000,000 volts. When the discharge is from cloud to earth the length of the

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[1] W. J. Humphreys, "The Thunderstorm: Its Phenomena."

path is seldom more than $1\frac{1}{2}$ to 2 miles. In the case of low-lying clouds it may be much less, especially so when they envelop a mountain peak. On the other hand, when the discharge is from cloud to cloud, the path is generally more tortuous and its total length much greater, not exceeding 20 kilometers.

THE AURORA BOREALIS.

The aurora borealis, or northern lights, usually consist of a whitish arc of light or quivering, rapidly moving beams. An arc aurora consists of a luminous segment of a circle. A form of aurora which is probably a modification of the arc form often appears as a band.

The aurora appears with a variety of colors, but the main part is usually whitish, accompanied in some of the brighter forms by a yellowish tinge. In forms which are not so bright it appears to be a silvery-white color. If the light is very intense a red tint may be seen about the lower edge and sometimes a green shade appears in the position nearest the zenith.

The height of the aurora above the earth may vary between wide limits. Estimates made at various times place the lowest at a height of about 0.6 kilometer and the highest at about 68 kilometers. The average height seems to be about 20 kilometers.

An auroral display usually takes place in the early evening and may last for a few hours. The maximum number of auroras occur in March and October and the belt of maximum frequency in the northern hemisphere extends from about 65° to 85° north latitude.

Auroras are believed to be due to electric currents in the atmosphere. It is thought that cathode rays emanate from the sun. These rays travel in straight lines, unless deflected by a magnet (the earth) and cause bright phosphorescence when they fall upon ice particles in the upper atmosphere.

ST. ELMO'S FIRE.

The electrical phenomenon known as Corposants, or St. Elmo's fire, which is frequently seen from projecting points, such as the masts of vessels in low-hanging clouds, appears when atmospheric electricity of low intensity induces electricity on the ship or other object that happens to be under its influence. This induced electricity concentrates at the extremities of structures either at sea or on shore, and becomes visible as a luminous brush discharge.

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CHAPTER XI.

OPTICAL PHENOMENA.

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The height of the aurora above the earth [illegible]

[illegible] between 55° to 60° north latitude.

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CHAPTER XI.

OPTICAL PHENOMENA.

There are a large number of optical phenomena which are of interest for two reasons: For their beauty and because they are more or less closely connected with the weather. They are important for both reasons and are worthy of careful observation.

The phenomena are due to various causes and take different forms, so for convenience they may be grouped under three heads:

(1) Phenomena which are due to the gases of the atmosphere themselves (refraction, twinkling, mirage, and looming); (2) those due to the particles sometimes present in the atmosphere (halos, rainbows, and cloud shadows); (3) those due to the small particles always present in the atmosphere (coloration of the sky, colors of sunset and sunrise, and twilight).[1]

Refraction.—According to a law in optics when a ray of light passes from a medium of one density into that of another, it is bent from its course, being bent toward the normal to the bounding surface when passing from a rarer to a denser medium, and vice versa. Therefore when a ray of light enters the earth's atmosphere from space and passes through air layers of steadily increasing density it must be continuously bent toward the normal.

Refraction thus has the effect of raising an object or increasing its altitude above the horizon. At the zenith, or point directly overhead, the amount of refraction is zero, but toward the horizon it steadily increases, where it has a maximum value of a little more than half a degree. As the amount of refraction depends upon the density of the air it is not constant. This condition is dependent upon the temperature, the pressure, and the amount of water vapor present for any given altitude.

By an effect of refraction the day in middle latitudes is lengthened several minutes. The angular diameter of both the sun and the moon is just about half a degree, while the value of refraction at the horizon is a little more than half a degree. The result is that both the sun and the moon come into view before they have really geometrically risen above the horizon and are still visible after thay have really set.

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[1] W. I. Milham, "Meteorology."

Twinkling.—A common phenomenon especially noticeable on cold winter nights near the horizon is the twinkling of the stars. It consists of an apparent change in position, a change in brightness, and a change in color.

Since the atmosphere consists of numerous layers and pockets of air of different temperature, moisture content, and density, which are in a disturbed condition by the action of the wind upon them, the condition of the air through which a ray of light comes to the observer's eye changes each moment, therefore constantly changing the amount of refraction. This refraction change accounts for the small change of position.

A constant change in brightness is caused by the wind wafting the various layers and pockets of air past the line of sight of the observer, concentrating the light one moment while the next moment it may be diverted.

The rays of light which reach the observer at the same instant may have come by paths of slightly different length. This is caused by the ether waves being out of phase, interfering, and causing the destruction of certain wave lengths or colors. The star under observation will appear to change color since the interference will be different at successive moments.

As the thickness of the air through which the rays of light come is much greater near the horizon, twinkling is more marked there. Except when near the horizon, the planets seldom appear to twinkle. This is because they are disks and are not mere points of light like the stars. Each point on the disk twinkles, but the twinklings do not synchronize, so that the average condition of the whole disk is much more nearly constant.

Mirage.—The conditions necessary for this phenomenon are a layer of very warm air next to the surface of the ground and above it a layer of cold dense air. To an observer at a distance from this warm layer, the rays of light may be so bent by refraction that a total reflection takes place, and an inverted image of the object is seen as if reflected from a horizontal body of water, and all intervening objects are invisible.[1]

A mirage usually occurs during the hot hours of the day when the air is quiet, in level desert regions or over water surfaces near the land. Ths position of the observer above the warm layer of air usually makes a great difference in the appearance of the mirage.

Looming.—When a cold dense layer of air is next to the surface of the ground and the warmer layer of air is above, conditions are favorable for another phenomenon called looming. The rays of light passing upward from an object may be so bent by refraction that total reflection again takes place, and an inverted image above the object

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[1] Milham, "Meteorology."

is seen. Nearer objects appear raised and elongated, while objects below the horizon may be brought into view. Looming, in a certain sense the opposite of mirage, occurs chiefly over the ocean near the shore.

Halos.—The sun and moon are often surrounded by rings or circles of light which are sometimes colored and of different diameters. Unless of great intensity, the ring appears white but when strongly developed the edge nearest the sun is a very pure red. Orange, yellow, and under favorable conditions green, appear outward from the red. Green is always faint and the blue which follows is hardly recognizable. Thus the ring appears white on its outer edge.

Halos are due to the refraction and reflection of the rays of the sun or moon by ice crystals.[1] There are many different types of halo, 14 having been enumerated. The most common form is the halo of 22°. A close relation exists between this halo and the occurrence of cirro-stratus cloud. Halos may last for several hours, depending on the duration of the cirro-stratus cloud sheet. Since halos depend upon the prevalence and intensity of the upper cloud layer, they frequently indicate coming storm conditions.

As a rule, a lunar halo is so little colored that it appears essentially white.

Another ring phenomenon is the corona which is frequently seen about the moon closely surrounding the luminary. Coronas are caused by the diffraction of light by water drops. The smaller the drops, the larger the ring. When several rings are seen at the same time, water drops of several sizes must be present.

A brownish red inner ring marks the corona which together with the bluish-white inner field between the ring and the source of light, forms the aureole.[2] Should other colors be distinguishable, they follow the brownish red in the order from violet to red. Thus the order of colors in a halo and a corona are opposite.

As coronas are diffraction phenomena they show the sequence of color two or three times over. This can never be the case with a halo.

Several other optical phenomena are occasionally seen that are closely associated with halos. Sometimes a circle of white light may be observed parallel to the horizon and at the altitude of the sun. Where this circle crosses the halos, patches of light appear which are known as mock suns or sun dogs. Arcs tangential to the halos and convex to the sun are occasionally seen. These phenomena may be explained as the refraction and reflection of light from the ice particles which are either oriented in a definite way because they are rising or falling, or haphazard in arrangement.

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[1] McAdie, "The Principles of Aerography."

[2] The Observer's Handbook, 1914.

Rainbows.—A rainbow, or arc of prismatic colors, is formed when the sun is shining and at the same time it is raining in a direction opposite to the sun. Violet, blue, green, yellow, orange, and red are so arranged that the red is on the outside and the violet on the inside. The radius of the red part is 42° 2′ while that of the violet part is 40° 17′. From this it is seen that no rainbow can be visible if the sun is more than 42° above the horizon. The sun, the observer's eye, and the center of the circle of which the bow is a part must always be in a straight line.

The maximum number of rainbows occur in the later part of a summer afternoon because they are nearly always associated with thunder showers.

The rainbow is caused by the refraction and reflection of sunlight in the falling raindrops. On the size of the drops and their uniformity depends the pureness of the rainbow's color.

Cloud shadows.—When the sky is covered with broken clouds, the sun is allowed to shine through openings in the clouds and illuminate the moisture and dust particles beneath. Light streaks radiating from the sun and extending down from the clouds are then seen. Cloud shadows on the atmosphere appear as dark bands between the light streaks and are due to unillumination. "The sun drawing water" is the common name given this phenomenon.[1]

The coloration of the sky.—A cloudless sky appears to be blue but it may show all possible gradations ranging from a deep blue to a whitish blue shade. The clearer the sky the purer and more intense the blue.

The blue color of the sky is due primarily to a selective scattering of sunlight by the numerous particles which are always present in the atmosphere.

Sunrise and sunset colors.—When the sun nears the horizon, the thickness of the atmosphere through which the light comes to the observer is large, so that the wave lengths have been efficiently sorted, and only the red, orange and yellow light gets through. The sun's color usually becomes yellow or orange at sunset unless the atmosphere is very dusty and hazy, when it may be decidedly red.

Changing sunset colors and glows are seen from the time the sun approaches the horizon until it is some 16° below.

At sunset, due to the colored light coming from the west and reflected to the observer by the dust particles in the east, colors are also visible in the eastern sky. As the sun goes farther and farther below the horizon the pink twilight arch is seen rising in the east. A blue-black patch, which is the shadow of the earth on its atmosphere, appears beneath this arch.

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[1] W. I. Milham, "Meteorology."

Sunrise colors are practically the same as those occurring at sunset, only they occur in the inverse order.

Twilight.—After the sun has gone below the horizon and is no longer directly visible to the observer, twilight is said to set in. It is caused by the reflection and diffraction of sunlight by the numerous particles in the upper atmosphere.

Twilight is the transition period between daylight and darkness. The duration of twilight varies at different phases and times of the year. Twilight is stated to last until the sun has gone about 18° below the horizon.

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CHAPTER XI.

INSTRUMENTS.

CHAPTER XII.

INSTRUMENTS.

The present chapter endeavors to give a clear but brief description of the instruments used by the Naval Aerographic Stations, their construction, and a few instructions for their use and care.

BAROGRAPH.

The barograph gives a continuous record of changes in atmospheric pressure. The motion is furnished by the action of a set of aneroid boxes, indicated on a chart by a pen. The pen rests against a drum revolved by a clock within. Over the drum is placed a recording sheet upon which the lines are traced.

1. *Case.*—The case is approximately 25 by 15 by 12 centimeters high and is substantially made of wood and metal. The two sides are glazed and the top and sides are removable to allow access to the instrument within. Securely fastened to the bottom is an aneroid barometer, pen-controlling mechanism, and a cylinder clock.

2. *Barometer.*—The instrument is an eight-cell aneroid barometer which controls the pen movement through a series of levers.

3. *Drum.*—The drum is approximately 30 centimeters in circumference and takes a record sheet 9 centimeters wide. There is a flange for the easy setting of the sheet in correct alignment. The sheet is held in place by rubber bands.

4. *Clock.*—The clock is of the cylinder type, set inside the drum and geared to it in such a manner that it can be conveniently removed for adjustment. It turns the drum surface at the rate of 1 centimeter per hour and has a 24-hour movement.

5. *Pen.*—The pen is metallic and glycerin ink is used.

Care should be taken to adjust the barograph from time to time using a mercurial barometer as a standard.

ANEMOSCOPE.

The anemoscope gives a continuous record of wind direction. The motion in the anemoscope is furnished by a wind vane, which motion is transferred by a rod through the roof to a revolving drum, upon which is the recording sheet. The pen rests on this drum and moves downward by clockwork.

The anemoscope used by the Naval Aerographic Stations has the following construction:

1. *Case.*—The instrument case is glazed on all four sides. The front is hinged to provide convenient access to the mechanism within. Securely fastened to the bottom is a support for a record drum and the clock with its connecting levers and pen arm.

2. *Wind vane.*—The vane is approximately 1 meter long supported at least 3 meters above the roof. It is properly balanced on noncorrosive bearings and is weatherproof. The outside sleeve is provided with guys or other means of secure fastening.

3. *Drum.*—The drum is pivoted to the wind vane. It is approximately 35 centimeters high and 24 centimeters in circumference.

4. *Clock.*—The clock is connected to the pen arm through a pulley and chain in such a way as to move pen downward at the rate of 1 centimeter per hour.

5. *Pen.*—The pen is of the large capacity type and uses glycerin ink.

ANEMOBIAGRAPH.

The anemobiagraph is a recording instrument combining the speedometer and the wind-direction indicator. That used at the Naval Aerographic Stations has the following construction:

1. *In general.*—The instrument consists of two parts; the head and the recorder.

2. *Head.*—The head is a combination wind vane and pitot tube manometer. From it two simultaneous records are made on the record sheet; one indicating wind direction, the other wind force. The head is of such a size as to assure sufficient power to control the movement of the anemoscope pen and to have proper air ducts to control the speedometer float and its pen. The head is carried on an annular ball bearing, or other means of support that will assure continual freedom of movement.

3. *Connections.*—Change of direction of flow is transmitted to the recorder by a rigid steel rod and cams, and variations of pressure (indicating velocity changes) through two flexible tubes leading, respectively, from the nozzle and staff of the head. The outer air support is approximately 11 meters high, is air-tight, and is anchored securely to a concrete base. No covering is required indoor over the connection to the recorder.

4. *Recorder.*—The wind direction is indicated by the movement of the pen actuated by the vane. The wind velocity is simultaneously recorded on the same sheet by a pen whose movement is varied according to the relative states of pressure at the opening in the head.

5. *Drum.*—The pens make traces on the record sheet on the drum, whose circumference is about 60 centimeters and which turns 2

centimeters an hour. The record sheet is 15 centimeters wide. The drum has a flange for the easy setting of this sheet in correct alignment.

6. *Clock.*—The clock is of the cylinder type and is set within the drum so as to be conveniently removable.

7. *Pens.*—The pens are metallic and use glycerin ink.

THERMOGRAPHS.

The thermograph gives a continuous record of change in temperature. The motion is furnished by a metallic helix which curls and uncurls with the fall and rise of temperature transferring its motion to levers which operate the pen arm. The pen rests on a drum which revolves under it by clockwork.

The thermograph used at the Naval Aerographic Stations has the following construction:

1. *Case.*—The instrument case is approximately 25 by 12 by 15 cms. high and is made substantially of wood or metal. The two sides are glazed and the top and sides are removable to allow access to the mechanism within. Securely fastened to the bottom is a metallic thermometer and a clock base.

2. *Thermometer.*—The thermometer is of Bourdon or helical metal type with the free end connected by levers to operate the pen arm.

3. *Drum.*—The drum is approximately 30 cms. in circumference to receive a 24-hour sheet 9 cms. wide. There is a flange for the easy setting of the sheet in correct alignment. The sheet is held in place by rubber bands.

4. *Clock.*—The clock is of the cylinder type, set inside the drum and geared to it in such a fashion that it is conveniently removable for adjustment. It turns the drum at a rate of one cm. per hour and has a 24-hour movement.

5. *Pen.*—The pen is metallic and uses glycerin ink.

ABSOLUTE HYGROGRAPH.

The hygrograph is a recording hygrometer which gives a continuous record from which can be deduced the relative humidity of the atmosphere and it records the actual weight of water vapor in the air per unit volume. A bundle of hair cured and dried so as to be responsive to changes in moisture, gives the percentage of saturation, while the dry and wet thermometers give the actual and sensible temperatures from which may be deduced the absolute humidity for different temperatures. In this hygrograph the relative humidity is recorded by a pen which takes its motion from connecting levers attached to a bundle of hair, the other pens are controlled by the thermometers. The hygrographs in use at the Naval Aerographic Stations are of the following construction.

1. *Case.*—The instrument case is 30 by 18 by 15 cms. high and is made substantially of wood or metal. The sides are glazed and the ends are open, protected by louvres or wire screening. The whole upper part is removable to allow access to the instrument within. Supported in the base is a water well, and fastened on the base are supporters for a hygrometer, a wet and dry thermometer, and a clock and drum for holding a record sheet.

2. *Well.*—The well has a capacity of about 25 ccs. It is concealed in the base with suitable apertures for filling and for receiving the moistening gauze of the wet thermometer.

3. *Hygrometer.*—The hygrometer is of the hair bundle type so connected to the pen that the latter will give a continuous trace of the percentage of moisture in the atmosphere. Provision is made for setting, by adjusting the distance between the jaws holding the hair. The hairs are not in a tight bundle but separated by a griddle.

4. *Thermometers.*—The two thermometers are identical in all respects and are mounted on the same axis. They are metallic, helical in form, with an outside diameter of about two cms. and have four turns between the point of support and the attachment of the pen controlling levers.

5. *Pen operating mechanism.*—The pens are controlled in such a manner that their traces are directly above one another. The pen movement is vertical, not curved.

6. *Drum.*—The drum is approximately 30 cms. in circumference to receive a 24-hour record sheet, 12 cms. in width. There is a flange for the easy setting of the sheet in correct alignment. The sheet is held in place by rubber bands.

7. *Clock.*—The clock is of the cylinder type, set inside the drum and geared to it in such a manner as to be easily removable for adjustment.

8. *Pens.*—The pens are metallic and use glycerin ink.

SUNSHINE RECORDER.

The sunshine recorder (Campbell-Stokes) is an instrument which gives a record of the amount of sunshine. The sunshine recorder used by the Naval Aerographic Stations has the following construction:

1. *General description.*—The instrument is substantially made to withstand continued exposure to the weather. It consists of a metal frame supporting a lens and bowl for the record sheets.

2. *Lens.*—The lens is crown glass with a standard diameter of 10 cms., a focal length of 7.5 cms., and weighing 1,360 grams.

3. *Bowl.*—The bowl is made to accommodate three cards, one for the summer sun, one for the equinoctial sun, and one for the winter

sun. There is provision for adjustment to accommodate a latitude change of 20°. The diameter of the bowl, measured between the 6 o'clock marks, is approximately 14.5 cms. and the radius 25 cms. The belt from which the bowl is made is so cut that when the bowl is adjusted for its mean latitude the plane of the top cut is nearly horizontal.

BALLOON EQUIPMENT.

Balloons are used for determining the direction of air flow; also temperature, humidity, and pressure at various levels. Sounding may be defined as the making of successive sights at regular intervals by means of the theodolite. With pilot balloons having an ascension speed nearly constant (previously determined), one can determine the successive positions of the balloon in space and can deduce from that the direction of the wind and its approximate speed at different altitudes.

GENERAL EQUIPMENT.

1. *Balloons.*—There are two sizes, one to inflate to 60 cms. and the larger to about 84 cms. They are made of rubber and are equipped with automatic valves. They are known, respectively, as small testers and pilot balloons.

2. *Hydrogen.*—The hydrogen supply comes in commercial iron tanks, and there is a suitable equipment of valves, pressure gauges, and tubing.

3. *Theodolites.*—The theodolites are similar to those developed for the use of the Canadian Meteorological Service. Two are required for simultaneous use.

It has been found that these balloons can not be safely inflated to lift more than an extra 10 grams.

It is believed that most of the balloon fillers supplied weigh 15 grams, but in case of possible variations the following table is given:

Weight of filler and weights to be left on.	Weights to be left on.
Grams.	*Grams.*
18.0	15.0
25.5	22.0
33.5	29.5
42.0	37.5
51.0	46.0
60.5	55.0

It is suggested that the weight to be left attached when the balloon is released should consist of a piece of lead wire.

LIGHTNING RECORDER.

A ceraunograph, or lightning recorder, is a device to provide a warning of the approach of a storm at a time sufficiently far in advance to increase the accuracy and value of local weather forecasts.

Practically all summer storms are accompanied by electrical disturbances in the ether. By use of antennae, some of these radiations may be intercepted and by a suitable apparatus be made to give an indication of not only the presence but also the relative proximity of the storm.

The necessary apparatus to construct a ceraunograph are an aerial, coherer, decoherer, relay, recorder and batteries.

The action of the instrument is based upon the effect that high-tension electric waves, in free air, have upon a coherer. When lightning occurs in the vicinity of the coherer, some of the electric waves travelling through the ether affect the filings, causing them to cohere. This decreases their electrical resistance, thereby allowing a local battery current to operate a relay in circuit with the filings, which in turn operates a decoherer. The decoherer separates the filings and restores them to their original condition and at the same time records the passage of the electrical waves.

Ceraunographs are capable of giving a warning of coming lightning from a few hours to 20 hours in advance, the strength and frequency of the signals not only denoting whether the storm is approaching or receding, but also if it is increasing or decreasing in energy.

MAXIMUM AND MINIMUM THERMOMETERS.[1]

The maximum thermometer is designed to record the highest temperature experienced during a given period. Two forms of instrument are in common use. Both are mercurial thermometers. In the Negretti & Zambra patterns, adopted by the Meteorological Office, the tube is greatly constricted just above the bulb. It is hung nearly horizontally with the bulb end slightly lower than the other. 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 to register the highest temperature reached.

Phillips's pattern is also hung horizontally. In it there is no constriction in the tube, but a small air bubble is placed in the mercury thread near the bulb. As the temperature falls the part of the mercury beyond the bubble is not drawn back toward the bulb and thus the end of the mercury column marks the highest temperature reached.

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[1] The Observer's Handbook.

The minimum thermometer records the lowest reading experienced in a general interval. The most common type of instrument is a spirit thermometer, having a small index in the stem. It is hung like the maximum thermometer. As the temperature falls, the index is carried toward the bulb by the spirit, but if the latter 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.

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 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.

(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.

SOLAR RADIATION THERMOMETER.[1]

(Black bulb in vacuo.)

For obtaining some indication of the intensity of the sun's radiation, a maximum thermometer having the bulb and 1 inch of the stem coated with dull lampblack is used. The whole is inclosed in a glass jacket which is exhausted of air.

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 feet). The bulb must be freely exposed to the sun, and hence the tube should be directed from east to west.

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.

Readings are taken once a day only, at 9 p. m. The method of off setting is precisely similar to that used in the case of the maximum thermometer.

TERRESTRIAL RADIATION THERMOMETER.

(Grass minimum.)

For estimating the effect of radiation from the earth's surface at nighttime, a minimum thermometer exposed freely on a grass surface is used. To secure greater sensitiveness, the wooden mounting of

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[1] The Observer's Handbook.

the ordinary minimum thermometer is dispensed with. With the same object, various forms of bulb have been suggested. An outer glass case is generally sealed round the stem of the instrument to protect the tube and prevent condensation of the spirit in the upper end.

The thermometer should be supported on two Y-shaped pieces of wood at a height of 1 or 2 inches above the ground, which should be covered with short grass. Care should be taken that the bulb does not touch the supports, as this would diminish the sensitiveness. The proximity of walls, trees, benches, etc., should be avoided.

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.

Hour of reading and setting.—The hour for reading and setting the grass minimum thermometer raises an important question. The climatic fact which the observations should supply is the number of nights of ground frost. If 9 a. m. be selected as the hour for setting, it will frequently happen that the reading to which the instrument is set will be the minimum for the ensuing 24 hours, and if the value happens to be below 30° F. (or 30.4° F. if the thermometer is read to tenths of a degree) the statistics may show more "days of ground frost" than there were nights of frost. At stations where evening readings are taken the thermometer should be read and set at the hour of evening observation. At stations at which observations are taken once a day only arrangements should be made for setting the instrument in the afternoon or evening; the reading may be taken in the morning.

Bubbles in stem.—The protection of the stem of a grass minimum thermometer by an outer jacket is not always sufficient to prevent the spirit separating into detached portions. During great cold and also when exposed to strong sunshine grass minimum thermometers are very liable to the development of bubbles on 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 it is advisable to place the instrument indoors during the daytime when the sun is very powerful. It should be kept in a vertical position, bulb downward, while not in use.

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, hold the thermometer with the bulb downward and the tube vertical and jolt the bulb end of the frame, or if there is no frame, the hand holding the thermometer, gently against a soft pad, keeping the instrument vertical all the time. One's knee or a thickly folded tablecloth forms a suitable pad to prevent the jar being too severe.

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. After all visible drops or bubbles have been removed in this way the thermometer should be left for a short time in a vertical position, bulb downward, to allow any liquid which may have collected on the walls of the tube to drain down to the main column. In hot weather especially it is advisable to take suitable opportunity for keeping spirit thermometers in this position in cold water for some hours in the daytime.

Occasionally the thread of a mercury thermometer gets broken; the defect may generally be remedied by jolting as described above.

SCREEN.[1]

The dry bulb, wet bulb, and the maximum and minimum thermometer are exposed in a screen of the following patterns. The screen for this climate in general use is the Stevenson screen. It is a box or cupboard with double louvred sides. It has the following construction:

Material.—The screen is to be constructed throughout of the best yellow pine and all its parts put together with tenons, mortises, and brass screws, with the exception of the louvres, which are fastened together and secured in place by brass rivets.

Framework.—This consists of four corner posts, connected above and below by rails.

Louvres.—The screen has double louvres. The outer louvres are slipped into shallow grooves cut in the inner sides of the four corner posts of the screen at an angle of 45° and one-half inch apart measured square to the groove. At the two back inner corners of the screen the louvres are mitred roughly. The outer edges of the outer louvres are made flush with the corner posts; the inner louvres project beyond the posts into the screen.

Door.—The door forms one of the longer sides of the screen. It is a rectangular frame fitted with double louvres similar to those described above. It is hung by its outer bottom edge to the lower front rail by two strong hinges and closes with its outer surface flush with the corner posts.

Bottom of screen.—This is formed by three boards, arranged as follows: The center or upper board is set into the end rail of the frame, so as to be flush with the top of the lower side rails, while the other two are screwed to the under sides of the end rails in such a way that one overlaps the back edge and the other by the same amount the front edge of the center board above.

Roof.—The roof is to be double. The inner roof is to be formed by a board one-half inch thick, resting upon the upper rails and cut

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[1] Adopted from The Observer's Handbook.

away to receive the corner posts. It has holes, each an inch in diameter, drilled in it at equal distances all around, the centers of the holes being 3½ inches from the outer edge.

The outer roof is to be a 1-inch board screwed on to the top of the corner posts, and also to a narrow bearing of wood, running across the center of the inner roof from front to back. The underside of the outer roof is 1½ inches above the inner roof in front, but only one-half inch above it at the back, and it must project beyond the sides of the screen all around. A clear space will thus be left between the two roofs, which in the front will measure 1½ inches, and in order to partly close this a small lathe, three-fourths inch wide and one-half inch thick, is to be fastened across the center of it.

Position of thermometer.—The upright for the dry and wet bulb thermometers is screwed to the back of the middle bottom board. The two uprights across which the maximum and minimum thermometers are hung are screwed to the front of the same bottom board. The upper ends of these uprights are screwed to fillets attached to the underside of the inner roof. If the dry and wet bulb thermometers are already fixed upon a frame, the frame may be hung upon the upright; but if the thermometers are separate, two strips of wood are fixed to the upright, at right angles to it. In these cross pieces grooves are cut, which in the case of the upper one are right across the strip, but in the lower stops short of the bottom. These grooves are wider at the back than at the front. The thermometer scale rests on the bottom of the lower groove, and the instrument is then secured in its place by means of small brass buttons, which are turned over the outside edge of the thermometer scale, and thus hold it firmly in the groove.

Painting.—Previous to their being put together all the different parts have two coats of white lead paint; and when completed the whole screen receives a finishing coat composed of white-zinc paint and copal varnish.

NEPHOSCOPE.

The nephoscope is used in determining the direction, height and velocity of clouds. It consists of a graduated black glass mirror, so mounted as to allow of accurate leveling, and an adjustable pointer.

The instrument in use by the Naval Aerographic Stations has the following construction:

1. *Mirror.*—The mirror has three equidistant concentric circles engraved on its surface, as well as the usual radial lines, and a transparent space through which the position of a magnetic needle mounted within the mirror case may be seen.

2. *Mounting.*—Mounted in the same plane as the mirror and in the same plane with it is an adjustable brass pointer. A magnetized

compass needle is pivoted under the center of the mirror with its pin supported by the mirror case.

3. *Mirror case.*—The mirror case is supported and balanced so that it will rest horizontally even though the instrument base is resting on an irregular surface. The bearings are adjustable, and the instrument made of brass or of aluminum.

4. *Case.*—The carrying case is made as small as possible and practically all of wood. The cover is hinged and a socket provided in which the instrument may be screwed in order to make use of the case as a base. Inside are plush-lined pockets to fit the various parts of the instrument.

The method of observing is as follows:

> 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 its tip is also brought into this straight line. This done, he moves his head so as to keep the cloud image and the tip of the pointer in coincidence and notes the radius along which the image appears to travel. This radius marks the direction of cloud drift. A compass needle mounted below the disk enables the observer to identify this direction; the variation of the compass, however, must always be noted and duly allowed for in all observations of direction.
>
> The velocity-height ratio of the cloud may be determined by noting the number of seconds required for the image to travel from the center of the mirror to the first circle or one circle to the next. If "a" be the radius of the inside circle, "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 millimeters), the value of the velocity-height ratio, as it would appear to an observer at a point on the surface vertically below the cloud is given by the equation—velocity-height ratio=a divided by bt.[1]

RAIN GAUGE.

A rain gauge is an instrument for ascertaining the amount of rainfall. The recording rain gauge in use at the Naval Aerographic Stations has the following construction:

1. *Construction.*—The outer casing is copper of sufficient weight to avoid denting and is weather-proofed. Over the top is a removable cover. Under the inner rim of the latter is a balance and train of levers to operate a pen. Also supported on the bottom is a clock and drum receiving a record sheet. On the front of the lower part of the outer casing is an access door, which is glazed.

2. *Cover.*—The cover of the same weight as the casing (copper) fits tightly, tapering inward to a standard brass rain-gauge ring at the lip of the opening. Its inner collar is long enough to project inside the rim of the receiver, and its outer collar 5 or 6 centimeters over the casing of the apparatus.

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[1] The Observer's Handbook.

3. *The receiver.*—The receiving can is cylindrical and of sufficient capacity to record a 15 centimeter rainfall in 24 hours without overflow.

4. *Balance, etc.*—The receiver will rest on a platform counterbalanced by a weight or spring and which will move downward according to the weight of the precipitation in the can. This movement raises a pen arm by means of a suitable train of levers, indicating on a drum the amount of rainfall.

5. *Drum.*—The drum is approximately 30 centimeters in circumference to receive a 24-hour record sheet 9 centimeters wide. There is a flange for the easy setting of this sheet in correct alignment The sheet is held in place by rubber bands.

6. *Clock.*—The clock is of the cylinder type, set inside the drum and geared to it in such a manner that it will be easily removable for adjustment. It turns the drum surface at a rate of 1 centimeter per hour.

7. *Pen.*—The pen is to be metallic, using glycerin ink.

AEROGRAPH.

The aerograph is a combination of the thermograph, barograph, and hygrograph, all making simultaneous, continuous records. The Naval Aerographic Stations are using an aerograph of the following construction:

1. *In general.*—For airplane work the instruments are as light and compact as possible.

2. *Case.*—The case is approximately 6 by 30 by 60 centimeters, made of sheet aluminum properly reinforced at the edges and corners. There are lugs on each side for making the instrument fast. There are one or more transparent panels of unbreakable material on the sides. The instrument is entirely inclosed and the doors securely fastened. Proper ventilation to the interior is provided.

3. *Instruments.*—The clock is as light as possible for accuracy of rate. It will drive the paper drum or drums and also make time marks on the record. The thermograph is a bi-metal helix, with its free end controlling a pen. The barograph is an aneroid of at least six cells. The hydrograph consists essentially of a bundle of prepared hairs, exposed in the line of most direct ventilation. To increase the sensitiveness the hairs are supported by a griddle. The pens are supported on cords, rather than on pivoted lever arms, in order that their motion may be directly vertical. The paper carrier is easily removable. All possible parts are cut from aluminum, and the others made of well-machined brass, as light as safety permits.

W. F. P.

CHAPTER XIII.

SIGNALS.

CHAPTER XIII.

SIGNALS.

Telegraphic reports of meteorological observations are to be forwarded according to the following code:

UNITED STATES NAVY WEATHER REPORT CODE.

Letters indicate *direction from* which wind and clouds are moving as follows:

[Cloud definitions according to the International System.]

Code letter.	Direction.	Cloud type.	Code letter.	Direction.	Cloud type.
B	0° north	Cloudless.	M	180° south	Strato-cumulus.
C	30°	Fog.	N	210°	Alto-stratus.
D	60°	Stratus.	P	240°	Alto-cumulus.
F	90° east	Cumulo-nimbus.	R	270° west	Cirro-cumulus.
G	120°	Cumulus.	S	300°	Cirro-stratus.
H	150°	Nimbus.	T	330°	Cirrus.

Wind tendency:
  (V) Veering or (B) backing.
  (I) Increasing or (D) decreasing.
  (C) Constant or (G) gusty.
Barogram description:
  (R) Rising or (F) falling.
  (S) Smooth or (J) jerky.
  ( ) Number of hours since recent change in direction.

The message is to be sent in eight parts with an interval (•▬•▬) between each part in the following order:

1. Place and day of the month: *Chatham 8.*
2. Time, a. m. or p. m.: *Ten A.*
3. Wind direction and its velocity in meters per second: *F5.* When calm send word "calm."
4. Pressure in kilobars above (A) or below (B) 1,000 kbs.: *A7.*
5. Temperatures in degrees absolute: *A284.*
6. Cloud type, direction of movement, and velocity: *SR5.*
7. Wind tendency and barogram description: *DCS3.*
8. Any additional information.

STORM SIGNALS.

As far as possible information concerning weather conditions should be obtained from the nearest weather station by telephone or telegraph.

Notice of threatening atmospherical disturbances in the vicinity of the coastal station should be displayed as a warning to pilots.

As there are several signal systems in use throughout the world, those in present use in the United States, Great Britain, and France are quoted below.

UNITED STATES.

Day apparatus.—Two red flags with black center, and red or white pennant displayed at masthead, one above the other.

Information given:

Pennant: Moderately strong winds.

Flag: Markedly violent storm.

Combination of flag and pennant indicates quadrant from which the wind may be expected, and also whether the center is approaching or receding.

Storm center has passed.		Storm center approaching.	
NW.	SW.	NE.	SE.
White pennant over flag.	Flag over white pennant.	Red pennant over flag.	Flag over red pennant.

Two red flags.—Expectation of a very dangerous storm or hurricane.

Night apparatus.—Red light and white light.

Information given.—Red light indicates easterly winds; white light below red, westerly winds; no night hurricane warnings.

Duration of signal.—Signals remain displayed for 24 hours from the time specified in the order to hoist, change, or continue them, and no longer, unless a subsequent telegram is sent ordering them down.

Sometimes a cautionary signal is displayed indicating that conditions dangerous to small craft but not unfavorable to large craft may be expected. The warning consists of a signal pennant, either white or red, depending whether the winds are to be easterly or westerly, respectively.

GREAT BRITAIN AND IRELAND.

Day apparatus.—Cone hoisted at yardarm or masthead.

Information given.—Expectation of strong wind or gales from north to east, backing through north (point upward), from south or east veering through south to northwest (point downward).

Night apparatus.—Three lanterns of any color, preferably red, and cross bar.

Information given.—Same as by day. A triangle of lanterns replace the cone.

NOTE.—Night signals are exhibited at very few stations in the British Isles. At some stations the cone is hoisted where it is illuminated by artificial light. A cone is 3 feet high and 3 feet wide at the base, is made of black canvas, and has the appearance of a triangle when hoisted.

Duration of signal.—From time of receipt of telegram till 8 p. m. of the following day. Orders to prolong or lower the signal are dispatched if necessary.

FRANCE.

Apparatus.—Two cones.

Information given.—Single cone, point upward: Gale commencing with wind in the northwest quadrant. Single cone, point downward: Gale commencing with wind in the southwest quadrant. Two cones, one above the other, both points upward: Gale commencing with wind in northeast quadrant. Two cones, one above the other, both points downward: Gale commencing with wind in southeast quadrant. Two cones with their bases together: Hurricane.

NOTE.—The distance between two cones hoisted in vertical line should be the same as the length of the slant side of the cones.

Night signals: None.

A. S. M.

CHAPTER XIV.

FORECASTING.

CHAPTER XIV.

Should [illegible] a cautionary signal be displayed indicating that [illegible] these dangerous to small craft but not unfavorable to large [illegible] be expected. The warning [illegible] pennant, either [illegible] so, depending whether the winds are to be easterly or we[illegible] respectively.

CHAPTER XIV.

FORECASTING, PART 1, STORMS.[1]

Types of storms.—It is the practice of the Forecast Division of the Weather Bureau to classify storms after the region where first charted. Thus, one of the most frequent types is known as the "Alberta," because it is definitely charted in that territory. The system has its defects, and with each enlargement of the area of observation some modification of the place of origin becomes apparent. In a recent publication by Bowie and Weightman[2] the types are given as Alberta, North Pacific, South Pacific, Northern Rocky Mountain, Colorado, Texas, East Gulf, South Atlantic, Central, and West Indian. Charts showing the normal 24-hour movement for 5° squares have been prepared to take the place of the earlier charts of paths of greatest frequency. Tables covering a period of 20 years are also available for the average velocity. Thus it is seen that storms of continental types move more rapidly in winter than in summer.

	Kilometers in 24 hours.	Miles.		Kilometers in 24 hours.	Miles.
January	1,199	745	August	788	489
February	1,110	690	September	883	549
March	1,080	673	October	919	571
April	871	542	November	1,040	646
May	792	492	December	1,156	718
June	772	480			
July	839	521	Average for year	954	593

In determining a possible deviation from a normal course, account is taken of unequal pressure distribution in the regions adjacent to the storm center, also the location of maximum 12-hour pressure fall and the trend of the isotherms. A number of empirical rules based upon the intensity and movement of the 12-hour pressure change are given by Bowie for the movement of lows.

The most important rules[3] for the guidance of the forecaster in determining the course of a hurricane are:

A hurricane does not move directly toward a region of high pressure when such an area is not moving perceptibly, but follows behind it. If the high moves east or northeast off to sea at a normal rate, the hurricane moves north or northeast. If the

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[1] From "Principles of Aerography," chapter 9, A. McAdie.

[2] Monthly Weather Review, Suppl. 1, July, 1914; also Suppl. 4, Jan., 1917.

[3] In "Weather Forecasting in the United States" many general statements are made by the various forecasters regarding the movements of highs and lows.

high hangs persistently over the coast, the hurricane is deflected far to the west before it can recurve.

If rain falls freely before the hurricane comes to land, the disturbance may decrease in intensity; but if heavy rain begins after the storm passes inland, the storm will probably continue.

When a West Indian hurricane is moving westward in the longitude of eastern Cuba and is north of that island, it will recurve east of the South Atlantic coast, when an area of high pressure covers the Northwestern States. If the hurricane is moving westward over Cuba or the western Caribbean Sea when a low area occupies the Northwest, and the pressure is high in the Eastern States, the storm will probably move to the Gulf of Mexico and reach the Gulf coast after recurving.

For storms over the Great Lakes it appears that depressions frequently remain stationary or move slowly, accompanied with much precipitation, when the pressure is high to the north and northeast. Again, the movement is slow when the air from an extensive high pressure area drains southeast from the Missouri Valley.

Other storms that increase with intensity appear to depend on marked horizontal temperature gradients. A rapid temperature rise in front of a storm implies an increase in intensity, especially if the temperature is falling rapidly over the Northwest. Sharp temperature rises in the eastern quadrants of a storm are a sure indication that the storm will move northeastward and increase in intensity.

On the Atlantic coast there are certain types of disturbance which, especially in March,[1] have provoked widespread comment owing to the failure of the Washington forecasters rightly to anticipate weather conditions of the succeeding 24 hours. Noteworthy instances were those at the time of the presidental inaugurations in 1897 and 1909.

For 45 years the forecasters at Washington and for shorter periods at other forecast centers such as San Francisco, Chicago, New Orleans, Portland, and Denver have depended mainly in making their forecasts upon certain auxiliary maps of pressure and temperature changes. Attempts have been made to use cloud change and humidity change maps, but for reasons hardly satisfactory, it would seem, no continuous use of these latter charts has been made. The pressure and temperature auxiliary maps show the 24 and 12 hour changes. The barometric tendency, as defined by the International Committee in 1913, is the change in the three hours preceding the observation. This is not used in the United States, but whenever the pressure has risen or fallen 1.02 mm (1.5 kb) within two hours preceding the observation, the change is reported, though not the character of the change, such as steady, unsteady, etc.

The pressure chart gives the area and intensity of the nonperiodic pressure changes. Henry, compiling the fluctuations in pressure at certain stations for a period of 10 years, found that the frequency was nearly the same for all parts of the country except that the changes are more rapid at northern stations. The average annual number of such pressure movements is 88 and the average time interval four and two-tenths days.

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[1] The snow and wind storm known as the great blizzard of New York occurred March 12–14, 1888.

Ekholm in 1911 suggested the terms allobar for the area of pressure change; anallobar for an area over which the pressure has risen; and katallobar for an area over which the pressure has fallen within the given time. The region of maximum change may be regarded as the center. The names are cumbersome and the conditions might well be described simply as "rises" and "falls." Henry[1] has described the basis of forecasting by synoptic maps, and given at some length the relation of the pressure change areas and the movements of highs and lows. Shaw[2] has discussed certain relations between the isallobars and the winds.

Storms over the Lakes region sometimes develop secondaries off the Virginia or New Jersey coasts; and these pass apparently slowly northward, causing heavy snows and high winds in the Middle Atlantic and New England States.

Of all secondaries, tornadoes are most destructive and most frequent. They are associated with storms of increasing energy, moving to the left of normal paths when the trough of low pressure extends well southward.[3] Again, when the southern portion of the trough swings eastward faster than the northern portion, there is likelihood of the development of a secondary storm south or southeast of the northern center.[4]

There is a tendency for secondaries to form to the leeward of the Appalachian Mountains, following the passage eastward of moderate disturbances from the northwest. A pressure rise coming from the Lakes region seems to play an important part. If this moves south of the low, secondaries do not develop.

A. McA.

FORECASTING, PART 2, MOVEMENT OF LOWS.[5]

There are ideas which are of importance to consider in the daily forecast, concurrently and simultaneously with the isobaric method. That is, the union of the two methods should lead sooner or later to a forecast of a high degree of perfection, if not to perfection itself.

We will imagine ourselves, in a central station at the time when the forecast is to be made, before an isobaric chart of Europe which is soon to be covered with conventional signs and multiple isobars.

The sky is to be examined.

Is there cirrus?

If yes, we will apply our principle, *cirrus comes from the center of the depression*, and the importance of the center is directly propor-

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[1] Weather Forecasting in the United States, p. 69.

[2] Forecasting Weather, pp. 337-341.

[3] Weather Map of April 29, 1909.

[4] Weather Map of November 8, 1913.

[5] Prévision du Temps, pp. 40-43. (G. Guilbert.)

tional to the speed of the cirrus. Rapid cirrus, strong storm. Slow cirrus, weak depression.

Now, it is necessary to first determine the direction and speed of the cirrus. Assume the northwest (a most usual direction) and rapid movement (a less frequent case). We may deduce from that that there is a strong storm at sea off the northwest advancing rapidly toward the continent.

Then we must consider the force and the direction of the controlling winds over Europe, principally over the regions menaced by the cirrus, that is to say, by the new storm which they reveal.

Two principal cases may present themselves—either the winds will be *convergent*, or else *divergent*, always in relation to the storm assumed to be over the ocean.

Thus, with the depression off to the northwest, convergence of the wind is perfect if the wind is in the southwest. It is then an obstacle to the advance of the depression; the stronger it is, the stronger resistance it offers. It leads the air, or at least the pressure, directly toward the indicated center, from southeast to northwest. It is important, then, to consider the velocity of the current opposed to the storm at sea.

Inversely, instead of being in the southwest, the wind might be in the north or northwest, that is, in the same direction as the cirrus (a frequent case), or even in the northeast.

These winds are all *divergent.* Far from opposing the least resistance, they favor, on the contrary, the rapid movement of the distant depression. They constitute for it a center of call or attraction, since the movement of the air, which takes place perpendicularly to these north winds from west to east, makes a hollow in front of it.

It is then essential to distinguish immediatdly between the convergence and the divergence of the winds.

It is next necessary to examine well their speed, and also the movement of pressure at the menaced points.

If the convergent wind is weak, and the drop of the barometer has already made itself evident, the resistance will be nil and of no effect. There is evident disproportion between the storm, which is very powerful, according to the velocity of the cirrus, and the opposing wind, which is weak. The depression will advance, then, with its initial speed toward the east, according to the general laws of translation of storms.

On the contrary, if the convergent wind is strong or violent, with no trace of a barometric drop visible in the most advanced stations, the resistance will be invincible, and might even, not only keep the depression at sea, but push it back, in conformance to our rule:

Every depression which, at its arrival from the sea, determines abnormally strong winds, can not advance and will remain stationary, if it is not even thrown back toward its place of origin.

For example, and to fix the idea, suppose that a 1 mm. (1.46 kb) drop at Valentia, with south winds, 7 (very strong), is due to a strong storm indicated to the west of this station by the cirrus.

There is every evidence that there is disproportion between the effort toward a lowering, which is only 1 mm. of pressure, and the resisting force, which is represented by a very strong convergent wind. The depression will be forced back; the barometer will rise again.

Let us take the opposite case. The barometer is down 10 mm (14.6 kb) in Ireland, and the wind remains weak there, 2, from the south. The important storm revealed by the clouds will meet no resistance, and consequently the twisting and centrifugal movement will develop still more. The velocity of the cyclone being considerable, according to the cirrus, the atmospheric perturbation will become proportionately great, and will provoke a vast tempest.

There will be similar condition (imminent danger) if the winds, instead of being convergent, were divergent. In this case even with the barometer still high the winds will be preparing a powerful cyclone. Far from piling up and forming a dike against the invasion of the storm, far from constituting thus an obstacle, the air is dispersed in front of the advancing center, and so facilitates its rapid movement.

The more violent the divergent wind is, and the more powerful the attraction of the air toward the east, and the greater is the void established in front of the storm, by so much will the initial vortex be accentuated, and a tempest is inevitable.

As it is seen, the depression at sea, invisible on the isobaric chart, may be indicated by the observation of the cirrus, whose velocity is proportional to the importance of the center. But the indication given by cirrus will only be justified by the facts if the surface winds do not modify the initial state of the storm.

The strongest storm at sea may be indeed broken to pieces by the excess of convergent wind, while a feeble depression may be transformed into a terrible cyclone by very powerful divergent winds.

Forecasting must take account of these elementary notions. It will be so much the surer if the indications given by the clouds be considered with the data of the isobaric method. In every case our rules permit daily appreciation of the opposing forces; the centrifugal and the centripetal force continually in battle in every atmospheric situation.

FORECASTING, PART 3, TURNING OF WINDS WITH ALTITUDE.[1]

With a distant *low* approaching from the southwest, surface winds are easterly and shallow, and above them is a layer about 1 kilometer in depth in which there is little or no wind; above this layer southwesterly winds prevail.

As a *low* passes north of the station, surface winds are successively southeast, south, and southwest, and the turning of wind with altitude is clockwise, the upper winds nearly always being southwest to west.

With a *low* northeast of the station and a *high* southwest, both surface and upper winds are northwest. As this *high* approaches and passes south of the station the surface winds are successively west-northwest, west, and west-southwest, turning clockwise with altitude to northwest.

With a *high* east of the station and a *low* approaching from the west or west-northwest, winds are southwest and strong both at the surface and aloft.

With a *high* north of the station and a *low* approaching from the southwest and passing south of the station, surface winds are north-northeast to east-northeast, and there is little turning up to 4,000 meters; the turning at higher levels is counterclockwise to north-northwest and northwest.

With a *high* northwest and a *low* south of the station, surface winds are north to northeast, turning clockwise with altitude to northeast, and at higher levels counterclockwise back to north-northwest.

With a *high* northwest and a *low* passing northward east of the station, surface winds are successively north, north-northwest, and northwest, turning counterclockwise with altitude to northwest and west-northwest.

In general, the turning of winds with altitude is usually such that they have a westerly component before the 3 km. level is reached.

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[1] Gregg, W. R., "Turning of winds with altitude." (Monthly Weather Review, January, 1918.)

CHAPTER XV

SOME METEOROLOGICAL CONDITIONS WHICH INCREASE THE DANGER OF FLYING

CHAPTER XV.

SOME METEOROLOGICAL CONDITIONS WHICH INCREASE THE DANGER OF FLYING.[1]

By Capt. C. J. P. Cave, R. E.

It may seem rather presumptuous for one who does not himself fly to discuss the dangers that may be met with in the air as though a landsman who had crossed the channel a few times were to write on the navigation of a ship across the ocean. At the same time, it may be of some use to point out certain conditions of the atmosphere which seem to me to constitute dangers, although I may be mistaken in my estimate of some of these, and would welcome any information from pilots bearing on the subject. In fact, my paper is meant to elicit information rather than to give it.

At the same time I should like to protest very strongly against the idea that we have made so much progress in the science and art of aviation that we can afford to disregard the weather altogether, except perhaps in the case of fog. The idea is a common one, and has been often stated, but it seems to me that it is a most dangerous idea to foster. An airman can not afford to disregard the weather any more than can a seaman. A seaman puts to sea in almost any weather, but the fact that storms take their toll of shipping is a proof that seamen can not entirely disregard these things. Neither are airmen immune. Only last summer it was stated in our official communique that five of our aeroplanes had failed to return owing to a severe rainstorm.

Probably what is meant when it is stated that airman can afford to disregard the weather is that so much progress has been made in the construction and design of aeroplanes that they can go up in almost any wind and can fly safely in winds that would have proved fatal to machines a few years ago. But there remain some conditions that are dangerous, and many that are severe hindrances to aeroplane work in war.

The chief conditions that suggest themselves to my mind as increasing the risks of flying are the following: (1) Gales; (2) squalls; (3) bumps and eddies; (4) clouds; (5) rain, hail and snow; (6) fog; (7) lightning. It is possible that the number might be added to by

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[1] Reprinted from London Aero Journal, Vol. 21, p. 301, 1917.

experienced pilots, and it is also possible that some of the conditions that seem to me to be dangers may not really be such, but I suggest them in the hope of getting more information.

(1) **Gales.**—In the early days of flying strong winds were more formidable than to-day, but there are still occasions when the wind is so strong that machines are able to make little or no headway against it, and such strong gale may arise with great suddenness and sometimes without much warning.

An example occurred on December 28, 1914, when a small depression formed over the Bristol Channel and passed across the south of England, causing a gale that did a considerable amount of damage. In the southeast of England it was nearly calm before the onset of the gale, which sprung up with great suddenness. At Farnborough, for instance, an anemometer exposed 140 feet above the ground level registered a velocity of 80 miles per hour, when only a quarter of an hour previously it had been quite calm. I do not know that there were any aeroplanes flying when the gale began; probably not. The gale began in the afternoon in the southwest of England, but it did not reach the southeastern counties nor the northeast of France till after dark. But a gale of 80 miles per hour 140 feet above the ground must have been considerably more at a height of 1,500 feet, and I venture to think that if aeroplanes were flying when such a wind sprang up many would have failed to return to their aerodromes. If at the same time there were a development of low clouds when such a gale came on, aeroplanes would be likely to lose their bearings entirely.

Besides the loss of aeroplanes actually flying, a gale such as the one under discussion would cause severe damage to hangars and tents, and I believe that on this occasion considerable damage was caused in this way. Anyone who was in northeastern France at the time may remember the tiles and chimney pots with which the roads through villages were strewn.

Gales may spring up with great suddenness at all times of the year; in fact, I think that a summer gale may often give less warning of its approach than a winter one. Anyone who has done any sailing round our coasts must remember cases when they have been caught in gales a couple of hours or so after having been lying becalmed. I think that easterly gales in the summer are apt to spring up suddenly in this way.

A gale however, usually gives warning of its approach, and may often be forecasted many hours in advance, and the weather map for the day will usually indicate when a gale is likely.

(2) **Squalls.**—A squall is a temporary rise in the wind above the mean velocity that preceeds and follows it, the rise in velocity being continued over some minutes at least, and is thus distinguished from

a gust, which only lasts a small part of a minute. Squalls are of innumerable degrees of severity. On a day of blustery northwest winds, when there are large cumulus clouds about, one may have a succession of squalls, whose approach can be seen at sea some time before their onset. Such squalls are probably not of any particular danger to aeroplanes, as at sea they are of not much danger to shipping, except in the case of small open sailing boats, but in peace time at seaside resorts they take their toll of holiday makers who are sailing with the main sheet made fast.

More intense squalls are associated with thunderstorms, and they are all the more dangerous since they are often preceded by very light winds or even by a complete calm, and within a minute or so from their onset the wind is blowing at the rate of even 60 to 80 miles per hour. A typical example of such a squall occurred on August 2, 1906. As seen in the East of Hampshire, this storm came up from the direction of the Isle of Wight in the shape of a huge cumulus cloud with a great extension of false cirrus at the top, giving it the appearance of a giant mushroom; the day had been very hot and the air was very still. As the storm approached it was seen that heavy rain was falling, but there was no sign of wind to the untrained eye. A few minutes before the rain reached the observer a continuous roar was heard, and as the first drops fell a furious blast of wind arose; the wind only lasted a few minutes, and in three-quarters of an hour the storm had passed and the weather was fine again. The storm passed over the South Downs, and the same storm or another moving parallel to it reached Guildford, where the damage done by the wind was very great. I can not imagine that an aeroplane caught in such a squall would not have been in danger. Certainly an airship would have been in the very greatest danger and could hardly have weathered the storm.

The squall in front of an ordinary thunderstorm is probably a modification of another variety known as the line squall. The sequence of events in a line squall is somewhat as follows: A bank of clouds is seen extending along the horizon, the upper parts being white and in shape like ordinary cumulus, though the whole cloud usually appears of a more uniform height, and not broken up into such distinct peaks as is ordinary cumulus. As the cloud approaches it is seen to be extremely dark below, and it usually extends in a long line, stretching from horizon to horizon, but owing to the effect of perspective it appears like an arch in the sky, the summit of the arch coming nearer and nearer overhead. As the cloud reaches the observer a violent squall springs up, the wind veers rapidly or even suddenly, rain falls in torrents and is often accompanied by hail, and there may be thunder and lightning; at the same time the temperature falls considerably, a fall of five or ten degrees being common, and it is sometimes as much as 20 degrees. When the cloud is approaching and is nearly overhead a curious sinuous line is seen at its base extending right along the front of the cloud, and it is this line which gives the name of line squall to the disturbance. After the first blast the wind blows strongly for a time and the heavy rain lasts for half an hour, more or less; this is followed by a less intense fall of rain and by decreasing wind, and often in an hour or so the weather clears up and becomes fine.

A line squall is only a few miles across, but it may be several hundred miles long, and it advances across the country broadside on at the rate of 20 to 40 miles per hour; one such squall has been traced from Cape Wrath to the center of France, another from the Northwest of Ireland to the center of Germany. The list of disasters caused by line squalls is a long one; the best known case is that of H. M. S. *Eurydice*, a training ship homeward bound that was struck by such a squall when off the Isle of Wight on March 24, 1878, and foundered with heavy loss of life.

Besides the blast of wind in front of the squall, there are great up currents in front and down currents near the middle of the squall, with much eddy motion between them. Such conditions could hardly fail to be dangerous, and though an aeroplane might possibly come safely through them, it is hardly likely that an airship would.

The onset of a line squall is generally sudden, though anyone with a very little training in meteorology can see it coming while it is still some way off. On January 20, 1916, a line squall passed across the country from northwest to southeast, reaching Farnborough at 10.30 a. m. The morning had been fine, and a number of machines were out on the common; the squall came on suddenly, and several machines were damaged before they could get back into their sheds. A storm such as this one can be predicted with some success if the machinery is ready for the purpose. The general conditions favorable for line squalls can usually be forecasted from the Daily Weather Map prepared at the Meteorological Office, but unless a line squall occurred at one of the Meteorological Office Observing Stations at the time of taking of the meteorological observations or shortly before, the existence of the squall may not be noticed on the map. The squall of January 20, 1916, was first observed in the south of Ireland at about 4.30 a. m. It was accompanied by much thunder and lightning. It crossed the Irish Sea and reached the coasts of Cornwall and Wales at about 7.30 a. m., and moved across the country in a line 100 miles long or so, the movement being, as usual, at right angles to its length. Now, this storm did not affect any of the Meteorological Office Observing Stations, and hence its existence was not officially known, as one may express it. But since a squall of this type is perfectly easily recognized, its coming might have been foretold if the proper machinery had been in existence to deal with it; such a warning might have been received in plenty of time for the aeroplanes on the common at Farnborough to have been put in their sheds in safety.

That there is time for such warnings to be given is shown by the fact that recently I had a telegram from Upavon telling me that a line squall had just passed over; the telegram was received about 10 minutes before the squall reached Farnborough. Ten minutes is doubtless too short a time for the warning to be acted upon, but a station further west than Upavon could have sent a warning that would have been received in plenty of time.

It appears to me that it would be quite feasible for an observer at every aerodrome to send a telegram to some central office when a line squall took place; at the central office the general weather conditions would be well known, and therefore the direction of motion of the squall could be foretold. In addition, other reports would come in as the squall reached other aerodromes, and the rate of travel could be obtained with some accuracy. Warnings could then be sent to all aerodromes which are likely to be affected, and some signal might be hoisted in a conspicuous place where it could be seen not only by those who were responsible for machines on the ground, but also by pilots who were flying in the immediate neighborhood of the aerodrome. Some such organization would not be complicated, and would only occasionally have to be put into use, but it might be the means of saving machines, and possibly lives also. If the information were to be sent out by wireless the warnings would be received still earlier. But weather forecasters are looked on in some quarters as the subjects for jokes, and it will take some serious accidents caused by line squalls before anything practical is likely to be done. A severe line squall is generally accompanied by thunder and lightning, and an automatic lightning recorder would indicate its approach, especially in winter, when thunderstorms are almost entirely of the line-squall type. The lightning recorder at Farnborough began to record lightning at about 5 a. m. on January 20, 1916, and it is quite evident from the chart that something quite out of the ordinary, for the winter, was occurring.

(3) **Bumps and eddies.**—I do not propose to deal with these at any length. The danger from bumps is small with modern aeroplanes, though in the early days of flying they were a source of great danger. Pilots are far better qualified to speak of bumps than is a meteorologist who has only flown a few times as a passenger. Bumps are mostly due to rising currents of air over surfaces of ground that are at different temperatures and to eddy motion due to the wind blowing over irregularities of the surface. They also seem to occur

at the cloud layer when there is a sheet of cloud, and they occur, of course, with cumulus clouds.

In this connection there is a point on which pilots could give some information. At Farnborough an easterly wind is far more bumpy than a westerly wind. Is this due to some local configuration of the ground, or is it something inherent in an easterly wind? I suspect that there is some connection between bumpiness and easterly winds, but what it is I can not attempt to explain. An easterly wind has, seemingly, peculiarities of its own; it is said, for instance, that there is always more sea in the channel with an easterly wind than with a wind of corresponding strength from other quarters.

(4) **Clouds.**—Clouds may be a danger in several ways. In the case of cumulo nimbus clouds the heavy rain, and possibly hail, or the snow in winter, may prove extremely dangerous. Such clouds, too, are often of great extent and are the seat of very rapidly ascending currents of air. A pilot might have to fly a considerable distance before getting clear and might easily lose his bearings. A cumulo nimbus cloud is one that should be avoided if it is possible to do so, and as these clouds often occur in isolated masses, it may be at times possible to fly around them. A cumulo nimbus, the true shower cloud, from which rain, hail, or snow is falling may be distinguished from simple cumulus by the fact that the top of the former cloud, instead of being rounded and hard edged, is brushed out into a soft-looking mass of fibrous cloud called false cirrus. It is true that showers fall from simple cumulus clouds, but the really heavy falls are from cumulo nimbus.

Cumulus clouds are more common in summer than in winter. They usually begin to form in the morning as the day gets warm, and reach their greatest development about 2 or 3 in the afternoon, after which they generally begin to disappear, and by sunset or soon after, the sky may be quite clear even after a day of great development of this form of cloud. But they may be met with at other times, and they form after sunset in the summer when shallow depressions, bringing thunderstorms, are approaching.

Low sheets of cloud may prove a hindrance to work with aeroplanes, and if they are very low they may cause difficulties for a pilot in finding his way back to the aerodrome, or even difficulties in landing at all. The possibility of low sheets of cloud forming after a clear morning, especially in winter during unsettled weather, should always be borne in mind. A glance at the latest weather map will often be a valuable guide as to whether a fine morning is likely to last.

Take, for instance, the map for 7 a. m. on December 24 last. This shows that the sky was clear in northeastern France, but subsequent reports show that it became overcast and rainy, and that there was a great extension of low clouds. Anyone who had in the least followed the weather in the days preceding this date and who had seen the map for the day, or even for the preceding evening, would have realized that the fine morning was not likely to last beyond a short time. I maintain that aeroplanes going up on such a morning would be extremely likely to find low clouds extending to within a few hundred feet of the ground before their return, and they would therefore be in some danger. It might be that it would be necessary to incur the danger for the results that might be obtained, but it would be absurd to say that such meteorological conditions would not add to the risks of flying.

(5) **Rain, hail, and snow.**—The danger arising from these is obvious, and it varies, of course, from nothing in the case of very light falls to a real danger in the case of very heavy falls. Danger from very heavy rain or from hail can often be avoided by keeping away from cumulo nimbus clouds. Such clouds are often seen in isolated masses, some miles in circumference, perhaps, but still they can on such occasions be avoided. In the case of a line squall it is, however, not possible to fly round the cloud, for this often extends in a long line for several hundred miles. It might be possible to fly over a line squall and so avoid the rain, hail, and turbulent motion of the air associated with the disturbance, but I do not know that there is any evidence as to the heights to which the line squall disturbance extends; it probably varies on different occasions.

Hailstones in summer thunderstorms constitute a real danger to an aeroplane that might be involved in the storm, for they sometimes attain an enormous size. In the British Rainfall Organization's Volume for 1913 is a photograph of hailstones that fell in Essex on May 27 of that year. Although they had partially melted before they were photographed, they are still shown as nearly as large as a hen's egg that was photographed with them for comparison. They fell at Wickham St. Pauls, near Halsted, in Essex. At Great Yeldham there was a fall of similar hailstones. At the latter place the fall lasted only eight minutes, but "the devastation was great," an observer says. "Crops were smitten to the ground, glasshouses all smashed, tarred roof felting cut to ribbons, corrugated iron riddled, tiles and windows smashed in thousands. * * * Man and beast were bruised, and among other animals killed on my own farm I saw rooks, wood pigeons, full-grown hares, partridges, pheasants, rabbits, and various small birds, wild ducks, farmyard fowls, and three cygnets." At Haverhill the stones varied from the size of nutmegs to that of walnuts. At Harston the stones were 25 millimeters to 32 millimeters (1¼ inches) in diameter, and at Sheerness 16 millimeters to 22 millimeters (⅝ to ⅞ inch). Damage from hail was reported from a wide region in the eastern counties on that day.

Doubtless it will be said that this was an exceptional occasion, and no doubt it was, but a glance through one of the rainfall volumes shows that very heavy falls of hail occur in the summer months in all parts of England. For instance, besides the 24th of the month, heavy falls occurred in May, 1913, on several occasions; on the 19th very heavy rain fell at Bolerno, in Midlothian; on the 26th hailstones over 1 inch in diameter fell at Bulvan, and at Bishops Castle scores of windows were shattered; on the 30th at Gravesend the hailstones were 1½ inches in diameter; on the 31st at Waltham, on the Wolds, there was an exceptionally heavy fall of hail.

A glance through the records for any summer month shows that so-called exceptional falls of hail are fairly common, and it scarcely needs pointing out that hailstones far smaller than hen's eggs would have fatal effects on an aeroplane that met them.

(6) **Fog.**—Perhaps fog is one of the worst of the dangers that beset flying, and I should like especially to call attention to fog to those who maintain that at the present time aviators can afford to disregard the weather. The subject of fog, however, has lately been dealt with before this society by Maj. Taylor. I may, however, give an example of how a fog may be formed by the mixing of air at different temperatures. On April 3 of this year there was a shower of snow at Farnborough which was followed immediately by bright sunshine; after a few minutes a mist began to form over the aerodrome, and for a short time wreaths of fog covered the common. No doubt the sun heated the ground and warmed the air in contact with it; the relatively warm air, which would have been fully saturated was mixed with the cold layer just above—air that had been cooled by the melting snow before the sun came out. The saturated warm air was chilled and its moisture was condensed into fog.

(7) **Lightning.**—It is difficult to say what is the danger to be apprehended from lightning as such. The dangers to flying from thunderstorms are due to the squalls and to the heavy rain and hail that accompany them. It is possible that the actual danger from lightning to an aeroplane flying through a thunderstorm may be no more than that incurred by a pedestrian walking across an open common during a storm. A pilot who was flying above a thundercloud last summer reported that long sparks were given off by his machine at intervals. It is very likely that this happened every time there was a flash of lightning from the cloud below him. But no inconvenience was caused by the sparks. In the case of an airship, however, it would be far otherwise, for quite small sparks might ignite the hydrogen. Lightning is also a danger to kite balloons owing to the conducting wire. There are several cases on record in which meteorological kites have been struck by lightning, and as some of these occurred when there was no thunderstorms in progress,

it must be remembered that the clouds may be highly charged with electricity at times when no actual storm is going on.

There is a particular type of violent thunderstorm in which most of the lightning takes place from cloud to cloud, and when it is almost incessant. It would probably be dangerous for an aeroplane to enter such a cloud, but the appearance of the danger is so obvious that it scarcely needs pointing out.

I hope that what I have said will make it clear that the airman is not entirely immune from the disturbances in the medium in which he flies. If I could persuade aviators in general to take meteorology rather more seriously I should feel that I had not read this paper in vain, but I am afraid that weather maps and forecasts are looked on by many, though not by all, I am glad to think, as mere matters of guess-work, and not worthy of serious consideration. The public in general exhibit a lamentable ignorance of the very elements of meteorology, which is largely due to our educational methods. I do not wish everyone to become a meteorologist, but there is no reason why everyone should not take an intelligent interest in the movements of depressions and anticyclones, and have some faint knowledge of what these terms mean. The English are supposed to talk so much about the weather that it is a pity they should not know what they are talking about, and those who are responsible for the safety of aeroplanes and airships ought to know as much about the weather as, say, a master mariner in the mercantile marine. There are cases where ignorance may be criminal.

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C. J. P. C.

CHAPTER XVI.

TABLES.

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TABLE 1.—*Inches into millimeters.*

[1 inch=25.40005 millimeters.]

Inches.	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	Mm.	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
0.00	0.00	0.25	0.51	0.76	1.02	1.27	1.52	1.78	2.03	2.29
0.10	2.54	2.79	3.05	3.30	3.56	3.81	4.06	4.32	4.57	4.83
0.20	5.08	5.33	5.59	5.84	6.10	6.35	6.60	6.86	7.11	7.37
0.30	7.62	7.87	8.13	8.38	8.64	8.89	9.14	9.40	9.65	9.91
0.40	10.16	10.41	10.67	10.92	11.18	11.43	11.68	11.94	12.19	12.45
0.50	12.70	12.95	13.21	13.46	13.72	13.97	14.22	14.48	14.73	14.99
0.60	15.24	15.49	15.75	16.00	16.26	16.51	16.76	17.02	17.27	17.53
0.70	17.78	18.03	18.29	18.54	18.80	19.05	19.30	19.56	19.81	20.07
0.80	20.32	20.57	20.83	21.08	21.34	21.59	21.84	22.10	22.35	22.61
0.90	22.86	23.11	23.37	23.62	23.88	24.13	24.38	24.64	24.89	25.15
1.00	25.40	......	......	......	......	......	......	......	......	......

TABLE 2.—*Feet into meters.*

[1 foot=0.3048006 meter.]

Feet.	0	1	2	3	4	5	6	7	8	9
	Meters.	*Meters.*	*Meters.*	*Meters.*	*Meters.*	*Meters.*	*Meters.*	*Meters.*	*Meters.*	*Meters.*
0	0.000	0.305	0.610	0.914	1.219	1.524	1.829	2.134	2.438	2.743
10	3.048	3.353	3.658	3.962	4.267	4.572	4.877	5.182	5.486	5.791
20	6.096	6.401	6.706	7.010	7.315	7.620	7.925	8.230	8.534	8.839
30	9.144	9.449	9.754	10.058	10.363	10.668	10.973	11.278	11.582	11.887
40	12.192	12.497	12.802	13.106	13.411	13.716	14.021	14.326	14.630	14.935
50	15.240	15.545	15.850	16.154	16.459	16.764	17.069	17.374	17.678	17.983
60	18.288	18.593	18.898	19.202	19.507	19.812	20.117	20.422	20.726	21.031
70	21.336	21.641	21.946	22.250	22.555	22.860	23.165	23.470	23.774	24.079
80	24.384	24.689	24.994	25.298	25.603	25.908	26.213	26.518	26.822	27.127
90	27.432	27.737	28.042	28.346	28.651	28.956	29.261	29.566	29.870	30.175
	0	10	20	30	40	50	60	70	80	90
100	30.48	33.53	36.58	39.62	42.67	45.72	48.77	51.82	54.86	57.91
200	60.96	64.01	67.06	70.10	73.15	76.20	79.25	82.30	85.34	88.39
300	91.44	94.49	97.54	100.58	103.63	106.68	109.73	112.78	115.82	118.87
400	121.92	124.97	128.02	131.06	134.11	137.16	140.21	143.26	146.30	149.35
500	152.40	155.45	158.50	161.54	164.59	167.64	170.69	173.74	176.78	179.83
600	182.88	185.93	188.98	192.02	195.07	198.12	201.17	204.22	207.26	210.31
700	213.36	216.41	219.46	222.50	225.55	228.60	231.65	234.70	237.74	240.79
800	243.84	246.89	249.94	252.98	256.03	259.08	262.13	265.18	268.22	271.27
900	274.32	277.37	280.42	283.46	286.51	289.56	292.61	295.66	298.70	301.75
1,000	304.80	......	......	......	......	......	......	......	......	......

TABLE 3.—*Miles into kilometers.*

[1 mile=1.609347 kilometers.]

Miles.	0	1	2	3	4	5	6	7	8	9
	Kilometers.	*Kilometers.*	*Kilometers.*	*Kilometers.*	*Kilometers.*	*Kilometers.*	*Kilometers.*	*Kilometers.*	*Kilometers.*	*Kilometers.*
0	0	2	3	5	6	8	10	11	13	14
10	16	18	19	21	23	24	26	27	29	31
20	32	34	35	37	39	40	42	43	45	47
30	48	50	51	53	55	56	58	60	61	63
40	64	66	68	69	71	72	74	76	77	79
50	80	82	84	85	87	89	90	92	93	95
60	97	98	100	101	103	105	106	108	109	111
70	113	114	116	117	119	121	122	124	126	127
80	129	130	132	134	135	137	138	140	142	143
90	145	146	148	150	151	153	154	156	158	159
100	161	......	......	......	......	......	......	......	......	......

TABLE 4.—*Kilometers into miles.*

[1 kilometer=0.621370 mile.]

Kilometers.	0	1	2	3	4	5	6	7	8	9
	Miles.	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles.*
0	0.0	0.6	1.2	1.9	2.5	3.1	3.7	4.3	5.0	5.6
10	6.2	6.8	7.5	8.1	8.7	9.3	9.9	10.6	11.2	11.8
20	12.4	13.0	13.7	14.3	14.9	15.5	16.2	16.8	17.4	18.0
30	18.6	19.3	19.9	20.5	21.1	21.7	22.4	23.0	23.6	24.2
40	24.9	25.5	26.1	26.7	27.3	28.0	28.6	29.2	29.8	30.4
50	31.1	31.7	32.3	32.9	33.6	34.2	34.8	35.4	36.0	36.7
60	37.3	37.9	38.5	39.1	39.8	40.4	41.0	41.6	42.3	42.9
70	43.5	44.1	44.7	45.4	46.0	46.6	47.2	47.8	48.5	49.1
80	49.7	50.3	51.0	51.6	52.2	52.8	53.4	54.1	54.7	55.3
90	55.9	56.5	57.2	57.8	58.4	59.0	59.7	60.3	60.9	61.5
100	62.1	....	....	....	....	....	....	....	....	....

TABLE 5.—*Conversion of area, volume, weight, and pressure.*

Multiply—	By—	To convert to—
Miles	1.6093	Kilometers.
Kilometers	.62137	Miles.
Square inches	6.4517	Sqare centimeters.
Square centimeters	.155	Square inches.
Square feet	.092903	Square meters.
Square meters	10.7639	Square feet.
Cubic inches	16.387	Cubic centimeters.
Cubic centimeters	.061025	Cubic inches.
Cubic feet	.028317	Cubic meters.
Cubic meters	35.314	Cubic feet.
Cubic feet	28.317	Liters.
Liters	.035315	Cubic feet.
Pounds	.45359	Kilograms.
Kilograms	2.2046	Pounds.
Ounces (avoirdupois)	28.348	Grams.
Grams	.035275	Ounces.
Pounds per square inch	.070308	Kilograms per square centimeter.
Kilograms per square meter	14.223	Pounds per square inch.
Pounds per square foot	4.8825	Kilograms per square meter.
Kilograms per square centimeter	.20481	Pounds per square foot.

Inches to millimeters.

Inch.	Millimeters.	Inch.	Millimeters.
$\frac{1}{16}$ (0.0625)	1.5875	$\frac{9}{16}$ (0.5625)	14.2875
$\frac{1}{8}$ (0.1250)	3.1750	$\frac{5}{8}$ (0.6250)	15.8750
$\frac{3}{16}$ (0.1875)	4.7625	$\frac{11}{16}$ (0.6875)	17.4625
$\frac{1}{4}$ (0.2500)	6.3500	$\frac{3}{4}$ (0.7500)	19.0500
$\frac{5}{16}$ (0.3125)	7.9375	$\frac{13}{16}$ (0.8125)	20.6375
$\frac{3}{8}$ (0.3750)	9.5250	$\frac{7}{8}$ (0.8750)	22.2250
$\frac{7}{16}$ (0.4375)	11.1125	$\frac{15}{16}$ (0.9375)	23.8125
$\frac{1}{2}$ (0.5000)	12.7000	1 (1.0000)	25.4000

Millimeters to inches.

Millimeter.	Inch.	Millimeter.	Inch.
0.005	0.000196	0.05	.001968
0.01	.000393	0.06	.002362
0.02	.000787	0.07	.002755
0.03	.001181	0.08	.003149
0.04	.001574	0.09	.003543

TABLE 6.—*Conversion of nautical and statute miles.*

[1 nautical mile[1] =6,080.27 feet.]

Nautical miles.	Statute miles.	Statute miles.	Nautical miles.
1	1.1516	1	0.8684
2	2.3031	2	1.7368
3	3.4547	3	2.6052
4	4.6062	4	3.4736
5	5.7578	5	4.3420
6	6.9093	6	5.2104
7	8.0609	7	6.0788
8	9.2124	8	6.9472
9	10.3640	9	7.8155

[1] As defined by the United States Coast Survey.

TABLE 7.—*Conversion of velocities—Miles per hour into meters per second, feet per second, and kilometers per hour.*

Miles per hour.	Meters per second.	Feet per second.	Kilometers per hour.	Miles per hour.	Meters per second.	Feet per second.	Kilometers per hour.
0.0	0.0	0.0	0.0	22.5	10.1	33.0	36.2
0.5	0.2	0.7	0.8	23.0	10.3	33.7	37.0
1.0	0.4	1.5	1.6	23.5	10.5	34.5	37.8
1.5	0.7	2.2	2.4	24.0	10.7	35.2	38.6
2.0	0.9	2.9	3.2	24.5	11.0	35.9	39.4
2.5	1.1	3.7	4.0	25.0	11.2	36.7	40.2
3.0	1.3	4.4	4.8	25.5	11.4	37.4	41.0
3.5	1.6	5.1	5.6	26.0	11.6	38.1	41.8
4.0	1.8	5.9	6.4	26.5	11.8	38.9	42.6
4.5	2.0	6.6	7.2	27.0	12.1	39.6	43.5
5.0	2.2	7.3	8.0	27.5	12.3	40.3	44.3
5.5	2.5	8.1	8.9	28.0	12.5	41.1	45.1
6.0	2.7	8.8	9.7	28.5	12.7	41.8	45.9
6.5	2.9	9.5	10.5	29.0	13.0	42.5	46.7
7.0	3.1	10.3	11.3	29.5	13.2	43.3	47.5
7.5	3.4	11.0	12.1	30.0	13.4	44.0	48.3
8.0	3.6	11.7	12.9	30.5	13.6	44.7	49.1
8.5	3.8	12.5	13.7	31.0	13.9	45.5	49.9
9.0	4.0	13.2	14.5	31.5	14.1	46.2	50.7
9.5	4.2	13.9	15.3	32.0	14.3	46.9	51.5
10.0	4.5	14.7	16.1	32.5	14.5	47.7	52.3
10.5	4.7	15.4	16.9	33.0	14.8	48.4	53.1
11.0	4.9	16.1	17.7	33.5	15.0	49.1	53.9
11.5	5.1	16.9	18.5	34.0	15.2	49.9	54.7
12.0	5.4	17.6	19.3	34.5	15.4	50.6	55.5
12.5	5.6	18.3	20.1	35.0	15.6	51.3	56.3
13.0	5.8	19.1	20.9	35.5	15.9	52.1	57.1
13.5	6.0	19.8	21.7	36.0	16.1	52.8	57.9
14.0	6.3	20.5	22.5	36.5	16.3	53.5	58.7
14.5	6.5	21.3	23.3	37.0	16.5	54.3	59.5
15.0	6.7	22.0	24.1	37.5	16.8	55.0	60.4
15.5	6.9	22.7	24.9	38.0	17.0	55.7	61.2
16.0	7.2	23.5	25.7	38.5	17.2	56.5	62.0
16.5	7.4	24.2	26.6	39.0	17.4	57.2	62.8
17.0	7.6	24.9	27.4	39.5	17.7	57.9	63.6
17.5	7.8	25.7	28.2	40.0	17.9	58.7	64.4
18.0	8.0	26.4	29.0	40.5	18.1	59.4	65.2
18.5	8.3	27.1	29.8	41.0	18.3	60.1	66.0
19.0	8.5	27.9	30.6	41.5	18.6	60.9	66.8
19.5	8.7	28.6	31.4	42.0	18.8	61.6	67.6
20.0	8.9	29.3	32.2	42.5	19.0	62.3	68.4
20.5	9.2	30.1	33.0	43.0	19.2	63.1	69.2
21.0	9.4	30.8	33.8	43.5	19.4	63.8	70.0
21.5	9.6	31.5	34.6	44.0	19.7	64.5	70.8
22.0	9.8	32.3	35.4	44.5	19.9	65.3	71.6

TABLE 7.—*Conversion of velocities—Miles per hour into meters per second, feet per second, and kilometers per hour*—Continued.

Miles per hour.	Meters per second.	Feet per second.	Kilometers per hour.	Miles per hour.	Meters per second.	Feet per second.	Kilometers per hour.
45.0	20.1	66.0	72.4	72.5	32.4	106.3	116.7
45.5	20.3	66.7	73.2	73.0	32.6	107.1	117.5
46.0	20.6	67.5	74.0	73.5	32.9	107.8	118.3
46.5	20.8	68.2	74.8	74.0	33.1	108.5	119.1
47.0	21.0	68.9	75.6	74.5	33.3	109.3	119.9
47.5	21.2	69.7	76.4	75.0	33.5	110.0	120.7
48.0	21.5	70.4	77.2	75.5	33.8	110.7	121.5
48.5	21.7	71.1	78.1	76.0	34.0	111.5	122.3
49.0	21.9	71.9	78.9	76.5	34.2	112.2	123.1
49.5	22.1	72.6	79.7	77 0	34.4	112.9	123.9
50.0	22.4	73.3	80.5	77.5	34.6	113.7	124.7
50.5	22.6	74.1	81.3	78.0	34.9	114.4	125.5
51.0	22.8	74.8	82.1	78.5	35.1	115.0	126.3
51.5	23.0	75.5	82.9	79.0	35.3	115.9	127.1
52.0	23.2	76.3	83.7	79.5	35.6	116.5	127.9
52.5	23.5	77.0	84.5	80.0	35.8	117.3	128.7
53.0	23.7	77.7	85.3	80.5	36.0	117.9	129.5
53.5	23.9	78.5	86.1	81.0	36.2	118.7	130.3
54.0	24.1	79.2	86.9	81.5	36.5	119.5	131.1
54.5	24.4	79.9	87.7	82.0	36.7	120.2	131.9
55.0	24.6	80.7	88.5	82.5	36.9	120.9	132.7
55.5	24.8	81.4	89.3	83.0	37.1	121.7	133.5
56.0	25.0	82.1	90.1	83.5	37.4	122.4	134.4
56.5	25.3	82.9	90.9	84.0	37.6	123.1	135.2
57.0	25.5	83.6	91.7	84.5	37.8	123.9	136.0
57.5	25.7	84.3	92.5	85.0	38.0	124.6	136.8
58.0	25.9	85.1	93.3	85.5	38.3	125.3	137.6
58.5	26.2	85.8	94.1	86.0	38.5	126.1	138.4
59.0	26.4	86.5	95.0	86.5	38.7	126.8	139.2
59.5	26.6	87.3	95.8	87.0	39.0	127.5	140.0
60.0	26.8	88.0	96.6	87.5	39.2	128.3	140.8
60.5	27.0	88.7	97.4	88.0	39.4	129.0	141.6
61.0	27.3	89.5	98.2	88.5	39.6	129.7	142.4
61.5	27.5	90.2	99.0	89.0	39.8	130.5	143.2
62.0	27.7	90.9	99.8	89.5	40.1	131.2	144.0
62.5	27.9	91.7	100.6	90.0	40.3	131.9	144.8
63.0	28.2	92.4	101.4	90.5	40.5	132.7	145.6
63.5	28.4	93.1	102.2	91.0	40.7	133.4	146.4
64.0	28.6	93.9	103.0	91.5	41.0	134.1	147.2
64.5	28.8	94.6	103.8	92.0	41.3	134.9	148.0
65.0	29.1	95.3	104.6	92.5	41.5	135.6	148.8
65.5	29.3	96.1	105.4	93.0	41.7	136.3	149.6
66.0	29.5	96.8	106.2	93.5	42.0	137.1	150.5
66.5	29.7	97.5	107.0	94.0	42.2	137.8	151.3
67.0	30.0	98.3	107.8	94.5	42.4	138.5	152.1
67.5	30.2	99.0	108.6	95.0	42.6	139.3	152.9
68.0	30.4	99.7	109.4	95.5	42.9	139.9	153.7
68.5	30.6	100.5	110.2	96.0	43.1	140.6	154.5
69.0	30.8	101.2	111.0	96.5	43.3	141.4	155.3
69.5	31.1	101.9	111.8	97.0	43.5	142.1	156.1
				97.5	43.8	142.8	156.9
70.0	31.3	102.7	112.7	98.0	44.0	143.5	157.7
70.5	31.5	103.4	113.5	98.5	44.2	144.3	158.5
71.0	31.7	104.1	114.3	99.0	44.4	145.0	159.3
71.5	32.0	104.9	115.1	99.5	44.7	145.7	160.1
72.0	32.2	105.6	115.9	100	44.9	146.4	160.9

TABLE 8.—*Pressure.*

[Inches of mercury at 273° A. and 45° latitude, to kilobars. For brevity, the fundamental equations may be written: $g_{45}=980.624$ cm/sec^2. Density of mercury at normal freezing point of water = 13.5959. 1 mercury-inch = 33.8660 kilobars; 1 millimeter = 1.33320 kilobars. 1,000 kilobars = 29.5306 mercury-inches = 750.076 millimeters.]

Inches.	Kilobars.				
	0.0	0.2	0.4	0.6	0.8
10	338.7	345.4	352.2	359.0	365.8
11	372.5	379.3	386.0	392.8	399.7
12	406.4	413.2	419.9	426.7	433.5
13	440.3	447.0	453.8	460.6	467.4
14	474.1	481.0	487.7	494.4	501.2
15	508.0	514.8	521.5	528.3	535.0
16	541.9	548.6	555.4	562.2	568.9
17	575.7	582.5	589.3	596.0	602.8
18	609.6	616.4	623.1	630.9	637.7
19	644.6	651.2	658.0	664.8	671.6
	0.00	0.02	0.04	0.06	0.08
20.0	677.3	678.0	678.7	679.4	680.0
20.1	680.7	681.4	682.0	682.7	683.4
20.2	684.1	684.8	685.5	686.1	686.8
20.3	687.5	688.2	688.8	689.5	690.2
20.4	690.9	691.5	692.2	692.9	693.6
20.5	694.3	694.9	695.6	696.3	697.0
20.6	697.6	698.3	699.0	699.7	700.4
20.7	701.0	701.7	702.4	703.2	703.8
20.8	704.5	705.2	705.9	706.5	707.2
20.9	707.9	708.6	709.2	709.9	710.6
21.0	711.3	712.0	712.6	713.3	714.0
21.1	714.7	715.3	716.0	716.7	717.4
21.2	718.0	718.7	719.4	720.0	720.7
21.3	721.4	722.1	722.8	723.5	724.1
21.4	724.8	725.5	726.2	726.8	727.5
21.5	728.2	728.9	729.6	730.2	730.9
21.6	731.6	732.3	732.9	733.6	734.3
21.7	735.0	735.7	736.3	737.0	737.7
21.8	738.4	739.0	739.7	740.4	741.1
21.9	741.7	742.4	743.1	743.8	744.4
22.0	745.4	746.1	746.8	747.4	748.1
22.1	748.8	749.5	750.1	750.8	751.3
22.2	751.9	752.6	753.3	754.0	754.6
22.3	755.3	756.0	756.7	757.3	758.0
22.4	758.7	759.4	760.1	760.7	761.4
22.5	762.1	762.8	763.4	764.1	764.8
22.6	765.5	766.2	766.8	767.5	768.2
22.7	768.8	769.5	770.2	770.9	771.6
22.8	772.3	772.9	773.6	774.3	775.0
22.9	775.6	776.3	777.0	777.7	777.3
23.0	779.0	779.7	780.4	781.0	781.7
23.1	782.7	783.4	784.1	784.8	785.4
23.2	786.1	786.8	787.5	788.2	788.8
23.3	789.5	790.2	790.9	791.5	792.2
23.4	792.9	793.6	794.3	795.0	795.6
23.5	796.3	797.0	797.6	798.3	799.0
23.6	799.7	800.3	801.0	801.7	802.4
23.7	803.1	803.7	804.4	805.1	805.8
23.8	806.4	806.1	806.8	807.5	808.2
23.9	808.8	809.5	810.2	810.9	811.5
24.0	812.8	813.5	814.1	814.8	815.5
24.1	816.2	816.8	817.5	818.2	818.9
24.2	819.6	820.2	820.9	821.6	822.3
24.3	822.9	823.6	824.3	825.0	825.7
24.4	826.3	827.0	827.7	828.4	829.0
24.5	829.7	830.4	831.1	831.8	832.4
24.6	833.1	833.8	834.5	835.1	835.8
24.7	836.5	837.2	837.8	838.5	839.2
24.8	839.9	840.6	841.3	841.9	842.6
24.9	843.3	843.9	844.6	845.3	846.0

TABLE 8.—*Pressure*—Continued.

Inches.	Kilobars.				
	0.00	0.02	0.04	0.06	0.08
25.0	846.7	847.4	848.1	848.8	849.5
25.1	850.1	850.8	851 5	852.2	852.8
25.2	853.5	854.2	854 9	855.6	856.2
25.3	856.9	857.6	858.3	858.9	859.6
25.4	860.3	861.0	861.7	862.3	863.0
25.5	863.7	864.4	865.0	865.7	866.4
25.6	867.1	867.7	868.4	869.1	869.8
25.7	870.5	871.1	871.8	872.5	873.2
25.8	873.8	874.5	875.2	875.9	876.5
25.9	877.2	877.9	878.5	879.2	879.9
26.0	880.6	881.3	882.0	882.6	883.3
26.1	884.0	884.7	885.3	886.0	886.7
26.2	887.4	888.0	888.7	889.4	890.1
26.3	890.8	891.4	892.1	892.8	893.5
26.4	894.2	894.8	895.5	896.2	896.9
26.5	897.5	898.2	898.9	899.6	900.2
26.6	900.9	901.6	902.3	902.9	903.6
26.7	904.3	905.0	905.6	906.3	907.0
26.8	907.7	908.4	909.0	906.7	910 4
26.9	911.1	911.7	912.4	913.2	913.9
27.0	914.3	915.0	915.7	916.3	917.0
27.1	917.7	918.4	919.0	919.7	920.4
27.2	921.1	921.8	922.4	923.1	923.8
27.3	924.5	925.1	925.8	926.5	927.2
27.4	927.9	928.5	929.2	929.9	930.6
27.5	931:2	931.9	932.6	933.3	933.9
27.6	934.6	935.3	936.0	936.7	937.3
27.7	938.0	938.7	939.4	940.0	940.7
27.8	941.4	942.1	942.8	943.4	944.1
27.9	944.8	945.5	946.1	946.8	947.5
28.0	948.2	948.8	949.5	950.2	950.9
28.1	951.6	952.2	952.9	953.6	954.3
28.2	954.9	955.6	956.3	957.0	957.7
28.3	958.3	959.0	959.7	960.4	961.0
28.4	961.7	962.4	963.1	963.7	964.4
28.5	965.1	965.8	966.5	967.1	967.8
28.6	968.5	969.2	969.8	970.5	971.2
28.7	971.9	972.6	973.2	973.9	974.6
28.8	975.3	975.9	976.6	977.3	978.0
28.9	978.6	979.3	980.0	980.7	981.4
29.0	982.0	982.7	983.4	984.1	984.7
29.1	985.4	986.1	986.8	987.5	988.1
29.2	988.8	989.5	990.2	990.8	991.5
29.3	992.2	992.9	993.5	994.2	994.9
29.4	995.6	996.3	996.9	997.6	998.3
29.5	999.0	999.6	1,000.3	1,001.0	1,001.7
29.6	1,002.4	1,003.0	1,003.7	1,004.4	1,005.1
29.7	1,005.7	1,006.4	1,007.1	1,007.8	1,008.4
29.8	1,009.1	1,009.8	1,010.5	1,011.2	1,011.8
29.9	1,012.5	1,013.2	1,013.9	1,014.5	1,015.2
30.0	1,015.9	1,016.6	1,017.3	1,017.9	1,018.6
30.1	1,019.3	1,020.0	1,020.6	1,021.3	1,022.0
30.2	1,022.7	1,023.3	1,024.0	1,024.7	1,025.4
30.3	1,026.1	1,026.7	1,027.4	1,028.1	1,028.8
30.4	1,029.4	1,030.1	1,030.8	1,031.5	1,032.2
30.5	1,032.8	1,033.5	1,034.2	1,034.9	1,035.5
30.6	1,036.2	1,036.9	1,037.6	1,038.2	1,038.9
30.7	1,039.6	1,040.3	1,041.0	1,041.6	1,042.3
30.8	1,043.0	1,043.7	1,044.3	1,045.0	1,045.7
30.9	1,046.4	1,047.1	1,047.7	1,048.4	1,049.1

NOTE.—The value for gravity is that of the United States Coast and Geodetic Survey. A value, 980.665, given by the Bureau of Standards was adopted in 1888 by the International Committee on Weights and Measures and has since been continued for convenience, although it is a conventional standard and not exactly equal to the value of 45°. There has been a slight change in the value for the density of mercury. The differences are small. See Monthly Weather Review for April, 1914, p. 230, article by R. N. Covert.

CHAPTER XVII.

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