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HANDBOOK
OF
METEOROLOGY

A Manual for Cooperative Observers and Students

BY

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NEW YORK
JOHN WILEY & SONS, Inc.
London: CHAPMAN & HALL, Limited
1921

PRESS OF
BRAUNWORTH & CO.
BOOK MANUFACTURERS
BROOKLYN, N. Y.

PREFACE

This text-book has been prepared for the use of cooperative observers and for the instruction of students in meteorology and aeronautics. It is essentially a laboratory manual.

Part I is an elementary synopsis of the general principles of air science, but is not wholly restricted thereto. The subject of atmospheric transparency and the principles of visibility may not be logically a part of meteorology, but it is one of great importance, not only to air men, but also to every one engaged in transportation. The chapter on the dust content of the air in part summarizes the researches of author in this field.

Part II is descriptive of the instruments used in meteorology and the construction and care of them. The methods of observation discussed is a résumé of the experience of many observers covering a period of half a century. This part of the text is specifically designed for the use of cooperative observers and students.

The Appendix contains conversion and other useful tables that are not included in the Circulars of Instruction published by the U. S. Weather Bureau. English units of measurement are used throughout the book, but the metric equivalents are used when necessary.

In the final revision of the text, the author desires to express his appreciation for the counsel received from James H. Scarr, forecaster in charge of the New York City Weather Bureau Office, and to J. H. Kimball of the same office in charge of marine work. Acknowledgments are due to Dr. Charles F. Brooks, editor of the Monthly Weather Review, for the cloud photographs used, and also for his critical knowledge of cloud science; to Dr. W. J. Humphreys for the use of illustrations in his *Physics of the Air;* and to Charles Scribner's Sons for the use of illustrations taken from *Redway's Physical Geography.*

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TABLE OF CONTENTS

PART I: GENERAL PRINCIPLES

PART II: INSTRUMENTS AND MEASUREMENT

METEOROLOGY

PART I

CHAPTER I

THE ATMOSPHERE: ITS CONSTITUENTS

Meteorology is the science of the air. The air is the outer shell, or layer, of the earth; hence it is called the *atmosphere*, a Greek word meaning "air-sphere." The movements of the air (the winds) and the variable proportion of water vapor, mingled with and forming a part of it, exert a profound influence which affects the climate, habitability and civilization of the earth.

For the greater part the movements of the air and the variations in the proportion of moisture are the results of changes in temperature. The fundamental study of the physics of the air, therefore, concerns the problems of variations in temperature and the far-reaching results of those variations.

Composition.—The atmosphere consists of a mixture of gases of which oxygen, nitrogen and the argon group constitute about 98 per cent.[1] The composition varies very slightly so far as these are concerned; but the proportion of water vapor and of the other components varies materially. The first of the two tables which follow is the average of many analyses made by Rayleigh and Ramsay; the second is on the authority of Humphreys. Other analyses show slight differences that indicate actual differences in proportion rather than errors in analyses.

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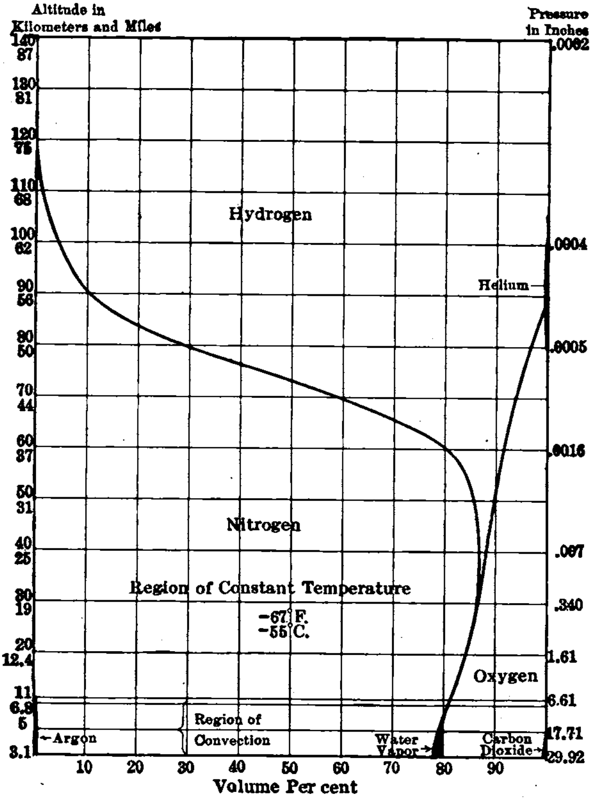
[1] The argon group consists of argon, krypton, xenon, and neon. Two other very rare elements, coronium and niton, are probable constituents of the air.

The values of all except the first three are variable; that of floating dust, hydrogen, and helium is empiric and calculated.

The values determined by Humphreys, are those of air from which the water vapor has been removed—that is, of *dry* air.



After Humphreys (Physics of the Air).

The distribution of the constituents of the air.

The foregoing represent the proportions at the surface of the earth. The proportions change with increasing altitude. The nitrogen disappears at a calculated height of 84 miles; the oxygen, at about 60 miles. Water vapor is calculated to exist at an altitude of 60 miles, but it is not observable above 7 or 8 miles. Carbon dioxide is not observable above an altitude of 2 or 3 miles; theoretically it may extend to a calculated height of more than 15 miles. The proportion of hydrogen and helium, on the other hand, increases with altitude, and they probably form the outer layer of the atmosphere.[1] Because of their lightness it is not unlikely that hydrogen and helium are gradually escaping from the earth.

Constituents	Parts in one million of air
Nitrogen	771,200
Oxygen	206,600
Argon group (approximately)	7,900
Water-vapor	13,953
Carbon dioxide	336
Ozone	12
Nitric and nitrous oxides	8
Ammonia	1
Dust, hydrogen, helium	1(?)

Depth of the Atmosphere.—Observations on the twilight arch indicate that at a height of 40 miles above sea level the air has a density sufficient to refract, reflect, and diffract light. A measurement of the parallax of a meteor seen by two observers at different stations indicates the existence of air at a height of 200 miles. Actual measurements, however, have not extended much higher than 20 miles, the height to which sounding balloons have reached.

Constituents	Per cent
Nitrogen	78.03
Oxygen	20.99
Argon	0.94
Carbon dioxide	0.03
Hydrogen	0.01
Neon	0.0012
Helium	0.0004

At an altitude varying approximately from 6 to 7 miles, according to latitude and also according to the season, a plane of contact occurs which apparently separates an upper from a

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[1] The foregoing are on the authority of W. J. Humphreys.

lower shell of air. Below this plane practically all the local movements, especially the upward and downward, or convectional movements of the air occur. The lower or convectional shell is the *troposphere;* the upper shell is the *stratosphere.*

Constituents of the Air.—*Nitrogen,* the constituent of greatest volume at the surface of the rock sphere, is very inert. It does not combine with the oxygen of the air, except in very minute quantities when influenced by lightning discharges. The nitrogen of the air is now used in the manufacture of ammonium nitrate, the basis of certain explosives. Nitrogen is the chemical base of nitric acid, HNO_3, and of several other oxygen compounds. It is a constituent of ammonia gas, NH_3, and of cyanogen, CN, all of which enter into the structure of many thousand other compounds. Many of these compounds are very unstable; hence the rapid decomposition of animal and vegetable compounds, commonly known as putrefactive decay. The instantaneous dissociation of the nitrogen constituents of such compounds as nitroglycerine and tri-nitrotoluol, or TNT, give to such compounds their value as explosives.

Atomic weight 13.93; sp. gr. .971; temperature of liquefaction −231° F (−146° C) at 35 atmospheres pressure.[1]

Oxygen is the active chemical element of the air. It unites readily with pretty nearly every other chemical element. Its union with carbon is the ordinary process of combustion. Iron wire in free oxygen burns about as freely as a match in the open air. The oxygen of respiration oxidizes the impurities of the blood.

The percentage of oxygen is slightly greater in the air of northerly winds of the north temperate zone than in southerly winds. It is slightly below normal over cities, as compared with open spaces. In crowded auditoriums the proportion of oxygen sometimes falls to 20 per cent; in mine tunnels it is sometimes as low as 18 per cent. Candles burn with difficulty with the oxygen content at 18 per cent; and human life cannot long exist with the proportion of oxygen as low as 17 per cent.

Atomic weight 15.88; sp. gr. 1.106; temperature of liquefaction −182° F (119° C) at 51 atmospheres.

Carbon dioxide (carbonic acid gas), CO_2, is the heaviest

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[1] The temperature and pressure of liquefaction of the gases mentioned in this chapter vary slightly according to different authorities.

gaseous constituent of the air. It is derived from carbon in the ordinary process of combustion:

$$C+2O=CO_2$$

It is also derived from various hydrocarbons of rotting vegetation by dissociation and combustion, as, for instance, methane (marsh gas):

$$CH_4+4O=CO_2+2H_2O$$

The normal proportion of carbon dioxide in the air is about 3.3 parts in 10,000 of air. In manufacturing districts, where coal is used for power-fuel, the proportion is greater. In the bracing air of a cold wave it is materially less. It is less during winter, when the temperature is below freezing and the ground is snow-covered, than in summer. Over the land the proportion is slightly greater at night than in the day-time, and during foggy weather it is materially greater than in dry weather.

In theaters, churches, schoolrooms, and poorly ventilated rooms the proportion of carbon dioxide may be as high as 12 parts per 10,000 of air; occasionally it is even greater. Breathed air is harmful, not so much on account of its carbon dioxide content as on account of the presence of products of putrefaction. Although carbon dioxide exists in the air at a calculated height of 15 miles, the proportion decreases so rapidly that it may be disregarded as a component of the air above the height of 1 mile.

Sp. gr. 1.53; liquefies and solidifies with moderate pressure at ordinary temperatures.

Water vapor in varying proportions is a constituent of the air. The maximum proportion depends chiefly on temperature. Thus at 30° F there may be nearly 2 grains by weight of water vapor per cubic foot; at 70° F, there may be nearly 8 grains. There may be less in either case, but there cannot be more; any excess will be condensed. When the maximum proportion is present the air is conveniently said to be "saturated."[1] The

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[1] According to common use air is said to "contain water vapor" or to be "saturated" under certain conditions, as though the air were a sponge, which may absorb and retain water up to a certain limit. The expression is inexact; but, in the literature of meteorology, inasmuch as the water vapor is rarely considered apart from the other constituents of the air, expressions

table, p. 280, shows the maximum weight of water vapor at different temperatures.

Although the proportion of water vapor mingled with the air differs from time to time, the per cent of total volume decreases from the equator toward the poles. The average annual per cent at the equator is 2.63; in latitude 70° it is only 0.22.[1] The proportional water vapor content of the air is commonly expressed as "per cent of humidity." Thus, with half the maximum proportion of vapor, the humidity is 50 per cent.

Sp. gr. 0.62; "boils" with vapor tension equal to that of the air at sea level, at 212° F (100° C); solidifies or "freezes" at 32° F (0° C).

Argon and the related group of elements, *neon*, *krypton* and *xenon*, constitute practically 8 parts per thousand of air. The gases of the argon group are chemically inert; no compounds with other elements are known to exist. This is true also of the other elements of the group. If they have any specific influence not possessed by nitrogen, the influence is not known.

Atomic weight of argon 39.88; sp. gr. 1.21; liquefies at $-184°$ F ($-120°$ C) under pressure of 40 atmospheres.

Hydrogen is the lightest of the chemical elements, and the weight of its atom is the unit of atomic weights. Ignited with oxygen it forms water:

$$2H + O = H_2O$$

Hydrogen is a constituent of all chemical compounds containing water, and of the various hydrides and hydrates. It occurs in the lower air in variable but very minute proportions which may be due to the chemical dissociation of organic matter. It is a constituent of natural gases, and of certain volcanic

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of the sort are convenient and will be so used in this manual. In a given space, whether vacuous or filled with the other constituents of the air, there may be a certain number of molecules of water vapor at a given temperature and pressure, and no more. If additional molecules are added the excess will be "condensed." and become a liquid. The water vapor is at its maximum density, and also it is "saturated," when the space contains all the water vapor which can exist therein up to the point of saturation. Strictly speaking, it is the vapor itself and not the space, nor the air which is "saturated."

[1] Hann: Lehrbuch der Meteorologie.

gases. The proportion increases as the height in the air increases. On account of its lightness meteorologists are of the opinion that the rapid movement of the earth in space is constantly throwing it off into space. At all events, there seems to be sufficient evidence that it is the chief if not the sole constituent of the outer part of the atmosphere. It is much used for the inflation of balloons and airships, being about 15 times as buoyant as air.

Atomic weight 1; sp. gr. 069; liquefies at about −375° F (−226° C) under a pressure of 15 atmospheres.

Helium is another inert element. It is a constituent of several minerals, including pitchblende, an oxide of uranium. It occurs by absorption in many deep rocks and also in the gases that escape from deep springs. Cottrell discovered it in the proportion of about 2 per cent in certain Texas gas wells. Because it is non-explosive and non-inflammable, it has been used in the inflation of balloons. Its buoyancy is about 92 per cent of that of hydrogen and it does not readily pass through balloon fabrics. Because of its lightness and also its high molecular speed, it is thought to occur chiefly in the outer shell of the atmosphere—possibly escaping from the earth altogether. If it plays any part in meteorological phenomena, its influence is not known.

Atomic weight 4; sp. gr. approximately .128; liquefies at −452° F (−269° C) at a pressure of about 3 atmospheres.

Nitric acid (HNO_3) and *ammonia* (NH_3) are present in the air in very minute proportions. Nitric acid is most readily detected at the time of thunderstorms. From time to time the proportions of these substances vary greatly from the proportions noted in the table. The presence of ammonia is due probably to the decomposition of organic matter.

Ozone (O_3) is an allotropic form of oxygen, whose normal molecule is O_2. Ozone possesses a pungent odor that frequently is discernible at the time of nearby lightning discharges and the passage of high-potential electric sparks. The normal proportion in the air is exceeded many times over during thunder-storms.

The proportion of ozone varies with environment. It is greater over the sea than over the land—possibly due to the lack of oxidizable matter; and this may explain its greater proportion in winter than in summer. The proportion is greater on clear, dry days than during cloudy spells. The daily variations of the ozone content of the atmosphere seem to correspond to the variations of the atmospheric electric potential.

Dust particles so fine that they escape measurement even with the highest power of the microscope, must be considered a part of the normal content of the atmosphere. Their presence is indicated by the fact that they may reflect enough light to make them visible *en masse* when a powerful light is turned upon them in a darkened room, or when a searchlight throws its beam at night. The path of the light is shown by the light reflected from dust motes. Dust particles of the size thus revealed behave like molecular rather than like matter of molar sizes. They are floating matter, the particles of which may not settle unless they are brought to the surface by means other than their own gravity.

The floating dust motes of the air are factors of great meteorological importance. They are the nuclei upon which the water vapor of the air condenses. Dense clouds of volcanic dust act as a screen preventing much of the sun's heat from reaching the earth. The dust particle is the normal nucleus for the cloud particle. The flying, or windblown dust, though a highly important physiographic agent, is not a factor of importance in meteorology.

Chlorine usually occurs in the air of localities bordering upon the oceans, and sodium chloride reactions may be obtained when sea winds are blowing inland. The presence of the salt is due to the action of the wind which whips a small amount of spray into the air. The chlorine content of the air apparently plays no part in meteorology. Like smoke and chimney products it may be regarded as "foreign" matter.

From the foregoing it is apparent that oxygen, nitrogen, and the argon group of gases practically constitute the "fixed" constituents of the atmosphere. Their proportions at sea level vary but little in different parts of the earth, and they constitute about 98 per cent of the atmosphere. Ozone, the nitrogen oxides, ammonia and the various radio-active emanations may be considered practically as negligible factors in meteorology; for the greater part they are accidental. Carbon dioxide is a factor chiefly in physiological meteorology.

Water vapor and the unmeasured dust content of the atmosphere are meteorological factors of the highest degree of importance. All the fresh waters of the earth are derived from the sea by a process that is clearly one of distillation; and life as it is organized on the earth depends upon this process. Even a slight change in nature's method of distillation would be followed by profound changes in the distribution of life.

Indoor Air and Mortality.—The difference between the sun-bathed air of out-of-doors and the air of dwellings has exerted a marked effect upon modern civilization. Various diseases of the densely peopled regions of Europe and America are practically unknown among peoples who live habitually out of doors. Tuberculosis is essentially a disease of modern civilization. Even in Europe and America, where the disease thrives, the mortality is twice as great among house dwellers as among those having out-of-door employment.

The mechanical ventilation of buildings has helped matters but very slightly. Air drawn through ventilating shafts has not the same therapeutic qualities as sunlit air coming through open windows into living rooms. An explanation of the difference is yet to be found. If meteorology is the science of the air, it should discover the difference between wholesome and unwholesome air.[1]

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[1] An investigation of the problem has been undertaken by a committee of the American Meteorological Society.

CHAPTER II

FORMS AND PROPERTIES OF MATTER IN ITS RELATION TO METEOROLOGY

Ether and Matter.—It is not necessary to assume that the universe and space are one and the same; nor that the universe is boundless; nor that space is without limits. So far as that part of the universe with which human knowledge comes in contact is concerned, the existence of two factors is assumed. Matter is perceptible to the human senses. It is visible, tangible, and transformable. It can be measured and compared; some, at least, of its properties are known. Its ultimate constitution, however, is not known. It is usually described in terms of atoms, molecules and masses.

In certain respects, more is known about ether than about matter: for although the existence of ether is merely assumed,[1] the magnitudes attributed to it are real values that have been fully established. That the universe is pervaded by an invisible, intangible, but measureable something is conceded. It is assumed that the manifestations to the senses known as heat, light, magnetism, electricity, and radiant energy traverse the known part of the universe by the means of the ether. It is not improbable that these manifestations are undulations of the ether itself.

The telescope and the spectroscope have shown that the matter entering into the composition of other visible bodies in the universe does not differ from that which composes the

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[1] "In recent years, doubt as to the necessity for assuming the existence of an ether has been expressed by some who claim that it is sufficient to attribute the power of transmitting radiation to *space itself*. It may be doubted whether this is more than a dispute about terms. One cannot discuss the question, here; but, pending the settlement of the controversy, it seems wise to continue the use of the word 'ether' as at least denoting the power of space, vacant or occupied by matter, to transmit radiation."—DUFF, *A Textbook of Physics*.

earth. Many of the chemical elements that compose the earth have been discovered in the sun and other heavenly bodies, and no chemical element has been discovered in any heavenly body that does not occur in the earth. Air and water vapor occur on the planet Mars, and it is not unreasonable to assume that the meteorology of this planet has much in common with the meteorology of the earth. The occasional occurrence of dust storms on Mars adds weight to the reasonableness of such an assumption.

Forms of Matter.—For practical purposes it may be assumed that matter exists in three forms—solid, liquid and gaseous.[1] Most of the metals and some of the non-metals may be changed easily from one form to another. Thus, iron is a solid at ordinary temperatures; it "melts" or liquefies at a temperature somewhat above 2100° F (1150° C); at a still higher temperature it gives off a reddish-brown vapor. Mercury is ordinarily a liquid; it "boils" or becomes a vapor at 675° F (375° C) and "freezes" or solidifies at −38° F (−39° C). Water is the most common illustration of all; it solidifies at 32° F (0° C) and gradually becomes a vapor at ordinary temperatures; but at 212° F (100° C) the vapor pressure is that of the air at sea level. Practically all the ordinary gases have been liquefied and solidified. Liquid air and carbon dioxide are articles of commerce.

The conditions which surround the liquefaction of ice and snow, the evaporation of water, and the condensation of the water vapor of the air are fundamental factors in the science of weather. The distribution of precipitation—that is, rain, snow, hail, and the floating forms of fog and cloud—affect the habitability of the earth and human activities to a very great degree.

Matter may be changed in physical form, but it cannot be annihilated. Thus, the coal in the fire-box is changed to carbon dioxide, a gas, instead of a solid; but the chemist may separate the carbon from the oxygen. Nothing, not even the energy, is lost; to nature nothing can be added, and from nature nothing can be taken away.

Properties of Matter.—All forms of matter have certain

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[1] In meteorology the discussion of the radiant form of matter may be omitted.

properties—volume, density, weight, etc., in common. Other properties, such as *malleability* and *ductility*, affect groups or classes of matter—chiefly the metals.

Cohesion is a somewhat archaic term denoting molecular attraction. In solids, the cohesion is usually strong, so that more or less force is required to sunder the mass—that is, to separate the molecules. The resistance of cohesion is usually expressed in such terms as tension, torsion, shearing, etc. In the liquefaction of a solid, or the vaporization of a liquid, the force employed to overcome cohesion is measured in terms of heat. For instance, in the liquefaction of ice, about 147 times as much heat is required to change ice at 32° to water at 32° as will raise the temperature of the same weight of water one degree Fahrenheit in temperature. In the case of liquids, the cohesion seems to be slight, inasmuch as the molecules possess a considerable mobility. Nevertheless, they are held together by a powerful force. Thus, the heat used in converting one pound of water at 212° F to a vapor at 212° F would raise 967 pounds of water one degree in temperature. Measured thus, in terms of heat units, great power is required to overcome molecular attraction. In the case of gases, not only is the molecular attraction negligible, but the molecules apparently repel one another.[1] Perhaps it is more nearly correct to say that they diffuse themselves throughout the space which contains them. In other words they apparently cease to possess molecular attraction.

Crystallization is a form of molecular attraction which indicates that the molecules possess a certain kind of polarity, usually assuming regular geometric forms. Frost and snowflakes frequently exhibit marvelous forms, infinite in variety but regular and similar in construction. The study of these forms is one of increasing importance in weather science.

Expansion-contraction is a property of matter true in its ordinary forms. The volume of a substance increases when it is heated and contracts with cooling. Thus, iron will increase

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[1] In mechanics the repellent force of the water vapor, usually called steam, is termed "pressure" and is rated in "pounds per square inch," or in "atmospheres" of 14.7 pounds per square inch. In meteorology the repellent force is expressed sometimes as *tension*, but more commonly as *pressure*.

0.00000648 of its length for each degree F of increase in temperature, this being its "coefficient of linear expansion." The coefficient of expansion of air is 0.00367; of ethyl alcohol, 0.0005; of mercury, 0.0002.[1] In meteorology the principles of this property are fundamental. The expansion of mercury and of alcohol are used to determine the intensity of heat; and to the unequal heating of the air in different localities are due the movements of the air—that is, the winds.

Magnetism is a property pertaining chiefly to iron and steel, but possessed to a lesser degree by other metals. When in the condition known as magnetized, a piece of iron or of steel attracts and holds other pieces of iron and steel. Steel retains its magnetism permanently; iron is sensibly magnetic only when within magnetic influence—that is, a "magnetic field." Nickel, cobalt, certain manganese alloys and tungsten alloys exhibit magnetism very sensibly. A bar of magnetized steel, suspended by a thread attached at its center of gravity, comes to rest pointing nearly or quite north and south, the negative or marked end pointing in a general way to the earth's north magnetic pole. A few substances, chiefly bismuth, similarly suspended come to rest across the magnetic field when between the poles of a horseshoe magnet. The investigations concerning the earth's magnetic properties are carried on in the United States by the Coast and Geodetic Survey.

Properties of Gases.—Gases are perfectly elastic. A gas fills any space within which it is confined. A cubic inch of a gas whose density has been measured, if set free in a space whose dimensions are a cubic foot, or a cubic yard, will fill the space.[2] Manifestly its density and tension will be lessened in proportion. It is the custom to say, therefore, that a gas has no specific volume of its own; its volume is that of the container.

Equal volumes of a gas, temperature and density remaining the same, contain an equal number of molecules. If hydrogen, the lightest known gas, be taken as the unit of measurement,

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[1] Different values are given by different authorities; the foregoing are on the authority of H. Whiting.

[2] This property of gases is not quite true at temperatures near to their condensation, but it holds good at temperatures which are materially higher than the temperature approaching condensation.

the molecular weight of any gas may be determined by comparing its weight with that of an equal volume of hydrogen. This is known as *Avogadro's law.*

If a volume of gas be heated from 32° to 459° F [1] (0° to 273° C) its volume will be doubled.[1] That is, equal volumes of gases expand equally with the same increase of temperature.

If a given volume of gas—say 1 cubic foot of oxygen—be introduced within a container, its pressure or tension noted, the same volume of another gas having the same tension may be introduced without an increase of tension of the mixture. Thus 1 volume of oxygen added to 1 volume of nitrogen will make but 1 volume of the mixture, having the same tension as each of the two gases. That is, one gas is practically a vacuum for another. This property has its limitations; when several other gases are introduced within the container a noticeable increase of the tension of the mixture takes place.

Inasmuch as the science of meteorology is chiefly a study of the air, a mixture of gases differing in their specific properties, a clear exposition of these general properties is necessary to an understanding thereof—more especially to the solving of the problems of weather, climate, and habitability.

Gravity is a property of matter that exists apparently throughout the known universe. The apparent fact that matter in masses attracts all other matter in masses is practically all that is known of the essence of it. The whirling of the sun and the planets about a common center of gravity balances the attraction that otherwise would bring them together. More exactly stated, planetary bodies tend to move in straight lines; gravity tends to draw them to a common center; the result is orbital movement. These complex movements and forces have a great and very measureable influence on the movements of the sea and the air.

It is convenient to note the density—practically the "weight"

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[1] This may be expressed by the formula

$$V' = V[1 + k(t' - t)],$$

where V is the given volume; V' the volume sought; t the given temperature; t' the temperature of the volume sought; and k, 0.00367. This is known as *Boyle's law,* and also as *Mariotte's law.* It is true at high temperatures, but not exact at ordinary temperatures.

—of various kinds of matter, comparing them volume for volume, under standard conditions, with the density of a given substance. This ratio of weight is the *specific gravity* of the substance. Distilled water at its maximum density, 39.1° F (3.94° C) is usually taken for the comparison. Thus, a given volume of mercury weighs 13.6 times as much as an equal volume of water, and an equal volume of alcohol 0.81 times as much as an equal volume of water.

For gases, air and hydrogen are both used as units of comparison. The specific gravity of hydrogen, in terms of air, is 0.069; of air in terms of hydrogen, 14.4; of coal gas, commonly used for inflating balloons, about 0.061; of water vapor, 0.62. When metric units are employed, the weight of a cubic decimeter is the specific gravity of the given substance,[1] a cubic decimeter of water under standard conditions, weighing in theory, but not in fact, 1 kilogram.

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[1] The following formulas are useful: $\text{Sp. gr.} = \frac{\text{wt.}}{\text{vol.}}$; $\text{weight} = \text{vol.} \times \text{sp.gr.}$; $\text{volume} = \frac{\text{wt.}}{\text{sp. gr.}}$.

CHAPTER III

HEAT: ITS NATURE, PROPERTIES AND DIFFUSION

The Nature of Heat.—The phenomena of heat and light are described, the one as "molecular motion," the other as the "radiation of solar energy." Roughly, either definition will apply to either phenomenon. Not much is known about the real essence of either, except that they are forms of energy which have been measured, and of which certain magnitudes have been established under the name of "wave lengths."

Radiant Heat.—It is assumed that heat and light traverse space in "waves" or vibrations of the ether. Positive knowledge is confined to the fact that heat is radiated by the sun and stars in every direction. Practically all the heat received by the earth comes from the sun; and of the whole amount radiated by the sun, the earth intercepts less than one two-billionth part. Nevertheless, this small fraction of the sun's radiant heat produces all the results upon the earth which are manifested by life and its activities.

Some of the ether waves stimulate the nerves of the eye, producing the phenomena of light and vision. Others do not affect the nerves of sight; as they fall on the body they produce the sensation of warmth, thereby stimulating the growth of living matter. Meteorology is concerned chiefly with radiant energy of this character; they are conveniently called *heat waves*.

Perhaps our nearest approach to actual knowledge of heat is the recognition of the fact that when heat waves fall upon matter—say, a piece of metal—they set up a motion in the molecules composing it. If the intensity of the waves increases, molecular attraction little by little is overcome; the solid becomes a liquid and, finally, a vapor. This important change is explained as being due to increasing and to wider amplitude of the oscillations of the molecules. Perhaps the theory may not be satisfactorily established, but the facts cannot be denied;

the heat has increased the motion of the molecules; finally it has overcome their cohesion.

Sources of Heat.—The warmth that is concerned with life and its activities is derived from the sun. The sun warms the rock envelope of the earth; the rock envelope radiates warmth to the atmosphere; the movements of the air diffuse the warmth, bringing cool air into warm regions and sending warm air into cold regions. Weather science is concerned chiefly with these movements of the air.

The earth itself is a source of heat. The interior of the rock envelope of the earth is intensely hot. Borings into the rock envelope show an increase of temperature with depth. The rate varies with the character of the rock, a rough average being 1° F for every 70 feet.[1] Some of the heat of the rock envelope, at such depths, is due to chemical action going on within the rocks themselves; some is due to vulcanism; but some is certainly due to the radiation of the heat of the interior of the rock envelope itself. In meteorology this source of heat practically is negligible.

The most common example of a terrestrial source of heat is the ordinary combustion of fuels. But even this is apparent rather than real terrestrial heat; in fact it is the heat of the sun stored and conserved by vital chemical processes. But all the original heat derived from within the earth and all the heat of vital chemical processes bears an infinitesimal ratio to that received from the sun. It is estimated that the heat received by the earth in one minute is sufficient to raise 42,000,000,000 tons of water from the freezing to the boiling point.

Heat as Motion.—If heat produces molecular motion, it must be assumed that the ether waves which traverse space warm nothing until they fall on matter—that is, on a substance composed of molecules which can be set in motion. But in many respects heat behaves to matter much as light does. It may pass through a substance just as light passes through glass; such a substance is said to be *diathermous*. Thus, glass itself is more or less diathermous, so also is clear water. Glass permits most of the heat of the sun to pass through it, but it intercepts

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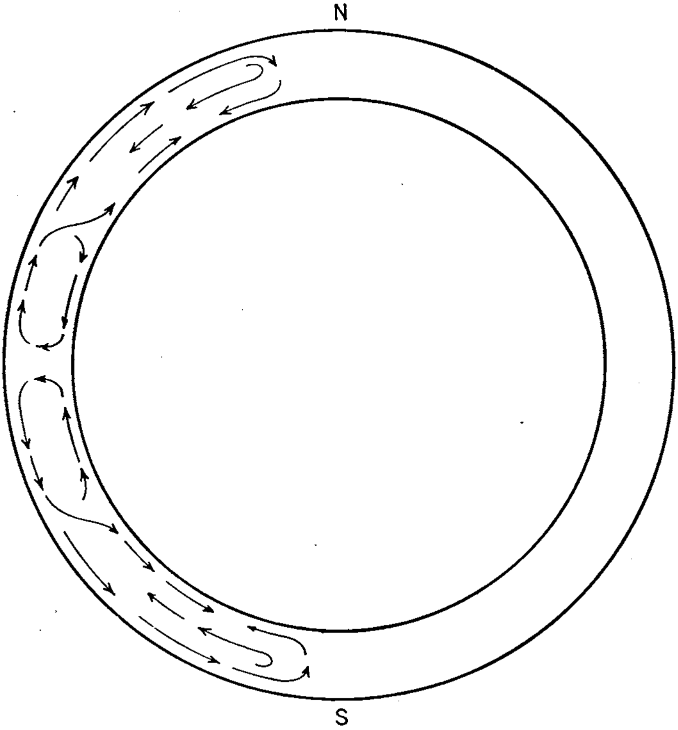
[1] At the Goff well, near Bridgeport, West Virginia, the temperature at a depth of 7310 feet is 159 F (106° C). The average increase of many measurements is somewhat less than 1° for each 70 feet.

some of it. Thereby molecular motion is set up in the glass itself and it becomes warm, radiating heat in just the same manner as a stove radiates it.

The heat "absorbed" by a substance—that is, converted into molecular motion—in time may be stored until it is again radiated and is given out as warmth. It is conveniently called "sensible heat." It is thus distinguished from the ether waves that have great physical power, but do not directly impart the sense of warmth. One cannot draw a line between the sensible and the ultra-sensible heat waves, however; and the use of the term, though convenient, is not exact. Weather science deals chiefly with the sensible heat of the air.



After Ferrel.

Convectional movements of the air; sectional view.

Diffusion of Heat.—As a body becomes warm, the heat may diffuse itself through the mass rapidly, as in the case of metals, or slowly, as in the case of non-metals. The former are *good conductors;* the latter are sometimes regarded as poor conductors, or *insulators.* Thus, steam pipes are wrapped with asbestos coverings. The metal pipe itself warms rapidly and, radiating heat rapidly, causes a loss of heat in the steam. The asbestos covering, being a non-conductor, or insulator, prevents the loss by radiation. In solid bodies, the diffusion of heat is accomplished by conduction. The motion imparted to molecules sets the molecules nearest to them in motion; finally the heat is diffused throughout the mass.

When liquids and gases are heated a movement of mixing occurs. This process is best observed when a handful of sawdust is placed in a beaker of water and the water is heated by a Bunsen burner. The rapid warming of the water carries the particles of sawdust upward, outward and downward through the water; they indicate the progressive movement of the water in different parts of the beaker. This mixing process is called *convection.*

Convection of the Air.—The convectional movements of the air are among the most important factors in weather science. Aside from the lateral movements of the air—the winds—convectional movements that are more or less vertical are going on all the time; that is, air is going up or coming down.[1] Warm air is ascending, cool air is descending.

The sun does not warm all parts of the earth evenly. In tropical latitudes the heat is far more intense than in extra-tropical latitudes. Because of the curvature of the earth's surface, polar regions receive the sun's rays very obliquely. The unequal heating results in a convectional movement of the air on a scale that affects the whole atmosphere. It produces an upward and poleward flow of air in tropical regions which is balanced by a downward and tropic-ward movement of the air in extra-tropical regions.

The principle of convection is one of the most important in meteorology, and is practically the foundation of that

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[1] W. J. Humphreys points out the interesting paradox that "more air goes up than comes down." Ascending air carries water vapor, an integral part of the air. But the updraught chills and condenses the water vapor which falls as rain or as snow. The descending air is less in quantity by the amount of water vapor that is lost by condensation.

part of weather forecasts which concerns storms and cold waves.

Specific Heat.—Different substances vary greatly in their "capacity" for heat. That is a much greater amount of heat is required to produce a given intensity of molecular motion in one kind of matter than in another. For convenience, the amount is called the *thermal capacity* of the substance. For convenience also, the heat taken up by a given weight of water is taken as the unit of measurement. Thus, a pound of water has 9 times the thermal capacity of the same weight of iron and 30 times that of mercury.[1]

Latent Heat.—Reference has already been made to the fact that a very great amount of heat disappears when water at 212° F (100° C) is converted to steam at 212° F. The heat apparently lost reappears when the steam is condensed to water at 212° F. The heat thus employed in overcoming molecular attraction is called *latent heat.* The latent heat of evaporation is an important factor in the diffusion of heat. Thus, water vapor from tropical regions is borne to higher latitudes and there condensed, setting free an enormous amount of latent heat, which becomes "sensible" heat again. The latent heat set free when water freezes is also a factor in climate.

Adiabatic Heating and Cooling.—If a volume of gas, or of air, is compressed, a noticeable amount of heat is given off. The hand-operated tire pump is an example; after a dozen strokes of the plunger the barrel of the pump becomes hot. If the compressed air expands to its original volume, just as much heat is absorbed in the expansion as was given off during compression. The ordinary ammonia gas compressor furnishes an instructive illustration. The pipe near the compression valve may be at a low red heat; the pipe at the release valve is usually cased with a thick jacket of ice. Heat has not been added to the gas in the process of compression; it has not been taken away during expansion.

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[1] Thus, if the *specific heat* of water is 1, that of iron is 0.1138; of mercury 0.0333; of glass, 0.1977; of dry air at constant pressure, 0.2375; of steam at 212° F, 0.341; of ice, 0.50. Because of its great specific heat and good conductivity it is evident that water is well adapted to the heating of buildings. It holds its warmth steadily; it also holds a greater amount than any other available substance.

This phenomenon is an important principle of weather science. As has been pointed out, convection in the air is always going on. Ascending air expands in volume because of decreasing pressure; descending air is compressed in volume because of increasing pressure. Therefore it follows that ascending air cools by expansion and descending air becomes warmer by compression. This phenomenon is called *adiabatic* heating and cooling; to all intents and purposes it is merely a form of latent heat. Adiabatic heating and cooling of the air therefore is practically due to convectional movements.

Units of Measurement.—Various units are employed in the measurement of heat. Two aspects of heat measurement concern meteorology—*quantity* and *intensity.* Thus, the quantity of heat which a given weight of a substance may contain is less than that of a greater weight of the same substance, and, as has been noted, equal weights of different substances may differ greatly in thermal capacity. Several units of quantity, or thermal capacity, are employed. The *calorie* is the amount of heat required to raise one gram of pure water one degree centigrade in temperature. This unit is employed very generally in scientific research. In some instances, however, it is more convenient to employ the *great calorie*, or the amount of heat required to raise one kilogram of water one degree centigrade in temperature. The *British thermal unit*, the heat required to raise one pound of water one degree Fahrenheit, is also much used—chiefly, however, in expressing the heat value of fuels.

The unit of intensity is the *degree*, of which there are several, each differing in value from the others. All of them, however, have a common basis—namely, the difference in intensity of molecular motion between melting ice and boiling water, under certain standard conditions. The various scales of degrees are explained in another chapter.

The Solar Constant.—Weather science is concerned in the amount of heat received by the earth from the sun. For expressing this value the calorie is used. The measurements begun by Ångstrom and Langley, and continued by Abbott, Kimball and others, cover a period of about forty years. Simultaneous cooperative observations carried on in the United States and elsewhere show that the value is by no means constant, but that it varies from time to time. The mean of observations deduced by Abbott is 1.932 calories per minute, less the amount absorbed by the air.

The air, with its dust and its moisture content, intercepts a great deal of the heat radiated from the sun. When the sky is clear and the sun is overhead, it is found that a little more than two-thirds of the sun's radiation reaches the earth, less than one-third being absorbed by the atmosphere. When the moisture content of the air increases, the value of the solar constant decreases. When the smoke pall that hovers over manufacturing centers thickens, the effect is the same. This also is true of any increase of atmospheric dust. The volcanic dust shot into the air by the eruption of Krakatoa lowered the value of the solar constant for a considerable length of time.

The moisture and dust content of the air acts as a blanket, intercepting and storing during the day a part of sun's heat, and at night becoming a source of heat in itself.

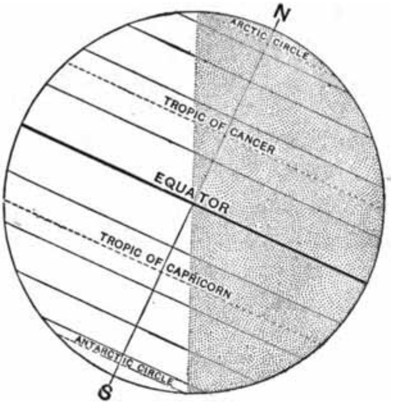
The fixed constituents of the air, the oxygen and the nitrogen, vary so slightly in proportion and the amount of heat which they intercept, that their effects may be regarded as constant. The great changes in the effects of insolation are due chiefly to the varying proportions of the water vapor and the dust content of the air. The layer of water vapor is comparatively thin—practically not more than five or six miles. The dust blanket, on the other hand, may extend many miles into the upper air.

CHAPTER IV

THE AIR; THE DISTRIBUTION OF WARMTH

Disregarding the very slight amount of heat radiated from the earth's interior to the surface, and also that received from other heavenly bodies, the sun must be regarded as the source of the heat received at the earth's surface. The greatest intensity of heat is received in equatorial regions where the sun's rays are practically vertical; the least intensity is in polar regions where the rays fall obliquely.

The inclination of the earth's axis to the plane of the ecliptic, 23° 27′, is an important factor in the distribution of warmth. The direction of the axis, minor oscillations excepted, is constant; it ranges very nearly toward the north star. One result of the constant parallelism of the earth's axis is a movement of the belt of vertical rays—the "heat belt"—back and forth, an angular distance of nearly 47 degrees—from the Tropic of Cancer to the Tropic of Capricorn. The polar circles, 23° 27′ from each pole, mark the farthest point beyond each pole to which the sun's rays extend when vertical at a tropic. Another result of the inclination of the earth's axis is the increasing length of summer days and winter nights as the latitude increases. At either tropical circle the longest day is a little more than 13.5 hours; the shortest, about 10.5 hours. Within the temperate zones the longest days vary from



Redway's Physical Geography.

Relative length of day and night.

13.5 hours to 24 hours. The possible hours of daily sunshine vary according to month and according to latitude.

Polar and tropical circles are the boundaries, not of climatic, but of light zones. The duration of daylight is of great importance; it governs, in no small degree, the maturing of crops, and therefore concerns practically all agricultural industries. In general, the regions of greatest productivity of staple foodstuffs are those in which the summer days are from 14 hours to 16 hours long. Both the navigator and the aviator must know whether he heads in the direction of increasing or of decreasing hours of daylight at any particular time of the year.

Climatic Zones.—Climatic zones correspond pretty closely to light zones, in position; but their boundaries are very irregular lines, called *isothermal lines*—that is, lines along which the annual mean temperature is the same. For all practical purposes, the climatic torrid zone is the zone where frost does not occur except at very high altitudes. Similarly, the southernmost line at which frost may occur is the southern boundary of the north temperate zone; and the line of mean temperature of 32° (0° C) may be considered its northern boundary. A more practical boundary is sometimes fixed at the northern limit at which barley will mature.

Climatology is chiefly concerned with the regions which will produce foodstuffs, and therefore sustain life. To a lesser degree it is concerned with the problems which affect transportation. In any case the problems are mainly those of temperature, pressure, moisture, wind and sunshine.

The Diffusion of Warmth.—The warmth of the various parts of the earth is modified chiefly by the movements of the air. Because of the vertical rays of the sun in equatorial regions, the air is not only warmed to a much higher temperature, but it is also warmed more quickly than in higher latitudes. Being expanded by the greater warmth, it becomes specifically lighter and is pushed upward by the denser cold air which flows in to take its place. The updraught of air flows poleward in upper currents, until it is chilled and descends to the surface again. A part of the descending current continues poleward but a considerable part flows back to tropical regions as a surface wind.[1]

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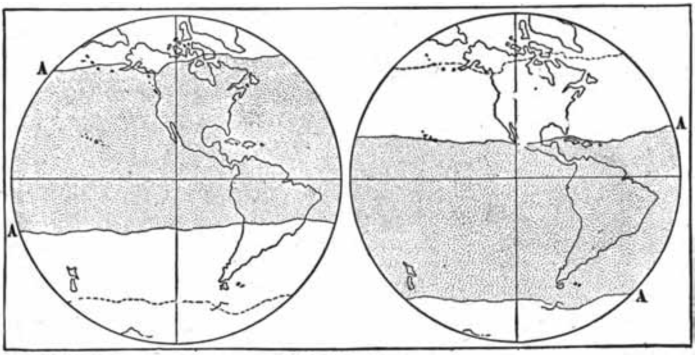
[1] This explanation is not accepted by all meteorologists, but it is supported by evidence that cannot be disregarded.

The actual movements of convection are much more complex. Calms alternate with eddying movements of great intensity. All general movements are deflected by the rotation of the earth on its axis—easterly in tropical latitudes, and westerly beyond the tropics. There are therefore three wind belts, one of easterly and two of westerly motion. Each of these has also a northerly and a southerly component; moreover, all three belts shift alternately north and south with the apparent movement of the sun. The belt of tropical easterly, or Trade Winds, extends a little further north than New Orleans in summer and its northern edge recedes as far south as Havana in winter. The position of the wind belts, month by month, is shown on the Coast Pilot charts of the United States Hydrographic Office.



June January

The migration of the heat belt.

The apparent motion of the sun, due to the inclination of the earth's axis, carries the zone of greatest warmth far north in June and far south in December. Thereby the warmth of tropical regions is carried well into the temperate zones, and thereby the production of foodstuffs is extended to about the sixtieth parallel of latitude, north and south.

All this complexity of movement adds to the diffusion of warmth. The warm air of tropical regions is mixed with the cold air of circumpolar regions. Complex as they are, the general movements of diffusion may be classified as the horizontal movements which include the winds, and the vertical convectional movements with which are classed the cyclones and the anticyclones.

Temperature and Altitude.—The effects of altitude on temperature may be considered in two aspects—altitude along a sloping surface, such as that of a mountain range, or a high plateau, and altitude above the surface, directly into the air. Altitudes are measured usually from mean sea level.

The variations in temperature of the various plains, plateaus, and mountain ranges are very great. In general, the temperature decreases with altitude until, in tropical regions, the limit of perpetual snow is reached at a height of about 16,000 feet; it decreases with increase of latitude until, in circumpolar regions, the snow line is not much above sea level. The variations of temperature with height are governed by so many conditions that specific rules apply to specific localities only.

The study of the relations between temperature and vertical altitudes is a matter of great importance in meteorology, and it has been prosecuted diligently during the last quarter of a century in various parts of the United States, Canada, Europe, South America and Africa.

Many thousand flights have been made by kites, manned balloons, captive balloons, pilot balloons, sounding balloons, airplanes and dirigible airships. At Uccle, Belgium, a pilot balloon reached an altitude of 20.1 miles, or 32,430 meters. Up to an altitude of about 9 miles, temperature and pressure statistics of the air have been obtained for about every thousand feet of altitude; beyond that plane the measurements are incomplete.

The fall in temperature with the increase in altitude has been in the traditional ratio of 1° F for every 300 feet[1]—the conventional temperature gradient. This has been a convenient ratio for general purposes, but it cannot be used in specific cases. Within the first 2 miles the temperature gradient is very irregular; at times there is even a rise in temperature with increased altitude; that is, the temperature gradient becomes negative. The rise in temperature with increasing altitude is technically known as *inversion*.

Inversion may occur in winter, when comparatively still air

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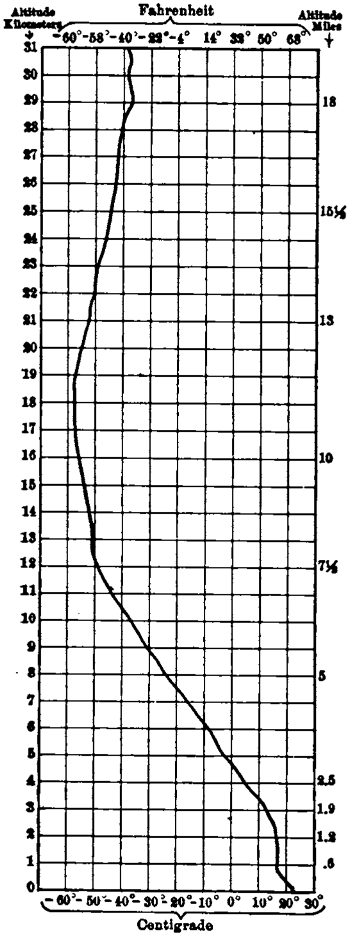
[1] This does not refer to the adiabatic cooling of air by expansion—about 1° F per 183 feet, or 1° C per 100 meters.

settles on a level surface or in a basin. It is pretty apt to be noticeable when a cloud layer separates two layers of air; the upper layer may be the warmer; indeed, the airman is quite apt to find a higher temperature above than below. Above a height of 2 miles, when the air is moderately still, the fall in temperature is apt to be fairly uniform. At a height varying from nearly 7 to 10 miles the fall in temperature ceases. Above this plane it remains stationary, or perhaps it rises. In one instance, a steady rise of temperature was observed between the altitudes of 8 miles and 20 miles.



Temperature records made by a sounding balloon at Avalon, California, July, 1913. Note that an inversion of temperature occurs at the altitude of about 12 miles, and at 20 miles the temperature is about 20 degrees higher than at 12 miles.

The plane which separates the stratum of falling temperature from that of stationary temperature is sometimes, but rather loosely, called the *isothermal layer.* It varies in height, being highest at the equator; it is likewise higher in summer than in winter. It separates the shell of the atmosphere into two distinct layers—the stratosphere, and the troposphere.

The air of the stratosphere is remarkable chiefly for its apparent inertness. At its lower part the temperature does not vary much from −67° F (−55° C). If, as seems probable, there is a rise of temperature with increase of altitude, the rise is normal rather than abnormal. It seems to be due to the fact that the base of the stratosphere is chilled by masses of extremely cold air that constantly are thrown upward against it.

The humidity of the air of the stratosphere is very low—so low that visible clouds do not form. Therefore, if the dew-point is ever reached, the condensation is confined to ice spicules so few in number that they do not affect the visibility of the air. There is no vertical convection; therefore they sink slowly; and if they are greater in size than are molecules of water vapor they sink more rapidly than the water vapor diffuses itself.

It seems certain that the air of the stratosphere contains dust a-plenty—both cosmic dust and dust that is hurled into it by volcanic eruptions. If dust is absent, the air of the stratosphere differs from that below it and from space above it. One thing is certain, the radio-activity within the stratosphere indicates the presence of dust particles highly electrified.

The depth of the troposphere is inconsiderable compared with that of the stratosphere; aviation has probably scaled its height probably within pistol shot distance of the isothermal layer. The troposphere is the region of convection. Its height is practically the height of cirrus clouds, and all the great movements of the air—wind, cloud, storm, and precipitation—take place within its limits.

Experience has taught the meteorologist that conditions in mid-air of the troposphere, in many instances, are the key to conditions at the surface. They are far more important in air flight; for the airman encounters bumps and holes, both of which are due to sudden inequalities in temperature. The airman and the navigating officer of the airship are likely to encounter cross-winds, the updraught of thunder-storms, and the vagaries of cloud-formation; these, too, are due to irregular conditions of temperature, all of which must be understood and reckoned with in flight.

Air Altitudes and Terrain Altitudes.—The laws and values which apply to vertical altitudes in free air are not applicable to altitudes on the earth's surface. In general, temperature decreases with altitude, but this is not always true. At various times the temperature of mountain valley floors is lower than that of the foot-hill slopes several hundred feet higher. On very cold, still nights, low spots, such as stream valleys, are almost always colder than higher ground. In regions where late frosts prevail, fruit growers have learned to take advantage of this fact. The difference between the temperature of a low spot and higher ground a few rods away is at times the difference between freezing and non-freezing temperature.

In tropical regions where mountains lie against the coast the difference between sea level temperature and that of the foot-hills a thousand feet higher is very marked. Thus, the temperature of the business district of Victoria, Hongkong, is almost intolerable to Europeans; on the Peak, a few hundred feet higher, the climate is pleasant. The same difference is noticeable between Rio Janeiro and its suburb, the Corcovado; it is even more noticeable in comparing the climate of Vera Cruz with that of Puebla or Orizaba.

On the other hand, extremely hot days in the foot-hills of the Sierra Nevada Mountains are apt to be cool days along the coast. The explanation is not hard to find: the ascending hot air of the foot-hills is replaced by cold air blowing in from the ocean.

In many instances the difference between low valley and hill stations is quite as much hygienic as climatic. It is the difference between moist, dusty and miasmatic air on the one hand; and clear, dry air on the other.

Temperature and Latitude.—In general, the mean temperature of the air decreases as latitude increases. In the southern hemisphere, which has chiefly an ocean surface, the decrease is quite regular and the direction of the isotherms does not vary much from that of the parallels. In the northern hemisphere the decrease is by no means regular, and the isotherms wander greatly from the parallels.

The following illustrates the decrease in the United States, as affected by latitude. In column I, the stations from south to north are approximately along the ninety-sixth meridian; in column II they are situated along the Atlantic Coast.

I		II	
Corpus Christi, Tex.	70°[1]	Key West, Fla.	68°
Fort Worth, Tex.	65°	Savannah, Ga.	65°
Wichita, Kan.	55°	Wilmington, N. C.	62°
Lincoln, Neb.	50°	Atlantic City, N. J.	54°
Huron, S. Dak.	42°	Boston, Mass.	49°
Devils Lake, N. Dak.	36°	Eastport, Me.	41°

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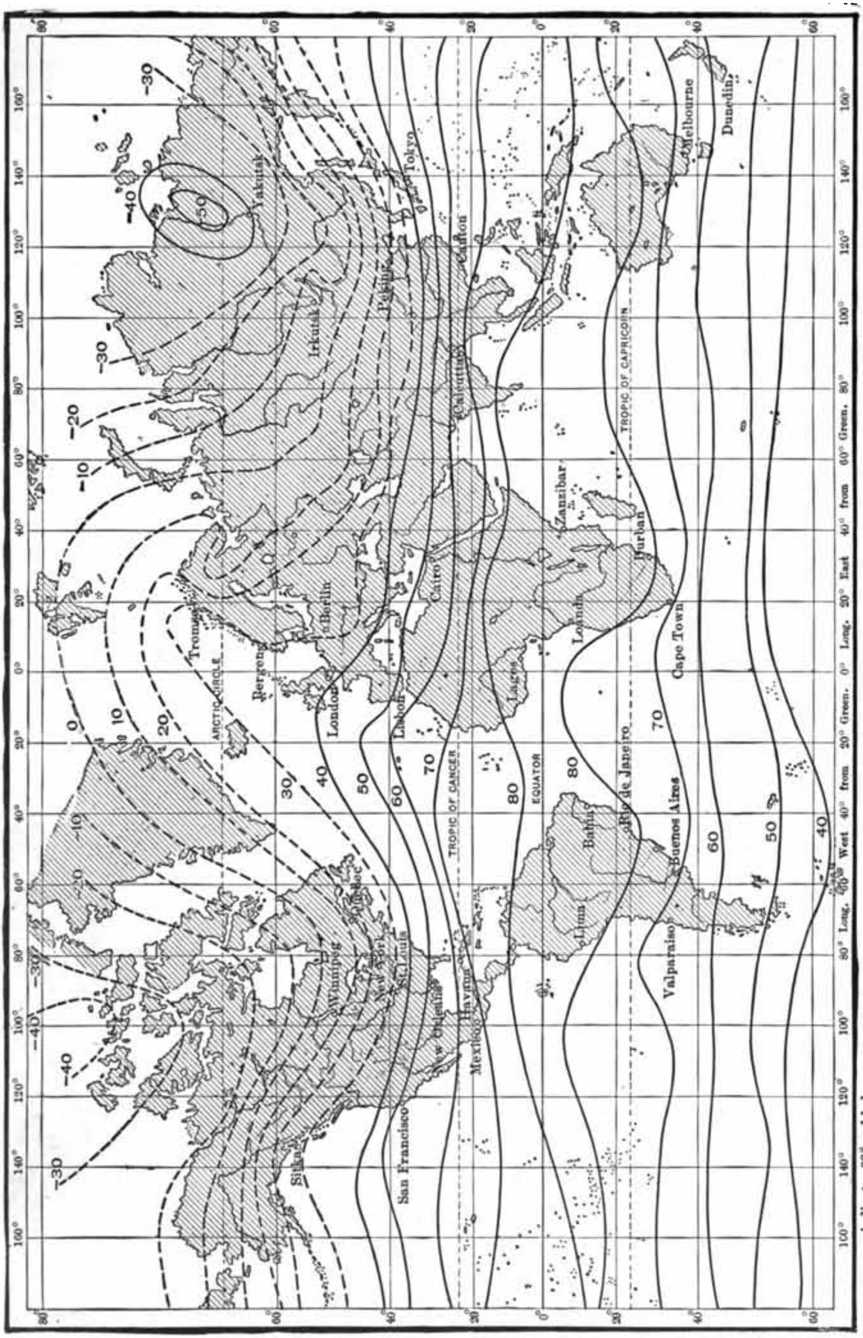
[1] The temperatures noted in the rest of this chapter are Fahrenheit, this scale being used for Weather Bureau reports.



Huntington and Cushing's *Principles of Human Geography.*

------- indicates 32° and below

Mean temperature, January.

The same results are seen in the temperature range in Europe, from Athens to Petrograd, or in South America, from Guayaquil to Punta Arenas.

Within the tropics and also in polar regions, temperature changes due to latitude are not regular, nor are they great. In the main they are due to causes and conditions more or less local in character.

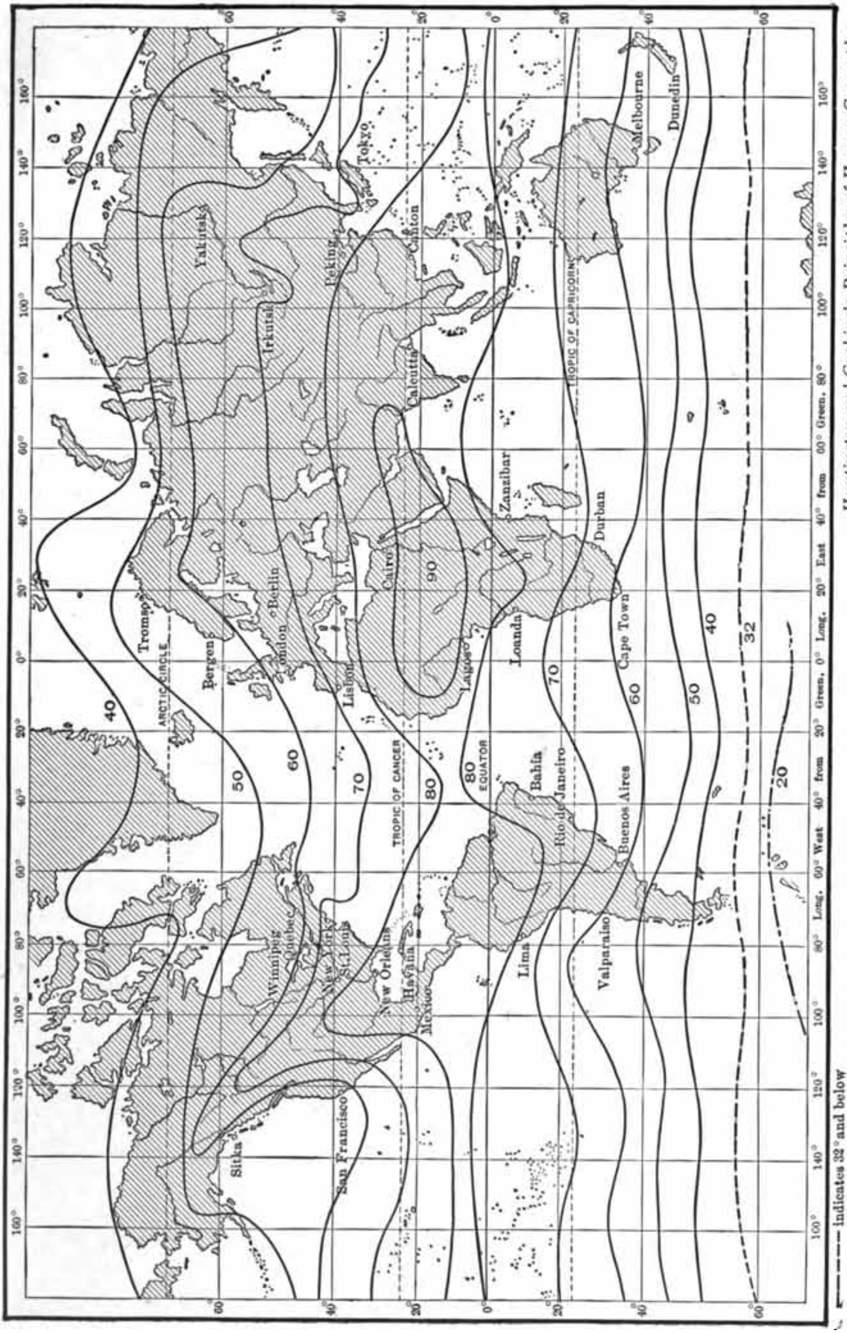
Mean Temperatures.—The daily, the monthly and the yearly means are required in weather service. The most accurate daily means would require the average of the hourly observations for the day; but the results would not be commensurate with the labor involved. The investigations of General A. W. Greely, while at the head of the U. S. Weather Bureau, showed that the average deduced from readings made at 7.00 A.M., 2.00 P.M., and 9.00 P.M., taking the last named twice and dividing by 4 gave a result very closely approaching the average of hourly means. This method has much to recommend it.

In the various Weather Bureau stations, where temperatures are recorded by regular observers, and in the various military field stations, the daily mean is found by taking half the sum of the daily maximum and the daily minimum. This mean is slightly in excess of the mean deduced by the preceding methods, but the error is so small that it may be disregarded.

The cooperative observer's day begins and ends with the time that the maximum thermometer is set—usually from sunset to the following sunset. The daily mean thus established, however, does not differ materially from the true mean. The monthly and the yearly means are sufficiently accurate for practical purposes.

The yearly mean is deduced by dividing the sum of the monthly averages by 12. A closer average may be found by adding the monthly sums and dividing by the number of days in the year on which observations are made.

The mean annual temperature of a region is not a key to its temperature conditions or to its habitability. Thus, New York City and San Francisco, both seaports, situated not far apart in latitude, have about the same mean yearly temperature. But while the difference between the winter and the summer means in San Francisco is not more than 8 degrees, in New York it is about 32 degrees, and while the difference



Huntington and Cushing's Principles of Human Geography.

Mean temperature, July.

between the warmest and the coldest month in San Francisco is 10 degrees, in New York it is 44 degrees.

In studying the temperature of a locality, therefore, in addition to the question of mean annual temperature, various other elements must be taken into consideration. In the main, these are the daily range, the range of monthly means, and the seasonal range. These are affected in turn by latitude, by altitude above sea level, by the direction of prevailing winds, and by distance from the sea. In a minor way they are also affected by the moisture and the smoke content of the air.

The mean annual temperature of a place varies but little from year to year. In New York City, the range of yearly means has varied about 6 degrees in ninety-seven years. The average of each ten-year period for that time varies but a trifle from the normal of 52°. The records of Cooperstown, New York, have been kept continuously since 1854. The averages of ten-year periods show neither apparent gain nor loss in temperature.[1]

Temperature Ranges.—The daily, monthly, yearly and extreme ranges all have an important bearing on the climate of a region. The daily range is a part of the records of every Weather Bureau station; and the greatest daily range in each month is an item of separate record.

The various ranges are usually, though not at all stations, least in tropical regions and greatest in inland regions where the humidity is low. In temperate latitudes they are lower on the coasts than in the interior. In the United States the average daily range is somewhat less along the Pacific Coast than along the Atlantic Coast; and the daily ranges of inland stations are greater than those of coast stations. The reason therefor is that the drier air of inland stations permits greater radiation of heat at night and greater absorption during the day. For a similar reason the daily ranges at stations of considerable altitude are apt to be greater than those at or near sea level.

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[1] The history of the cultivation of the grape in Europe shows even more conclusively that no material changes have occurred in two thousand years. The grape of southern and western Europe is semi-hardy; it likewise is sensitive to temperature changes. But in twenty centuries its limits of latitude have not changed.

Along the Atlantic Coast the greatest daily range within a month does not often exceed 30 degrees; and the average monthly range is not far from 20 degrees. Away from the coast belt daily ranges above 40 degrees are common. In the Plateau Region of the western highlands the average of daily ranges in June varies from 40 degrees to 50 degrees. At Pacific Coast stations the average daily range is not far from 15 degrees. In Arizona, a part of the Plateau Region, owing to dry air and altitude, the daily ranges have usually been greater than in most other parts of the United States. At Florence, Arizona, a daily range of 63 degrees has been recorded, and ranges above 45 degrees are noted occasionally.

Undoubtedly the greatest daily ranges occur in the high desert plateaus of Asia. The temperature records for this region are few in number, and not always trustworthy. One fact, however, has been established beyond reasonable doubt: excessively hot days are sometimes followed by freezing temperature at night.

Excessive extremes are characteristic of inland regions; and in Siberia, where inland distances are greater than in the American continent, the extremes of temperature are also greater. At Verkoyansk a minimum of –.96° F has been noted; and at Wargla, a caravan station in the Sahara, a maximum of 127° F has been reported by a trained observer.[1] In the northern part of the United States, a temperature of –30° accompanying a cold wave, is not uncommon.

In the United States, the highest official temperature record, 134°, is reported at Greenland Ranch, California; the lowest, –67°, at Poplar River, Montana. It seems certain that desert regions in low latitudes are the hottest places in the world.

Temperature Normals.—The daily normals of a station are the averages of each day of the year for a period of not less than ten years. The monthly normal is the average for the particular month for not less than the same length of time; the yearly normal is computed from an average of the monthly normals. It is the custom of Weather Bureau stations to extend the computation of the means to the end of succes-

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[1] If the figures are authentic, the absolute range for the earth, so far as is known, is 217 degrees.

sive years[1] but normals once established seldom change materially.

It is the custom of many observers to note, as a part of the daily record, the number of degrees above or below the daily normal; this is the "departure from the normal." If below the normal the number is prefixed by a minus sign. It is an excellent plan to carry the algebraic sum of the daily departures to the end of the year. Many of the daily neswpapers desire these figures as a matter of public interest.

The monthly normals, by comparison, furnish the most instructive data concerning the temperature conditions of a given locality. Thus the January mean at Devils Lake, North Dakota, is 0°; at New Orleans it is 53°. The one is an inland station in comparatively high latitude; the other is practically a coast station in much lower latitude. The January mean of San Francisco is 50°; that of New York is 30°. Both are coast stations, but San Francisco is warmed by ocean winds. For the eastern part of the United States, the coast stations excepted, January normals are not far from 30°, and July normals range from 70° to 75°. At Moorhead, Minnesota, the summer mean is 67°; at San Francisco, 58°; at Seattle, 63°; at New Orleans, 81°; at Key West, 83°; at Yuma, 90°. A few stations excepted, January is the coldest and July the warmest month.

Temperature and Prevailing Winds.— Land winds are marked by great ranges in temperature. In regions far from the sea, changing winds are far more frequent than in maritime regions. Some of these winds, like the anticyclones which bring cold waves, are widespread in prevalence; others, like the simoon, an intensely hot and dry wind, are confined mainly to desert regions.

Throughout the greater part of Europe and the United States, westerly winds prevail; in summer they are frequently from the southwest, and in winter mainly from the northwest. The Pacific Coast of the United States receives ocean winds, and the winters are mild; west of the high mountain ranges zero temperatures rarely if ever occur. Along the coast, summer

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[1] Bulletin R, U. S. Weather Bureau, the first edition in 1908, contains the normals of nearly two hundred stations computed by Professor Frank H. Bigelow. The changes since that time are very slight.

temperatures are never high; towards the foot-hills they occasionally exceed 100°.

East of the Rocky Mountains moist, southerly winds are common during the summer months, and occasionally these extend to the northern border. In the southern half of the United States the prevailing winds are persistent, moist, and hot. In the northern part they are not so moist, but very warm. Rhode Island and Delaware possibly excepted, summer temperatures of 100° and over occur in every state, when hot westerly winds prevail for a few days.

It is obvious that sea winds are more equable in temperature than land winds. Thus, summer days in San Francisco do not often reach 90°, and freezing weather occurs perhaps two or three times in a decade. When such temperatures occur they come almost always with land winds. The normal wind at this station is from the Pacific Ocean. In New York City, on the other hand, prevailing winds are land winds; and within a period of eight months a range of 115 degrees, −13° and 102°, has occurred.

Temperature and Radiation.—Very dry, clear air permits the sun's rays to pass readily to the earth with but little perceptible loss—that is, dry, clean air is diathermous to the heat rays that impart the feeling of warmth to living bodies.[1] The heat is in turn absorbed by the earth. Earth temperature at the surface, or to a depth of an inch or two, may be many degrees higher than that of the air. Thus, in desert regions, pieces of metal lying on the ground in the sun become so hot they cannot be held in the hand. All this is due to the absorption of rays to which the air is diathermous.

But if dry, clean air permits excessive absorption, it also

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[1] Not all the heat rays impart the feeling of warmth; in many instances, they blister and burn the skin without imparting this sensation. It is thought that heat of this character consists of wave-lengths which, though they may destroy living tissue of certain kinds, do not stimulate the nerves to which the temperature sense responds. Thus, in popular tradition, there is "sensible" and also "insensible" heat. These terms, though inexact, are not without meaning. On dry, winter days, the flagstones of a sidewalk frequently absorb enough heat to melt ice and snow, even though the temperature of the air is as low as 20°; and occasionally side walks and hard-paved streets are slushy with the thermometer scarcely above 25°.

permits rapid radiation. The nights, in regions of very dry air, may be bitterly cold although mid-afternoon has been intolerably hot; indeed, at considerable altitudes, freezing temperatures during summer nights are not unknown in desert regions.

Both the moisture and the dust and smoke content of the air modify the absorption of the sun's heat and its radiation by the earth. The moisture and, to a less extent, the dust and smoke content of the air absorb a considerable and likewise a measureable part of the heat that passes readily through dry clean air. And if they intercept and retard the passage of heat coming to the earth, they also retard radiation from the earth at night. In other words, the amount of insolation—that is, of solar heat—received at the earth's surface is quite as variable as is the daily range; indeed, it is the highest expression of the daily range. At sea level dry air does not always indicate warm days and cool nights; but at levels of 5000 feet or more this is the rule rather than the exception. At any level, changes in temperature are more rapid in dry than in moist air, and the reason therefor is obvious.

Over areas of moist air a considerable part of the heat of insolation is absorbed in another way. Almost always in such areas there is a considerable water in the form of mist—that is, minute droplets of water. When the sun's warmth converts these to vapor the absorbed heat becomes latent heat, and no longer appears as sensible heat. This fact furnishes another reason why the air over desert regions, as well as the ground surface itself, becomes heated to a higher degree.[1]

Conditions of temperature exercise a great control, not only over civilization, but over the distribution of life itself. Humanity may overcome its environment so far as temperature is concerned—man can command fire, food, and fuel to be brought to him; but other forms of life cannot rise superior to conditions of temperature. The line beyond which grass will not grow is determined in part by temperature; it marks the limit beyond which grazing animals cannot thrive, and, with a

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[1] A moist surface, and very moist air as well, does not have a temperture materially higher than the wet-bulb thermometer; a dry surface, or very dry air, acquires a temperature approximating that registered by the black-bulb thermometer.

few exceptions, cannot survive. Conditions of temperature, such as obtain in the temperate zones, stimulate both the bodily and the mental faculties of humanity.[1] Therefore they have resulted in a civilization fundamentally different from that of tropical regions.

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[1] "Every species of plant and animal has an optimum temperature at which it thrives most vigorously, and man is no exception. The optimum may vary a little from individual to individual, but not much. It is more likely to vary from one type of activity to another. For physical health among the white race as a whole, the best temperature is an average of 64° F for day and night together. In other words, people's health and strength are greatest when the temperature drops to about 56° to 60° at night, and rises to somewhere between 68° and 72° during the middle of the day. For mental activity the temperature is much lower than for physical, being an average of approximately 40°. In other words, people's minds are most alert and inventive when the temperature falls to about freezing at night and rises to 45° or 50° by day."—*Huntington and Cushing's Human Geography.*

CHAPTER V

THE AIR: THE DISTRIBUTION OF PRESSURE

Measurement of Atmospheric Pressure.—Practically all the movements of the air are due to differences in its temperature; but, inasmuch as differences in temperature result in differences in the density of the air, it is convenient to express such differences in terms denoting the force with which the air presses upon the earth at sea level. It is also more convenient in weather science to express this pressure in terms of the length of a column of mercury which the air balances—that is, a *barometer*.[1]

Thus, a column of air 1 square inch in cross-section weighs at sea level about 14.7 lbs., or 1 *atmosphere*. It balances a column of mercury of the same sectional area, 29.92 inches in length. In metric terms, the weight of a column of air 1 square centimeter in sectional area is 1033.3 grams, and it balances a column of mercury 760 millimeters in length.[2] The length of a column of water which balances a column of air of the same sectional area is about 34 feet.

Distribution of Pressure.—The movements of the air caused by heating, cooling, expansion and contraction include the general or planetary movements, as well as the massing of the air in one locality and the counterbalancing depressions formed in another. The expansion of the air by heating has been determined many times. If 1000 parts of air at 32° F be heated to 33° F, its volume will be increased 2.035 parts; at 50° F the increase will be 36.63 parts; at 130° F, a temperature very common under a summer sun, the 1000 parts will become 1199.43

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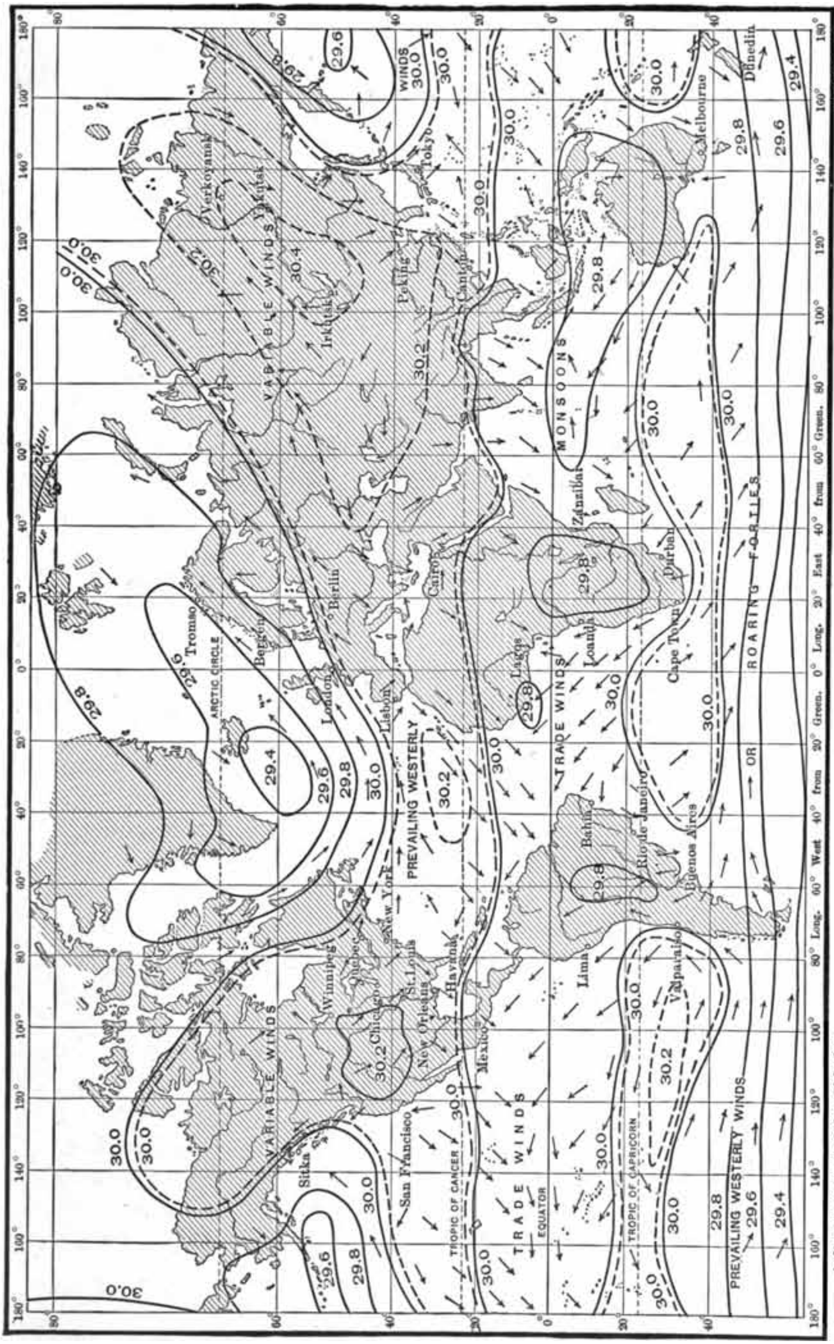
[1] From two Greek words meaning "measure of weight."

[2] British observers usually express the pressure of the atmosphere in *millibars:* 1 inch = 33.864 mb; 1 mb = 0.02953 inch; therefore at 29.53 inches, the barometer reading is 1000 mb. At 29.92 inches, or 1 atmosphere, the barometer reading is 1013.2 mb. In certain computations, the millibar scale of the barometer possesses many conveniences.



Pressure and winds in January.

—— indicates pressures below 30 inches

parts. In centigrade terms, the increment is 0.00037 for each degree, measured from the absolute zero. Small as seems the rate of expansion, the actual increment over a continent, even for a rise of temperature of a few degrees, must be measured in terms of cubic miles, and its aggregate weight in millions of tons.

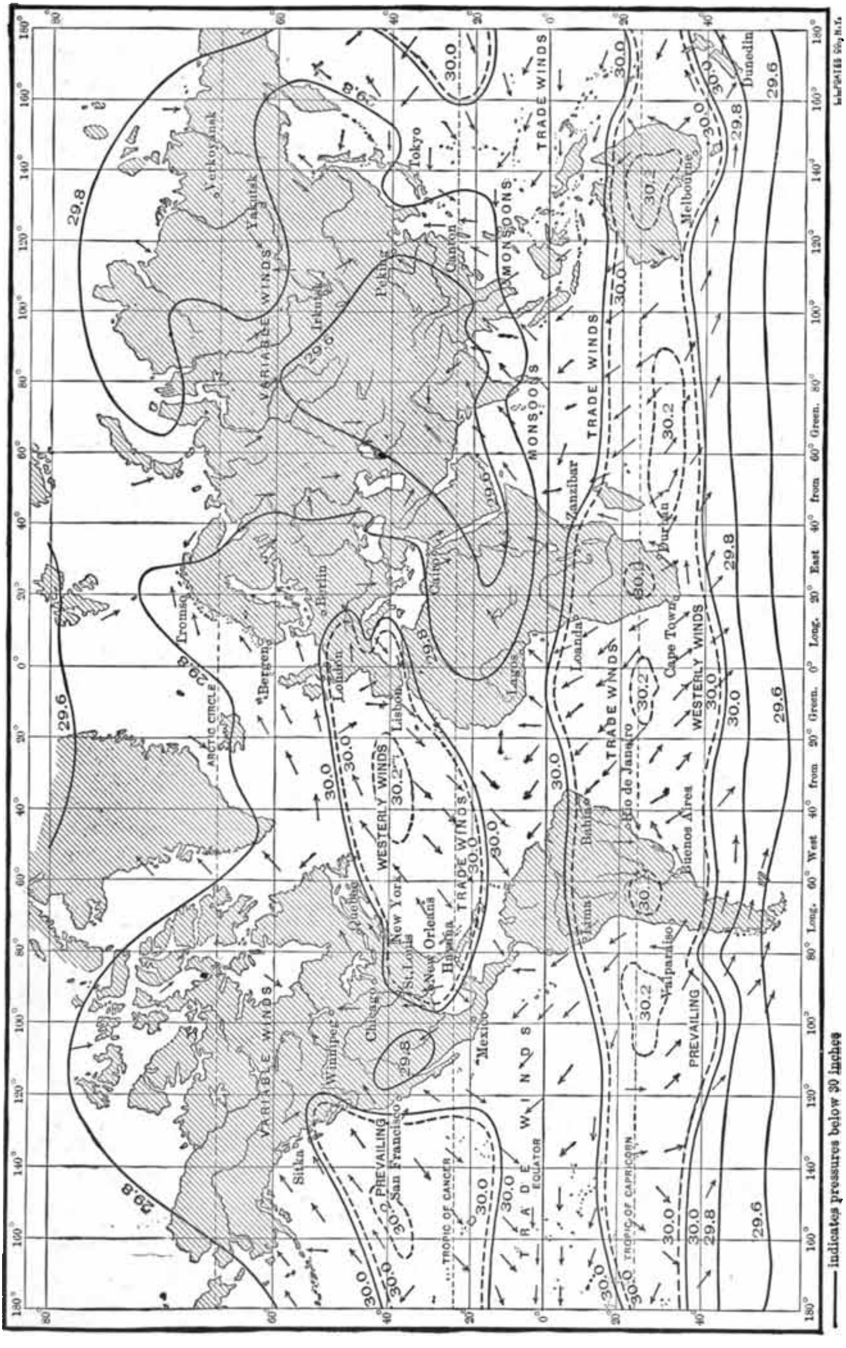
Observations show that the mean pressure over the earth varies from season to season; at any given locality existing pressure varies from hour to hour. It also varies according to latitude; but the variation for latitude is not regular. The maps on pages 40 and 42 show the several regions of high pressure. They show also that the pressure in these regions in January is slightly lower than in July. The regions of summer high pressure are situated in latitude 30° to 35° north and south.

The southerly regions cover the ocean and, for the greater part, are far removed from human activities. The northerly regions are of great importance from the fact that they modify the climate, the one of North America, the other of Europe and Asia.

The North Pacific high covers ocean waters in July, and it tends to carry cool air to the adjacent coast. In January it covers the western part of Canada and at times pours an enormous volume of cold air over the greater part of the United States.

The North Atlantic high covers western Asia in January; in July it covers the ocean east of the United States. At times, the area of maximum pressure, 30.30 inches (1026 mb) or more, is close enough to the continental coast to retard the easterly flow of air and cause a pretty general stagnation of air over the eastern part of the United States. It is therefore a feature in the formation of hot spells over that region.

The area covered by the North Pacific has a January pressure of 30.20 inches and a July pressure of 30.30 inches (1026 mb). The Bermuda, or Atlantic high, is about 30.25 inches (1024 mb); over Siberia, however, the winter high is not far from 30.50 inches (1033 mb). It is thought that the two zones of high pressure in mid latitudes are due to the descent of the upper currents that constituted the updraught in equatorial regions. This is denied by many meteorologists, however.



— indicates pressures below 30 inches

Pressure and winds in July.

The areas of low pressure are much larger in extent than those of high pressure and, as a rule, they are not so well defined. The area of lowest pressure is in the south polar region; it is inclosed by the sixtieth parallel; its mean pressure is 29.40 inches (996 mb). A low pressure area in the North Atlantic lies east of Greenland; a similar low pressure area in the North Pacific covers Bering Sea.

The zone of ascending air currents in equatorial regions is a region of low pressure. Its mean, summer and winter, does not vary much from 29.80 inches (1009 mb). Indeed, the changes in pressure from month to month throughout tropical regions are very slight. The ascending currents in equatorial regions and the descending currents near the tropics are assumed to exist. Their existence, established circumstantially rather than positively, explains satisfactorily the position of the constant highs and lows.

The great differences between summer temperature and winter temperature explain the apparent shifting of each summer high from a position over the ocean in summer to one over the nearby continent in winter. Cold air is heavier than warm air; and, in the latitude of the constant highs, the temperature of the air over the land in winter is much lower than over the ocean; in the summer, on the other hand, the temperature is lower over the ocean. In each case the high forms in the region of lower temperature.

Mean Pressure over the Earth.—It is customary to reduce all pressure observations used for comparison to a sea level basis and to a temperature of 32° F (0° C). The maps, pages 40 and 42, show the marked variations in pressure that are seasonal. From these pressures the mean pressure over the earth has been calculated by meteorologists to be between 29.90 and 29.85 inches. W. M. Davis has calculated the mean pressure over the northern and the southern hemispheres, for the summer and the winter months, deducing the following values: 29.99 inches (1016 mb) for January and 29.87 inches (1012 mb) for July in the northern hemisphere; 2991 inches (1013 mb) in July (midwinter) and 29.79 inches (1009 mb) in January (midsummer) in the southern hemisphere.

The determination of mean pressure over each of the two hemispheres is more important than that of the mean pressure of the earth as a whole. The fact that the pressure over the southern hemisphere is lowest at the time when it is highest over the northern hemisphere, and vice versa, indicates the shifting of an enormous volume and weight of air from one hemisphere to the other, twice a year. Davis estimates that the weight of air thus moved is equivalent to a pressure of 0.12 inch (4.1 mb), or between 30 and 35 million tons in weight.

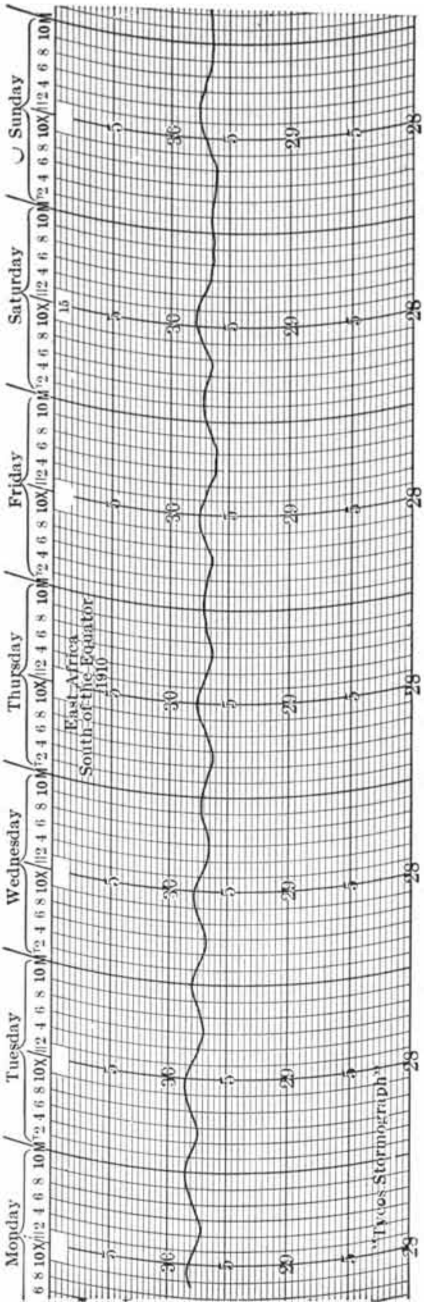
Density.—It is evident that a close relation exists between the temperature, pressure and density of the air. With lowering temperature, the volume of air contracts, and air flows in to equalize the loss. The cold air contains a greater number of molecules per given volume and therefore its density is increased; because it contains more matter per given volume its weight, and therefore its pressure is increased. Density varies directly with pressure and inversely with temperature. It also varies inversely with the moisture content of the air.

For the greater part, human activities are carried on at the plane of contact, where earth and air meet. Weather science, however, includes a study of density and pressure at all observable altitudes from sea level upward. Density of the air at different heights also affects air flight and the flight of projectiles. Hence, a knowledge of the density of the air at different altitudes is necessary.

The changes in the density of the air are most marked at the earth's surface. The daily range in density may be as much as 10 per cent, and the extreme range in a year has exceeded 20 per cent. The range is greatest in temperate latitudes at or near sea level. The changes in density due to temperature variations explain the high midwinter pressure over inland regions and the high midsummer pressure in oceanic regions; the rock envelope of the earth radiates its heat more rapidly than does the water. Very low temperatures in winter increase the density of the air. High temperatures in summer decrease the density, with the result that oceanic regions are cooler in summer and warmer in winter than far-inland continental regions.

Diurnal and Semi-Diurnal Changes in Pressure.—At stations of considerable elevation a maximum daily pressure at the warmest part of the day is observable. It is attributed to the heating of the air, thereby causing an accumulation which practically forms the crest of the wave of greatest warmth. During the coldest hours of the day a reverse movement takes place and forms a corresponding trough of pressure. This diurnal maximum and minimum of pressure is practically a raising and lowering of the center of mass. As a result, a greater mass means greater pressure, and vice versa.

The semi-diurnal maximum and minimum is very regular and obtains in every part of the earth. It is best studied from the barogram, a strip of paper attached to the revolving drum of a recording barometer. The line drawn by the barograph pen shows a slight rise above mean pressure at 10 o'clock, morning and night, followed by a depression at



After Jameson.

The barogram of a quiet week in equatorial regions, showing the semi-diurnal oscillations in pressure. The maximum at 12 o'clock instead of 10 o'clock is due to clock time instead of solar time.

4 o'clock, morning and afternoon. These oscillations in pressure are probably due to the waves of temperature which ceaselessly follow the sun with the rotation of the earth.

The semi-diurnal maxima and minima are greatest in equatorial latitudes; they decrease in higher latitudes. According to the observations of General Greely, the oscillations of the barograph pen were scarcely noticeable in polar regions. The amplitude of oscillation is greater by day than by night; it is greater at the equinoxes than at the solstices. The day amplitude is greater over the continents than over the sea; the night amplitude is the reverse. According to Humphreys, the whole atmospheric shell vibrates in waves which happen to be in 12-hour wave lengths. Records made by P. R. Jameson on the East African Coast near the equator show a maximum of about 0.025 inch above and the same minimum below normal pressure.[1] In tropical regions the irregular variations in pressure are infrequent; the semi-diurnal oscillations, on the other hand, are very regular. The claim that an observer can tell the time of day by the barometric pressure is not without foundation.

Other Variations in Pressure.—Pressure ranges exceeding 1.5 inches during a week—the record of a barograph sheet—are not uncommon. Weekly and monthly ranges are usually much greater in winter than in summer and much greater in mid-latitudes than in low or high latitudes. Professor Mohn has summarized as follows:[2] The barometer is high when the air is cold, when it is dry, and when an upper current flows into a given area. It is low when the lower air is heated, when it is damp, and when it has an upward movement.

The variations in pressure with which weather science is chiefly concerned are the daily *highs* and *lows* which cross the continents in mid-latitudes from west to east and, for the greater part, are lost in mid-ocean. These great billows of the atmosphere are comparable to the billows of the sea; but, as is shown in Chapter XIII, the lows are usually storm centers and the highs are rapidly moving masses of cold air. The former are the cyclones of the forecaster; the latter, the anticyclones.

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[1] At Mount Vernon, N. Y., Lat 40° 54′, the values are approximately 0.022 inch—possibly less.

[2] Grundzüge der Meteorologie.

When accompanied by rain or by snow they are the "storms" of popular tradition. Local disturbances, such as tornadoes, water spouts and thunder-storms, usually affect pressure, and leave each its record on the sheet of the recording barometer. Observers learn quickly to interpret these records.

Isobars and Gradients.—The distribution of pressure is best shown by means of lines drawn on a map through adjacent points having the same pressure. These lines are *isobars*. The maps, pp. 40 and 42, show midwinter and midsummer isobars. For the sake of comparison, the figures are reduced to the basis of sea level and temperature of 32° F (0° C). The isobars on the daily weather map show the respective positions of highs and lows, and from them the daily forecasts are made.

On the daily weather map the conditions of pressure are interpreted by a study of the relative positions of the isobars, which constitute a contour map of the air. If the isobars of a high, or of a low, are close to one another, the slope of the air wave is steep; if far apart, the slope is gentle. Therefore, in either case, they show the gradient of pressure, and from the gradient of pressure an approximate velocity of the wind may be indicated.

About half a century ago, Whipple, of Kew Observatory, prepared an empiric table based upon isobars 15 nautical miles apart—that is, a 15-mile gradient. If, for instance, the gradient is 0.1 inch, the indicated velocity of the wind will be approximately 9 miles per hour; if 0.2 inch, it will be about 17 miles per hour, etc. The study of the pressure gradient, therefore, is a fairly accurate indication of wind velocity. It also enables the observer to make a reasonably accurate forecast of wind velocity from twenty-four to thirty-six hours in advance.

Actual and Recorded Pressure.—Pressure decreases with altitude, at a varying rate. If the lowest of a pile of ten books is lifted, the weight of the nine books above it must be overcome; but if the fifth book is lifted, the weight of only four books must be overcome. The same principle applies to the atmosphere. At sea level a column of air 1 square inch in cross-section, presses with a weight of 14.7 lbs., but at a height of 19,000 feet the weight of the column is only half as great. For the first few hundred feet above sea level the pressure decreases at the rate of 0.1 inch for each 90 feet of ascent; at an altitude of 3000 feet it is at the rate of 0.1 inch for 100 feet of ascept. The greater number of weather stations in the United States are 1000 feet or more above sea level, and many of those west of the Denver meridian are more than 5000 feet above sea level.

For purposes of comparison in the preparation of daily weather maps, all pressure observations are reduced to sea level basis. For this purpose such a reduction is necessary, and all reduced pressures within an altitude of a few hundred feet of sea level are sufficiently correct for practical purposes. For altitudes materially greater than 1000 feet, the results when applied to mean pressure, are erroneous. Thus, at Mount Washington, the mean recorded pressure for January, reduced to sea level, is greater than that for July. As a matter of fact, the actual mean pressure is less in January than in July. The following illustration will explain:

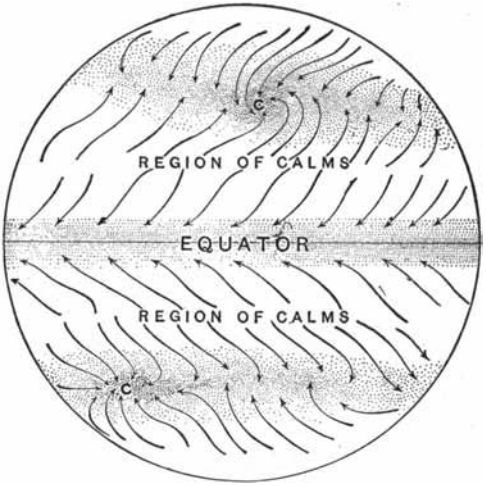
A compress 12 feet in height is filled with loose cotton. The pressure of its weight at the bottom is, say, 16 lbs. per square foot. Half way to the top, at the 6-foot level, the pressure is half as much. Now let us assume that the cotton is compressed so that its depth is only 9 feet. The pressure at the bottom remains the same; but at the 6-foot level, there is only half as much cotton as before compression; hence the pressure is half as great. The center of mass has been lowered in the process of compression.

The same principle applies in the case of measurements of the atmosphere. Thus, at Mount Washington, and at other stations of considerable altitude, expansion due to temperature-increase raises the center of mass in summer; mean pressure, therefore, is raised. In winter, low temperature causes contraction, lowering the center of mass and therefore the pressure. In other words, while sea level and also the observer's station are at fixed altitudes, the center of mass is a varying altitude; it is raised by increasing temperature and lowered by decreasing temperature. Hence its effect on mean pressure.

CHAPTER VI

THE AIR: MAJOR CIRCULATION: LOCAL WINDS

The convectional or vertical movements of the air have been mentioned incidentally as affecting the diffusion of warmth. They are considered in detail in succeeding chapters. The horizontal movements constitute the *winds*. So far as human activities are concerned, the general horizontal movements consist of a broad tropical belt of easterly winds flanked on the north and on the south by a broad belt of westerly winds. The three belts move northward with the apparent motion of the sun northward in June, and southward in December. The yearly oscillation covers about 120 degrees of latitude, a total of about 7200 nautical miles.



Redway's Physical Geography.

General movements of the atmosphere.

Trade Winds.—The broad belt of easterly winds within the tropics is popularly known as the *Trade Winds*. Their direction is southwesterly in the northern and northwesterly in the southern part of the belt. The heating of the air in equatorial regions causes a convectional updraught; and this is balanced by an inflow of air from higher latitudes. The rotation of the earth deflects the movement of the air, giving a westerly motion to the winds. Their force and direction are best studied from the monthly pilot charts published by the United States Hydrographic Office. Although the pilot charts refer specifically to ocean winds, the general information published, so far as wind direction is concerned, applies to land winds also.

The strength of the Trade Winds varies according to latitude and also according to season. The velocity is highest near the edges of the belt and lowest at its center; it varies from about 8 miles per hour in the fall months to about twice this rate in the spring and summer months. The southeast winds are materially stronger than the northeast winds. The easterly component is the important commercial factor—hence the popular name. For the year their average is from 11 to 14 miles per hour, or from 2 to 3, Beaufort scale.[1] On the Pacific Ocean the Trade Winds are neither so strong nor so regular as in the Atlantic; on the Indian Ocean only the southern part of the belt is observable.

Prevailing Westerlies.—The two broad belts which flank the Trade Winds are variously named "Counter Trades," "Return Trades," and "Anti-Trades." Their direction varies—northeast, east, and southeast as shown on the pilot charts, and their strength is indicated by the arrows. In the southern hemisphere because of their strength, they are known, as the "Roaring Forties." In the days of sailing vessels, a ship from a port of Europe to Australia could usually make the return trip more expeditiously by way of Cape Horn. The force of the Prevailing Westerlies is from 2 to 4, Beaufort scale.

The Prevailing Westerlies begin as an upper wind in Trade Wind latitudes, descending to sea level at the edges of the Trade Wind belt, approximately Lat. 30° N. and S. Over Cuba the airman may find them at the height of about 11,500 feet; over Jamaica about 19,500 feet; and over Trinidad about

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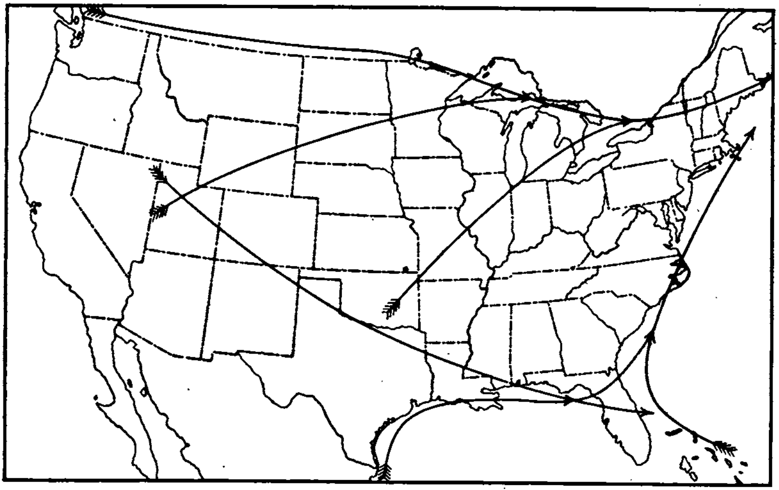
[1] Table, page 240.

26,000 feet. In each case the height of the Prevailing Westerlies is also the depth of the Trade Wind belt.

Winds of the United States.—The main body of the United States is situated in the belt of Prevailing Westerlies. The prevailing surface winds therefore are northwest, west, and southwest. East of the Missouri River northwest winds prevail except during the hottest part of summer when southwest winds are the rule. These include practically all the winds of various altitudes between sea level and the summit of Mount Washington (6293 feet), one of the highest points east of the Mississippi River.



Tracks of cyclonic storms preceded by easterly and followed by westerly winds.

South of the thirty-first parallel the influence of the Trade Winds is very apparent, and the prevailing winds in summer vary from northeasterly to easterly. Along the coast this influence extends much higher than the thirty-first parallel, and northeasterly fair weather winds occur at times as far north as the Maine Coast.

West of the Mississippi River to the Rocky Mountains, the winds vary from southwesterly to northwesterly. They are steadier and stronger than those east of the Mississippi River. Southwesterly winds prevail much of the time.

From the Atlantic Coast to the Rocky Mountains the general westerly direction of the winds prevails pretty steadily, except as it is upset occasionally by cyclonic storm winds.

In the plateau region and the basin, the upper winds are westerly—southwest to northwest; but the surface winds in many instances are deflected by mountain ranges and become either southerly or northerly.

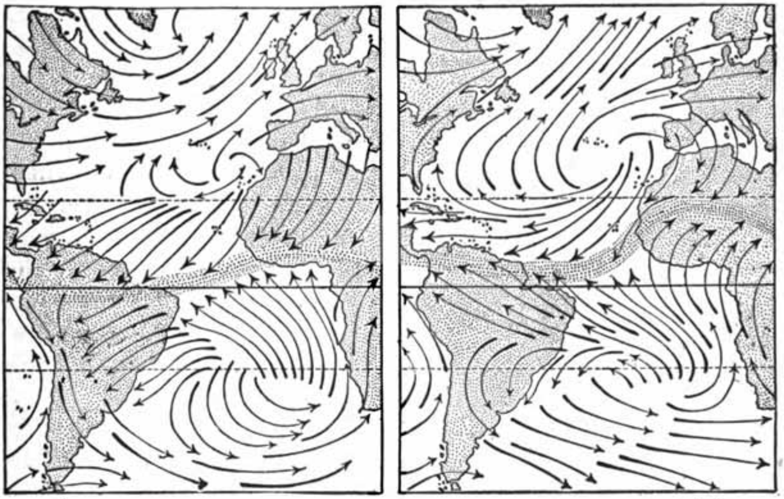
The surface winds of the Pacific Coast are westerly; but in the Sacramento and San Joaquin valleys they become northerly or southerly, being deflected by the mountain ranges. When the temperature of the interior is high, strong westerly winds are the rule along the coast. This is especially noticeable in the vicinity of San Francisco.

Monsoons.—The monsoons are seasonal winds which blow from the sea over the land during summer months and in an opposite direction during winter months. The name, meaning "season," was first applied to the seasonal winds of the Indian Ocean Coast; subsequently it was applied to various seasonal winds of ocean coasts. In southern Asia the crop yield depends very largely on the rainfall which accompanies the southwest monsoon; hence its importance in the economic history of a considerable part of southern Asia.

The advance and recession of the Trade Wind belt along the Gulf Coast of the United States seems to emphasize a similar alternation of sea wind and land wind; but the monsoon characteristics extend as far north as Long Island Sound on the north and far into Mexico on the south. In the latitude of New York City, about eight weeks of southwesterly winds prevail in summer, while northwest winds prevail the rest of the year.

Calm Belts.—Along the narrow belt where the northeast and the southeast Trade Winds meet, the easterly components of the winds disappear, the only movement being an updraught. In the days of sailing vessels ships sometimes lay becalmed for many days—hence the expressive name, *Doldrums*. This calm belt lies north of the equator and practically covers the thermal equator. It is a region of low barometer, very moist air, cumulus clouds and excessive rains. It is practically coincident with the tropical rain-belt. Its detrimental effects on marine transportation ceased with the advent of steam navigation. Years ago it was a terror to sailing craft.

The *Calms of Cancer* and of *Capricorn* separate the belts of prevailing westerly winds from the Trade Wind belt. They are regions of high pressure and usually of cloudless skies. Vessels from ports of Europe and the United States crossed the Calms of Cancer when making West Indian ports. These calms were therefore a great drawback to commerce. Steam navigation has eliminated the waste of time and the loss of jettisoned cargoes;[1] but conditions more or less detrimental, which humanity cannot overcome, still exist. Much of the southwestern part of the United States and northern Mexico are covered by the high-pressure Calms of Cancer, and, at a little distance from the ocean coasts, rain-bearing winds are infrequent. Similarly, the sparse rainfall of parts of South America is due to the Calms of Capricorn.


January *July*

Redway's Physical Geography.

Winds of the Atlantic.

Local Winds.—The local winds of a region appeal to a community more forcibly than do the general movements. One may not appreciate the fact that the habitability of a region

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[1] On various occasions vessels whose cargoes consisted of horses were becalmed in this region. When the supply of water gave out the horses were thrown overboard—hence the name "horse latitudes."

depends very largely upon the general movements of the air; but no one can fail to realize the importance of a hot blast, a blizzard, a tornado or a sand storm—or, indeed, of any occasional storm wind that may injure growing crops and destroy property.

Along coasts, the *sea breeze* and the alternating *land breeze* are the rule rather than the exception during a considerable part of the year. As a rule, the sea breeze extends rarely higher than 3000 feet. At such times it may be merely a cross-wind, and the clouds at a height of a mile may be moving in an opposite direction. The succeeding land breeze which sets in is apt to be a much stronger wind.

Mountain Valley Winds are common in all mountain regions. During the day, when the air is growing warmer, the wind blows up the valley; at night, when it is losing its heat the flow is down the valley. In narrow canyons, the night winds may be very strong—a force of 6 to 7 of the Beaufort scale.

The *Chinook*, one of the most important local winds, derives its name from the jargon of a tribe of Indians living near the mouth of the Columbia River. According to tradition the name means "snow-eater," from the fact that, with its appearance, the snow begins to melt first from the higher parts of the mountain slopes and, last of all, from flood plains and valley floors.

The Chinook was made known first by early settlers in Oregon. In time it was found to exist throughout much of the montane part of the northwest. The Chinook begins as a moist wind on the windward side of a high range. As it is pushed upward along the mountain slope it is chilled by expansion below the dew-point, and condensation takes place. This liberates a great deal of latent heat, materially warming the air. The air is warmed still further by compression as it rolls down the leeward slope of the range.

In Montana, Idaho and Alberta, the Chinook wind is far-reaching in its climatic effects. Both grazing and wheat-growing are made possible in regions that otherwise would be unproductive. The Chinook wind does not differ from the Foehn wind of Europe with which it is classed. In each case moist air drawn into a cyclone and pushed over a range, descends on the other side as a warm, dry wind.

The *Hot Winds* of the Plains, including the *Summer Winds* of Texas, and the *Norther* of the San Joaquin-Sacramento Valleys are classed among the "destroyers," from the fact that, in many localities, two or three days of their duration is fatal to growing crops.

The *Santa Ana* of southern California is the outpouring of a hot, dust-laden desert wind through one or more of the mountain passes. In the past thirty-five years, irrigation and cultivation have been extended into the arid region, with a result that the Santa Ana is largely deprived of its dust content and its high temperature. The Santa Ana in its old time vigor was merely the edge of a desert *simoon* that intruded upon nearby fertile lands. The simoon itself occurs in every desert so far as is known. It is a sand storm because of its velocity. In the Colorado and Mohave deserts the simoon may have a velocity exceeding 75 miles an hour. The *Washoe Zephyr* of the Basin Region of the United States, and the *Khamsin* of Egypt are desert winds of the same kind. They are thought to be cyclonic in character, but practically they are dust-laden winds, either blowing into a desert, or out of a desert.

The *Texas Northers* are biting cold winds, common to the high western plains of the United States and northern Mexico. They usually follow warm and balmy winds of southerly direction. The onset may be very sudden. A fall of temperature of 50 degrees within a day is not uncommon. The *Bora* and the *Mistral* of the Mediterranean coast of Europe are similar in character; they are cold winds sliding down the steep mountain slopes because of increasing pressure to the northward. In the southern hemisphere, the *Pampero* is the counterpart. It is most noticeable in the pampas, or great plains east of the Andes, and in many instances it extends to the coast. Although a southwest wind, it is classed with Northers because of its origin.[1] The *Blizzard* is nominally a cold-wave wind which is sufficiently vigorous to pick up and carry loose snow; it is a northwesterly wind. Popular usage applies the name to any wind of gale force that accompanies a snowstorm.

Direction and Velocity.—The diagram of the major circulation of air shows that the normal movements of winds are north-

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[1] The name is also applied to the "squall" type of descending wind accompanied by thunder and lightning, occasioned in the pampas of South America.

west, southwest, northeast, and southeast and that winds from the north, south, east or west are the exception. Winds over the land, however, are apt to be modified by local topography; and it frequently happens that a surface wind differs materially in direction from the wind at low cloud heights.

Throughout the eastern half of the United States, about half the recorded mileage of the wind is from points between north and west. Along the Gulf Coast to a distance of about 300 miles inland, winds with a southerly element of movement prevail. As a rule, the winds are strongest during the winter months and mildest in summer.[1] For the greater part, the prevailing winds of the Pacific Coast region are northwesterly. At San Diego about two-thirds of the mileage is recorded by winds blowing between west and north.

The strongest winds are apt to occur along the coasts of the sea and the Great Lakes. The mean hourly velocity at Sandy Hook, Block Island, Delaware Breakwater and Cape Mendocino exceeds 14 miles. Throughout the plains west of the Missouri River, high winds prevail. The long downward slope over a smooth surface adds to the velocity of westerly winds. During winter months the cold-wave winds from Canada contribute a mass of air which, moving eastward, gives added velocity to the winds of this region.

The latitude of strongest winds in the United States is approximately along the forty-fifth parallel in the summer and a few degrees lower in winter. Winter months are the season of the strongest winds. The winds of greatest strength, however, are storm winds—winter cold-wave blasts, or the recurved portion of West Indian hurricanes which sweep northward along the Atlantic Coast.

Other Features of General Circulation.—The foregoing paragraphs present a very elementary view of the greater circulation of the air. As a matter of fact, not much is known, even of the surface winds over a very large part of the earth.

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[1] The records of about twenty stations in the northeast quarter of the United States show the following mean velocities in miles per hour for the year:

Northwest	8.8	Northeast	5.3
West	4.6	East	4.7
Southwest	5.2	Southeast	4.8

Until within the past few years, knowledge of the upper winds was imperfect and fragmentary. Sounding balloons and kites furnished with recording apparatus are beginning to supply humanity with much-needed information concerning horizontal movements of the upper air; the airmen are furnishing knowledge of vertical movements.

Research in recent years shows that the updraught in equatorial regions is not uniform in force nor continuous at all times. Neither is the overflow of rising air toward polar regions uniform or regular. Sounding balloons occasionally have been carried toward the equator instead of away from it. Stiff west winds also have been observed in equatorial regions at the height of a few thousand feet, surmounted by easterly winds at a still greater elevation.

Sounding balloons do not find the decrease of temperature with increasing altitude to be regular; on the contrary, they encounter layers of air throughout which the temperature is practically unchanged. They also encounter other layers in which an inversion occurs—that is, the temperature rises with increasing altitude. In other words, instead of a uniform temperature gradient from ground level to stratosphere, the air consists of a succession of layers, differing in temperature, humidity and horizontal velocity of movement. Usually the planes of contact between adjacent layers are indicated by clouds.

The air of adjacent layers, or strata, does not readily mix one with the other. Smoke, dust, and cloud matter, rising to the top, or sinking to the bottom of a layer does not always penetrate the adjacent layer. In the absence of strong winds such matter is apt to spread out laterally. Moreover, the aviator, in passing from one layer to another, is apt to receive a sharp bump at the plane of contact. In meteorology the plane of contact is commonly known as a *ceiling* or *lid*.

The convectional layer of air—that is, from ground level to stratosphere—is marked by constant motion as noted, the movements consisting of general circulation, local winds and the turbulence connected with vertical movements. There seems to be no such complexity of movement in the stratosphere; indeed the knowledge of the movements of the air in the stratosphere is next to nothing. Tidal movements probably warp the shape of the shell of air composing it; but they may not cause a general circulation. The fact that the air of the stratosphere is warmer in high than in equatorial latitudes indicates that a circulation of some sort exists and that the general movement may be the reverse of that of the lower shell of air. The coldest air is over the warmest zone.

Winds Encountered by the Airman.—The marine pilot is concerned wholly with the horizontal movements of the surface air; he is not conscious of the updraughts or the downdraughts of convection. To the airman, on the other hand, the horizontal air movements are usually less of consequence than the vertical movements. Good air for flying must be free from *holes* and *bumps*.

An air hole is not a vacuous space, nor is it one in which the density of the air is abnormally low. Sometimes it is a downdraught; quite often it is convectionally still air. If the airman has been flying over hot, bare ground, where the updraught is strong, his plane takes a drop when he passes over a patch of greensward, where the updraught ceases; this is the airman's "hole." In going from convectionally still air into an updraught, he gets a "bump." The same result is apparent if, while traversing a downdraught, he strikes still air.

It has been noted that the air ranges itself in layers differing in density, temperature, and moisture content. In many cases an acquired sense born of experience enables the airman to discern these layers and to adjust the wings of his plane in encountering them. Frequently a sheet of smoke or dust separates two cloud layers and experience has taught how to avoid or how to penetrate it.

Air is either going up or coming down. Turbulent ascending currents are manifest in the rapid motion of cumulus clouds, both within the cloud and beneath it. Measurements have shown that ordinary updraughts may have a velocity of 10 feet per second; under a cumulus cloud of the thunderhead type the velocity may be as high as 40 feet per second. The updraughts that produce clouds give visible signs of their existence. Those caused during clear days by bosses of rock or by bare ground are not so easily detected. They are not apt to begin existence until the sun is high enough to heat the areas producing them; they rarely form during cloudy days.

Downdraughts are sometimes real and sometimes only apparent. In passing from an ascending current into still air the drop may be real, but the downdraught may be merely apparent. In flying from an adverse wind into a wind blowing in the direction in which the plane is moving, the drop is real but the downdraught is apparent merely.

There are actual downdraughts, however, which the airman is certain to encounter—because air going up must be balanced by air coming down. Just as water pours over a perpendicular ledge, forming thereby a cataract, so air is usually pouring over a steep scarp in a similar manner. The air over a plateau is apt to be colder than that several hundred feet below. More certainly it will be colder if it has traversed great fields of snow. When, therefore, it reaches a steep scarp it pours over the edge by virtue of its own gravity. Air-falls of this sort are common in mountainous regions, but they rarely occur in lowlands.

Billow-cloud levels may be a serious problem to the airman, not because they interfere with visibility, but because occasionally they do not do so. When billow clouds are in sight the airman may fly above them or below them. If the two wind layers have about the same degree of humidity there may be no clouds to indicate the position of the plane of contact. Once within this plane, the airman experiences a series of disconcerting bumps, due to the quick transition from one billow to another; sometimes he finds it difficult to rise to the upper layer of air.

Gusty winds, eddies and whirls occur most frequently near ground level; they rarely affect high flights. Even in low flights they are infrequent, unless the plane is within the influence of cumulus clouds. They are disconcerting in making sharp turns and they may be dangerous in making a landing.

CHAPTER VII

THE MOISTURE OF THE AIR: EVAPORATION AND CONDENSATION

Water vapor and floating dust are components of the air which vary from day to day and even from hour to hour. All the waters of the land are derived from the water vapor of the air; and this in turn is brought from the oceans. Inasmuch as life in its various forms depends on the process whereby ocean waters are taken into the air and are dropped upon the land as rain or as snow, the study of the water vapor content of the air is of vital importance to humanity. Before the waters of the sea can be poured over the land, several distinct processes take place: *Evaporation*, *diffusion*, *condensation*, and *precipitation*.

Evaporation.—It is assumed that the molecules of a volume of water are in constant motion among themselves. Some of the molecules at the surface are in such rapid motion that they bombard themselves into the air, thereby becoming a part of it. This loss to the water goes on at all ordinary temperatures and even at very low temperatures. At 212° F (100° C) the pressure, or tension of the vapor is as great as that of the air, and the water is said to *boil*.

In meteorology, evaporation is a term applied practically to the net loss of water, or other liquid exposed to the air. Free water surfaces, soil and vegetation have each their problems; meteorology is concerned chiefly with evaporation from a free surface of water. *Diffusion* of the water vapor derived from the ocean, and from bodies of fresh water, is so universal that in no part of the earth is the air free from water vapor.

Various conditions affect evaporation. Under ordinary conditions of light winds and moderately dry air the rate of evaporation is proportional to the surface.[1] It is also directly

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[1] In still air over a circular area evaporation increases as the square root of the area; with a horizontal wind it varies approximately in theory, at least, as the three-fourth power of the area. If the rate be calculated in direct proportion to the area, the result will not be materially incorrect.

proportional to the difference in the readings of the dry bulb and the wet bulb of a sling psychrometer. Evaporation increases very rapidly with a dry wind[1] and more slowly as the relative humidity of the air increases. It increases rapidly with rising temperature and decreases with falling temperature. It increases inversely with barometric pressure. The rate of evaporation of sea water is about 95 per cent that of fresh water, all other conditions being the same.

Condensation.—The process whereby water vapor changes to a liquid form is *condensation*. Condensation may occur as a result of mechanical processes, such as pressure and artificial cooling; in the free air, however, it results from cooling by contact, cooling by mixture, or cooling by expansion—practically adiabatic cooling. More definitely: warm air resting on the ground, or on the sea, may be cooled by contact therewith, until some of its moisture is condensed. An area of warm, moist air may be invaded by a cold wind and the mixing process may cool the vapor to the temperature of condensation. A body of air warmed above the temperature of the surrounding air is pushed upward. Its expansion causes adiabatic cooling and if the temperature falls below that of saturation, condensation of the water vapor occurs. Practically all the cases of condensation with which weather science has to do result from one or another of the causes named. The condensation resulting from contact causes dew and frost; that which results from mixing causes fog and cloud; that resulting from adiabatic cooling—that is, updraught—causes rain and snow. There are occasional exceptions to the foregoing, especially where superficial turbulence of the air is involved; in the main, however, these processes of condensation are fundamental in weather science.

Dust Motes and Condensation.—The invisible, floating dust motes of the air and many of the gaseous products of combustion are important factors in condensation. Each droplet of cloud or fog condenses upon a dust mote or upon a hygroscopic gas product.[2] In general, the dust motes which cool most

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[1] The rate varies approximately as the square root of the wind velocity, and as the cube of the square root of the diameter of a circular container.

[2] There are certain cases of super-saturation to which this statement is an exception; indeed, condensation is still a field for investigation.

quickly are regarded as the "most favorable" nuclei. Were it not for this feature of condensation, gentle rains would become sporadic cloudbursts. The measurement of the dust content of the air is not yet a part of the scope of weather observations, but the importance of it is universally recognized.

Conditions of Condensation and Precipitation.—In another chapter the relation of temperature to the amount of water vapor has been discussed. The absolute water vapor content of the air is the gross amount of water it contains. This is usually estimated in grains per cubic foot or in milligrams per cubic decimeter. Between the twenty-fifth and fiftieth parallels of latitude the amount of water per cubic foot averages roughly from 1 to 3 grains in winter and from 5 to 7 grains in summer—north to south. The proportion varies, however. Sea winds are wet winds; land winds are usually dry. The higher the temperature, the greater the possible absolute content of water vapor.

Condensation does not begin until the temperature of the air has reached the degree below which only a certain proportion of vapor can exist—that is, below the temperature of *saturation*, or *dew-point.* Any excess is condensed and appears in one or another of the forms noted.

Relative Humidity.—The water vapor content of the air which is not condensed is so important to life and to human comfort that its measurement is an essential part of Weather Bureau observations. The higher the temperature of the air, the greater the amount of water vapor it may contain—about 4 times as much at 70° F (21° C) as at 32° F (0° C), and 10 times as much at 100° F (38° C); hence the term *relative humidity.* This is expressed in terms of the per cent of water vapor necessary to saturation. Thus, if the relative humidity is 50 per cent, half the vapor necessary for saturation at the observed temperature is present.

Ordinarily, the humidity is highest in early morning, when the temperature is lowest; it is usually lowest at the warmest part of the day. On dewy and frosty mornings the humidity at ground level is 100 per cent; a few feet above ground it is probably at 96 per cent; during the hottest part of the day it may be as low as 30 per cent, or even lower; on cloudy days it may not vary materially during the day. During foggy weather it is practically 100 per cent.[1] During summer rainstorms it is approximately 95 per cent.

The relative humidity of the air has a profound effect upon public health. General Greely noted the fact that, during prolonged spells of very dry air when the per cent of humidity fell materially below the normal, a notable increase in the death rate followed. Dr. Ellsworth Huntington has shown that the same result is true of the death rate in hospitals.

Humanity, both the conscious and the sub-conscious self, is sensitive to changes in temperature, noting a difference even of 1 degree Fahrenheit. The conscious self rarely notices changes in humidity between 35 per cent and 85 per cent. The sub-conscious self is far more sensitive; it rebels against a condition of humidity materially higher than 75 per cent or lower than 40 per cent when the temperature of the air is that of comfort. There is a noticeable difference to the feelings between indoor and out-of-door air. Indoors, a humidity of 25 per cent is extremely uncomfortable; out of doors it is hardly perceptible.

During the winter season when buildings are artificially heated, the humidity of living-rooms is not often above 40 per cent; usually it is lower than 35 per cent; in school rooms it may be less than 25 per cent. Dr. C.-E. A. Winslow has pointed out the effect upon the health of the pupils of air so deficient in moisture.[2] P. R. Jameson, using empiric but very practical standards of measurement—that is, comfort or discomfort—has tabulated the results of several thousand tests:

Rel. Hum. 75%	55° F	very cold
	65° F	chilly
	75° F	comfortable
Rel. Hum. 50%	35° F	very cold
	50° F	chilly
	65° F	comfortable
Rel. Hum. 30%	55° F	very cold
	65° F	chilly
	75° F	comfortable

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[1] During the prevalence of a "dry fog" the humidity may be not higher than 85 per cent.

[2] Dr. Winslow has noted that the air of schoolrooms in winter is as dry as that of a desert. As a matter of fact, the air of the Gila Desert, Arizona, is rarely so dry as that of a schoolroom at 9 o'clock.

That is, with the relative humidity at 50 per cent, the temperature of comfort is 10 degrees lower than with a very dry or a moist air. These conclusions do not differ from those of Dr. Huntington.

Many manufacturers have installed humidifiers within their factories in order to provide wholesome air to their employees and a correct atmosphere for the economical production of their output. Exhaust ducts carry the air from the work rooms to the humidifier where it is screened, washed, and returned to the various rooms with but little loss of temperature. The saving in fuel very soon pays the cost of a humidifying plant.

Forms of Condensation.—The condensation of the water vapor of the air takes place in many forms—fog, cloud, dew, frost, rain, snow, and hail. The "sweating" of walls, and the film of moisture that forms on the outside of a vessel filled with iced water are also examples of condensation. In any case the cause is the same; the temperature of the air falls below the temperature of saturation and the excess of water vapor is condensed in one or another of the forms noted. The formation of fog and cloud are considered in the following chapter; hail is a feature of thunder-storms.

Dew.—Dew consists of the moisture condensed on such surfaces as radiate their warmth after sundown. If the chilling of the air next to such surfaces carries its temperature below that of saturation—that is, the "dew-point"—the excess is deposited in the form of minute droplets. Not infrequently so much moisture is deposited that foliage and grass become very wet. Vegetation radiates its heat rapidly, and therefore dew is apt to form copiously thereon. At night the temperature of the air two or three inches from the ground may be as much as 5 degrees lower than at a height of 6 feet. Dew therefore may form on grassy surfaces when none occurs on objects materially above ground.

Falling temperature at night is the rule; nevertheless, dew does not always form. The temperature may not go down to the dew-point; the absolute humidity may be very low; wind may keep the air stirring so that the air next the ground may not remain long enough to be cooled to the dew-point; low clouds may prevent the radiation of ground warmth; a "lid" also may prevent radiation. For the foregoing reasons the problems concerning the formation of dew are of much importance.

Frost.—If the temperature of the air is below freezing, the water vapor will be deposited in the form of minute crystals of ice, which reflect the light in such a manner that a silvery appearance results—the *hoar frost* of popular tradition. In some instances the moisture is doubtless deposited as dew, which afterwards is frozen. Sometimes, too, partly melted frost or slowly freezing dew forms a glazed and semi-transparent coating—the *rime* of tradition. From the nature of the case, rime is more hurtful to vegetation than is hoar frost.

When rain freezes as it falls on leaves, stalks, and twigs the ice varnish is the traditional *black frost.* Strictly speaking, it is not frost at all. It is a freezing which involves the surface of the vegetation. The superficial juices of the plant are frozen, to the extent that the cells of the plant are ruptured.

Hoar frost injures tender plants but does not necessarily kill them. Black frost, on the other hand, is apt to kill tender plants and to injure many hardy plants. A temperature as low as 25°, without frost, may be as fatal to tender plants as a black frost.

Warnings of late spring and early fall frosts are sent out from Weather Bureau stations. Close observation, however, will enable one to foretell a possible frost by watching the temperature and humidity. When the air is still, the humidity high, and the sky clear, frost may be expected if the temperature at sunset is 40° or lower; indeed, under such conditions the temperature is likely to fall to the freezing point by 2 o'clock on the following morning and to remain below freezing for a short time after sunrise.

The greater likelihood of frost in low spots, such as valley floors, as compared with the higher levels of the adjacent slopes, is an important factor in fruit farming and, in fruit-growing regions, pretty accurate surveys have been made of the lands likely to be visited by killing frosts. Nevertheless, by far the greater area of tender crops is within the region of killing frosts; hence the necessity of making use of all available knowledge in the matter.[1]

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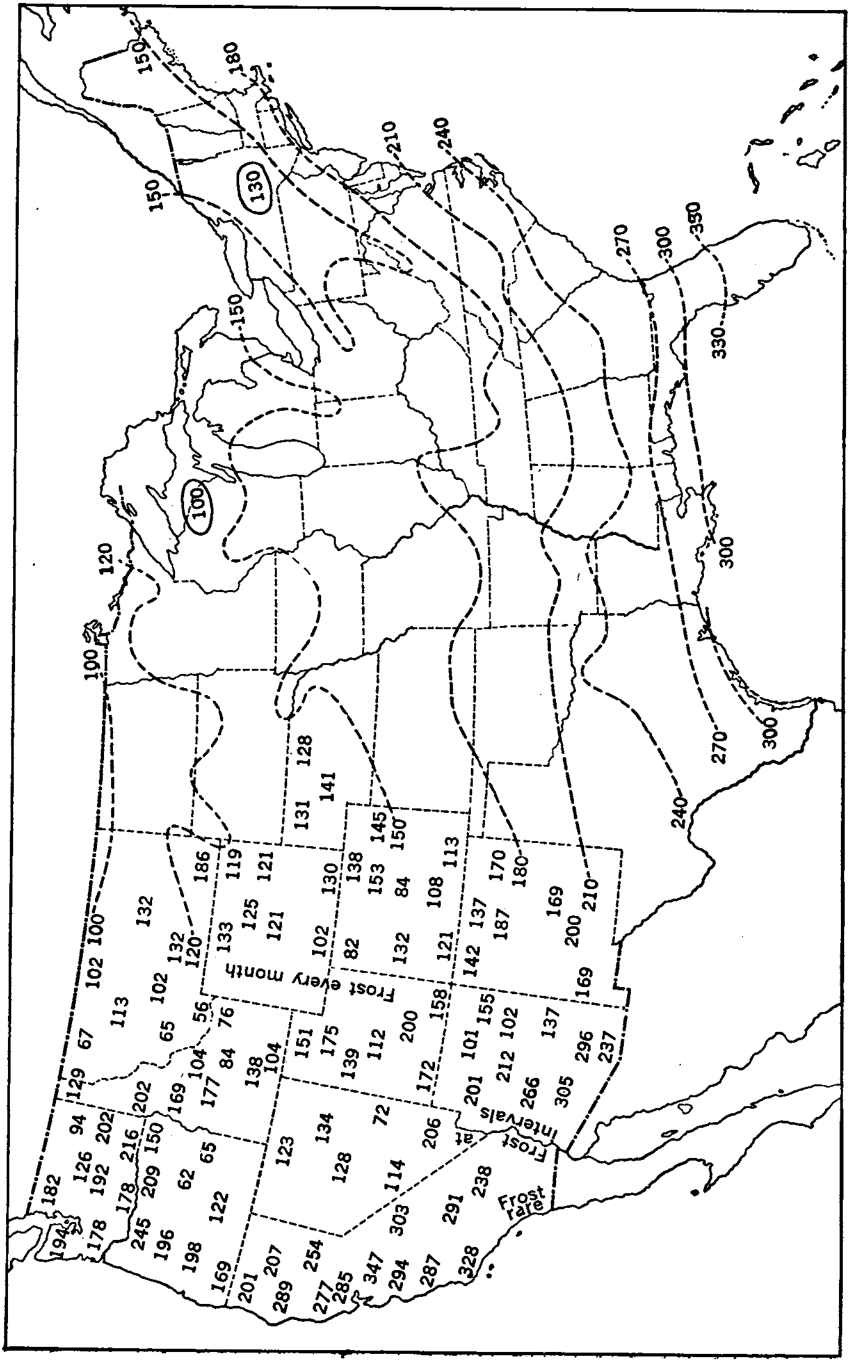
[1] Bulletin V of the U. S. Weather Bureau publications is a summary of observations collected from more than one thousand stations and sub-



After Day.

The growing season. The figures show the number of days between spring and fall frosts.

Weather Bureau records make a distinction between light frosts and *killing frosts*, the latter being so called because of their destructive effects. Ground frosts, as a rule, are not killing; the freezing temperature does not extend more than a few inches above the grass. If the freezing temperature extends so high that frost covers the roofs of buildings, the frost is apt to be killing. Records of the dates of the latest killing spring frost and the earliest killing fall frost are highly important from the fact that the number of days intervening constitutes the *growing season.*

In the latitude of the Great Lakes the growing season is from 110 days to 150 days; in the latitude of Illinois and Missouri it is from 150 days to 200 days; in the belt extending from the northern boundary of Tennessee to the Gulf it is from 200 to 300 days. Florida and Texas, south of the twenty-seventh parallel, are very rarely visited by killing frosts.

stations. The information is graphically charted on maps which show the dates of late spring and early fall frosts, the average dates of killing frosts, and the number of days between spring and fall frosts. The following paragraphs apply pretty generally to all parts of the United States:

Frost becomes more severe as one goes from hillside to low spots, such as hollows and stream valleys.

It is more severe on the grass than at shrub heights. It may form on the grass when the temperature 3 or 4 feet above ground is several degrees above the freezing-point.

If the temperature at sunset is not lower than 40° F (5° C) and the sky is overcast, frost is not likely to occur. But if the sky is clear and the wind is at calm, frost is likely.

With a brisk wind and a sky either clear or cloudy, frost is not likely to occur unless the temperature falls materially below freezing.

If the air is *moist at sunset* and the temperature is 40° F or lower, frost is likely to occur even with a light wind; but if fog occurs, enough latent heat may be set free to prevent frost. A low-lying fog is a blanket which retards radiation, not only from grass and shrubbery, but from the ground itself.

CHAPTER VIII

THE MOISTURE OF THE AIR: FOG AND CLOUD

FOG

In his "Floating Matter of the Air" Tyndall demonstrated that, when the air pressure under the receiver of an air pump was reduced, the cooling of the air by expansion produced a perceptible fog. He demonstrated also that, if the air admitted to the receiver were filtered, a second exhaustion would produce a fog only to an extent scarcely observable, or not at all. In other words, the dust motes and molecules of hygroscopic gases are necessary for condensation. When there were no longer any dust motes, there was no condensation.

Fog and cloud are the most striking examples of condensation on a large scale; in weather science it is commonly called *volume condensation*. One cannot readily make a distinction between fog and cloud; in general, fog is cloud on the ground, while cloud is fog high in the air. When the blue sky becomes white, the change in color is due to condensation—perhaps water dust, perhaps ice dust. If the condensation thickens, distant objects become blurred by the accumulated condensation; a *moisture-haze*, quite distinct in color from the blue dust-haze, occurs. Perhaps the white sky might not be called cloud; but if the condensation increases until the color becomes a dark gray, by common consent it is "cloud" in the air, or "fog" if it extends to the ground. The distinction is merely one of degree. Fog and cloud are examples of condensation; but until the droplets coalesce into drops that fall to the ground they are not precipitation.

It is likely that fog and cloud droplets vary much in size; but definite knowledge of the extent of this variation is wanting. Wells found that fog droplets were approximately 0.0002 inch (0.005 mm) in dimension, and that the fog droplets in a cubic yard were not far from 7 grains in weight.

Fog Types.—A common illustration of fog formation may be observed when a cake of ice is at the doorstep. Almost immediately it begins to "steam." The ice chills the air in contact below the dew-point, and condensation is at once apparent in the form of fog. Condensation liberates enough latent heat to give the moisture a certain amount of updraught, and therefore a steaming effect. It is an instructive illustration of contact cooling, and the fog produced is the *radiation fog* of weather science.

On still nights during spring and fall, fog is frequent over rivers and ponds, especially in relatively low places. If the air is still over such bodies of water during the day, it is apt to be moist. Therefore the normal lowering of temperature soon reaches the dew-point and, as a result, a radiation fog forms. Sometimes its depth is only a few feet; occasionally it overtops buildings and trees.

In various instances fogs hover over manufacturing districts when nearby rural areas are free from them. It is pretty certain that the products of combustion are the "favorable nuclei" in such cases. Dr. Owen of the British Meteorological Office found that many such floating particles were extremely hygroscopic, and that they tended to produce condensation when it did not occur in air free from them.[1] At all events, the *city fog* has become a factor in meteorology as well as in city traffic.

Advection fog[2] is the name given to fogs that result when warm moist air invades a surface so cold that dew-point temperature is reached. The sea fogs of the North Atlantic are an example. Warm, moist winds of a southerly origin invade the region of cold Arctic currents, and condensation of the moisture brought to the region occurs. "Skin friction" between wind and water causes the eddying movements of the air known as *turbulence*, and the fog blanket extends higher and higher as

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[1] In the fog over a manufacturing district Dr. Owen also found moisture droplets coated with liquid hydrocarbon, derived evidently from coal smoke. In other words, the fog droplet itself was a nucleus upon which the smoke-hydrocarbon condensed. The author failed to find this condensation in the manufacturing districts near New York City; but it is highly probable that it occurs in such atmospheres as those of Pittsburgh and South Chicago.

[2] From the Latin *ad*, "to," and *vehere*, to "carry"—that is, fog produced by conditions carried to a locality from an external source. Although the name is comparatively recent, it is very aptly formed.

CLOUD PHOTOGRAPHY

According to Arthur J. Weed, Chief Instrument Maker, U. S. Weather Bureau, the first requisite for cloud photography is a good camera with a rigid support. To this equipment a ray filter to shut out the excess of actinic rays from the blue sky is added. The filter, consisting of colored screens varying from yellow to red, is usually necessary, inasmuch as the exposure required for the cloud results in an over exposed sky. Very dense clouds may be photographed without the use of a ray filter. Cirrus clouds, however, require a strongly-colored ray filter. A black mirror answers the purpose of a ray filter and, in certain cases, gives a better negative. The details of cloud photography are described in the *Monthly Weather Review*, August, 1920.

Ellerman, photo.

Nimbus, with fog or stratus hovering in the valleys, Mount Wilson, Cal.

the chilling of the air progresses. Advection fogs are more apt to follow gentle movements of the air; gale winds may create mixing to the extent that dew-point temperature is not reached. The advance of a cold wave moving gently into a region of warm, moist air—the fog in front of a high—is an example of advection fog.

Velo cloud [1] is a name now commonly given to fog drifting in from the sea and hovering over a coast a few hundred feet from the ground. It is of frequent occurrence along the coast of southern California during summer months, and is occasional along the Atlantic coast. The velo is an example of advection condensation. Perhaps, strictly speaking, it should be classed as cloud rather than as fog; nevertheless it is advective condensation. Inasmuch as the term "high fog" is sometimes popularly used to denote a very thick fog meteorologists have generally adopted the term "velo." The velo is rarely more than 1000 feet high.

CLOUDS

Cooperative observers are not required to report information concerning cloudiness, except the extent of cloud-covered sky during the daylight period. At the regular Weather Bureau stations the character, movement and height of clouds are recorded and at some stations nephoscopes are provided. With the aid of these instruments, the velocity of the clouds, and therefore that of the upper winds, may be determined.

The photogrammeter is one of the most practical instruments for measuring cloud heights. It consists of a pair of cameras mounted in the same manner as a surveyor's transit. Two instruments set at different positions are employed. The sensitive plates are ruled with intersecting horizontal and vertical lines. By the aid of these, the photographs of the cloud indicate its comparative position, and from this both its altitude and its velocity may be determined. Air navigation now demands definite knowledge of wind at different elevations, and this knowledge is best obtained by a study of the clouds.

Formation of Clouds.—A cloud consists of an aggregation

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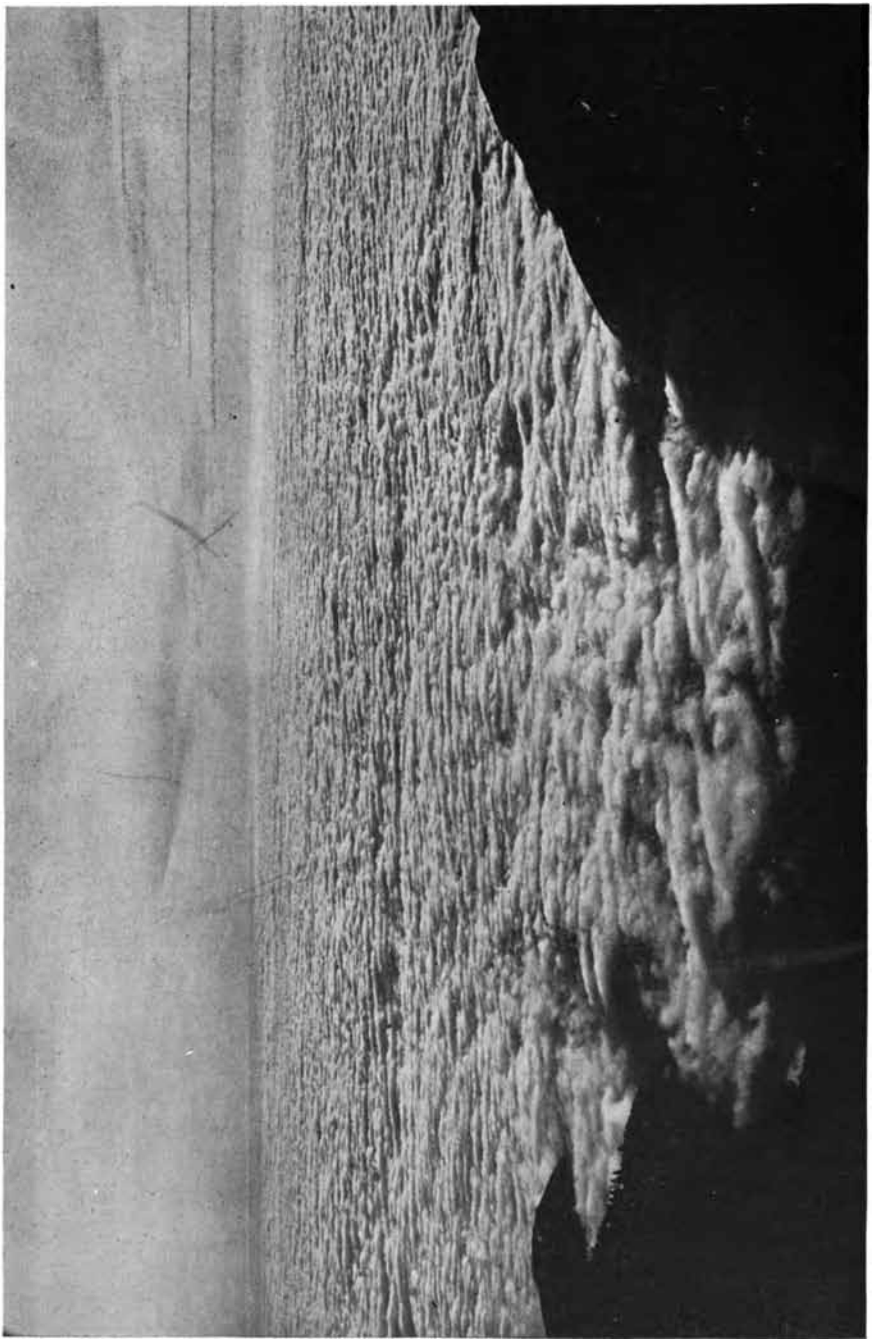
[1] From a Spanish word meaning "veil." The velo is a characteristic of San Diego.



Ellerman, photo.

Wind ripples in upper surface of fog, or stratus cloud. Cirro-stratus clouds above, Mount Wilson, Cal.

of visible particles of condensed water vapor. As in the formation of fog, each particle of cloud matter has condensed upon a dust mote. One cannot say why cloud matter floats in the air, apparently contrary to the laws of gravity. A theory that the cloud particle is repelled from the earth because it is charged with the same kind of electricity has been advanced; but it is not certain that this theory satisfies all conditions. That clouds form and disappear in accordance with the laws of temperature and dew-point is the fact that is important in weather science.

For convenience, cloud matter may be considered to be in a stage of condensation intermediate between vapor and liquid —a condition which may be brought about by several means:

Local ascending currents, or updraughts, which are vertical or nearly vertical;
Very slow obliquely ascending currents;
The rapid chilling of the lower air by the radiation of earth warmth;
The contact of high air layers which differ in temperature and humidity.

Any one of the foregoing conditions will produce cloud if the temperature falls below the dewpoint; nevertheless it is probable that cloud condensation is more complex in fact than the foregoing paragraphs indicate.

Classification.—Various schemes of cloud classification have appeared from time to time. Some of them have possessed great merit, but have been too complicated for practical use. More than a century ago, Luke Howard, of London, devised the classification upon which the scheme now in use was elaborated by the Cloud Committee of the International Meteorological Congress in 1891. The four fundamental forms are *cirrus*, *cumulus*, *stratus*, and *nimbus*.[1] Other forms are designated by the combination of the foregoing terms. Two

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[1] From the Latin *cirrus* (pl. *cirri*), a curl or wisp; *cumulus* (pl. *cumuli*), a heap, or pile; *stratus* (pl. *strati*, rarely used), a layer; *nimbus* (pl. not used), a rain cloud. The adjective derivatives are: *cirro-*, *cumulo-*, and *strato-*. Other definitive adjectives are *alto-*, high, and *fracto-*, broken.

[1] Some observers still employ the abbreviations of cloud names employed when the Weather Bureau was a part of the Signal Corps: Cirrus, C; Cumulus, K; Stratus, S; Nimbus, N. These symbols are used in Army and Navy practice.

Weed, photo.

Cirrus plumes and "cattail" streamers, upper half; cirro-stratus, lower half, Mount Weather, Va.

factors, appearance and altitude, aid the observer in determining the name and character of a cloud. For all practical purposes the physical form and appearance must always be the chief feature in cloud determination; experience will teach the observer to determine whether the cloud in question is to be classed as "upper," "intermediate," or "lower"; a distinction which is sometimes essential. The following is the classification elaborated by Abercromby and Hildebrandsson and adopted by the International Meteorological Congress:

(*a*) Detached clouds with rounded upper outlines.

(*b*) Clouds of great horizontal extent suggesting a layer or sheet.

The first (*a*) are most frequent in fair weather; the second (*b*) are wet-weather clouds.

Upper clouds, 30,000 feet (9000 meters)		*a*.	1.	*Cirrus* [1]
		b.	2.	*Cirro-stratus*
Intermediate clouds, 10,000 to 23,000 feet (3000 to 7000 meters)		*a*.	3.	*Cirro-cumulus*
		a.	4.	*Alto-cumulus*
		b.	5.	*Alto-stratus*
Lower clouds, less than 6500 feet (2000 meters)		*a*.	6.	*Strato-cumulus*
		b.	7.	*Nimbus*
Clouds of diurnal ascending currents	top 6000 feet (1800 meters); base 4500 feet (1400 meters)	*a*.	8.	*Cumulus*
	top 10,000 to 260,00 feet (3000 to 8000 meters); base 4500 feet (1400 meters)	*b*.	9.	*Cumulo-nimbus*
High fogs, less than 3500 feet (1000 meters)			10.	*Stratus*

1. CIRRUS (Ci).[1]—*Detached clouds of delicate and fibrous appearance, often showing a featherlike structure, generally of a whitish color.* Cirrus clouds take the most varied shapes, such as isolated tufts, thin filaments on a blue sky, threads spreading out in the form of feathers, curved filaments ending in tufts, sometimes called *cirrus uncinus*, etc.; they are sometimes arranged in parallel belts which cross a portion of the sky in a great circle and, by an effect of perspective, appear to converge toward a point on the horizon, or, if sufficiently extended, towards the opposite point also (Ci-St and Cu-Ci, etc., are also sometimes arranged in similar bands).

Cirrus clouds moving from the southwest indicate falling temperature; moving from the northwest they indicate the probability of rising temperature. They are the mares' tails and cattails of sailors' cant. Near the horizon, cirrus clouds may have a stratiform appearance.

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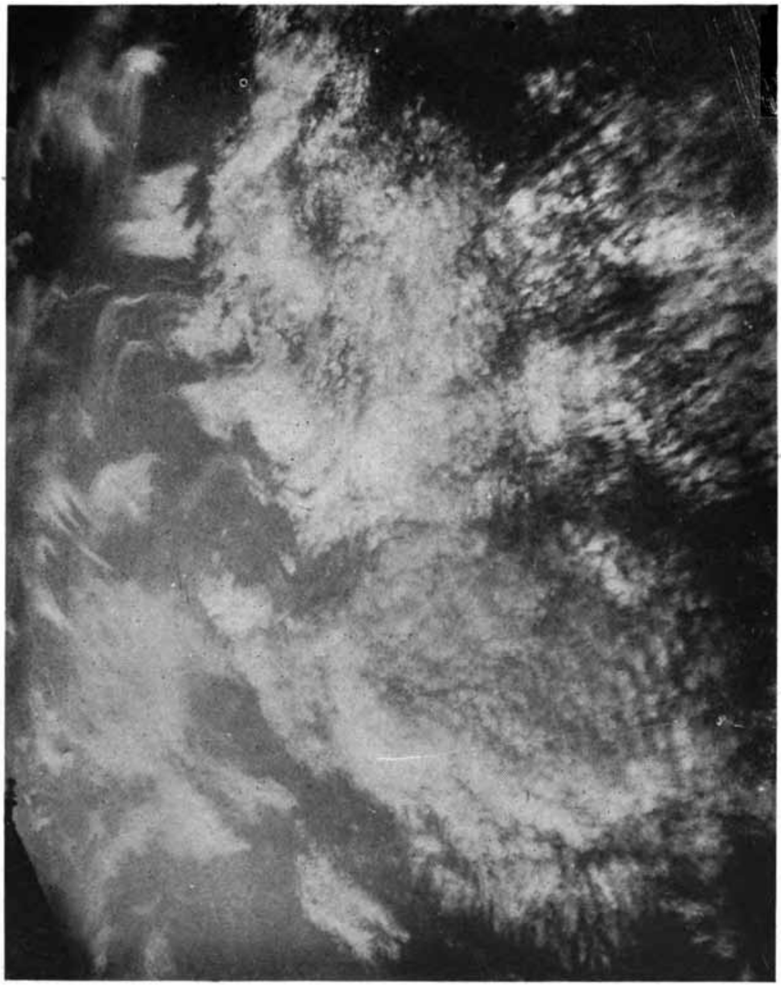
[1] For the sake of uniformity of definition and description, the following paragraphs are taken from the report of the Committee.



Weed, photo.

Tufted cirrus (top); cirro-cumulus (bottom); Mount Weather, Va.

2. CIRRO-STRATUS (Ci-St).—*A thin, whitish sheet of cloud,*[1] sometimes covering the sky and giving it only a milky appearance; it is then called cirro-nebula—at other times presenting more or less distinctly a formation like a tangled web. This sheet often produces halos around the sun and the moon.

This name is apt to be misleading to observers who have followed the old nomenclature. It applies not so much to the striated or banded cirri as to the whitish, or creamy, haze with banded or feathery edges. Frequently it appears as a whitish bank, with here and there a web of tangled fibers; at times it covers the whole visible sky. The halo produced when a cirro-stratus film is in front of the moon is varied in form. Occasionally mock moons, paraselenae, are formed; so also are the light pillar and the "heavenly cross."

Cirro-stratus clouds have long been associated with approaching stormy weather, and tradition seems to be borne out by investigation. The name *cirrus haze* is sometimes applied to cirro-nebula.

3. CIRRO-CUMULUS (Ci-Cu).—MACKEREL SKY.—*Small globular masses or white flakes without shadows, or showing very light shadows, arranged in groups and often in lines.*

Cirro-cumulus clouds are not always distinguishable from alto-cumulus clouds. They are much higher, however, and the arrangement usually possesses a geometric regularity. C. F. Brooks describes them as "small white flakes or tenuous globular masses which produce no diffraction colors when covering the sun or the moon."

4. ALTO-STRATUS (A-St).—*A thick sheet of gray or bluish color,* sometimes forming a compact mass of dark gray color and fibrous structure. At other times the sheet is thin, resembling thick Ci-St; and through it the sun or the moon may be seen dimly, gleaming as through ground-glass. This form exhibits all the changes peculiar to Ci-St, but it is about one-half as high.

It is not always easy to distinguish alto-stratus from cirro-stratus clouds. One cannot always estimate its altitude and, if the cloud is thin, it may be about as white as a cirro-stratus formation. The lower edge may be undulate, but it is hardly

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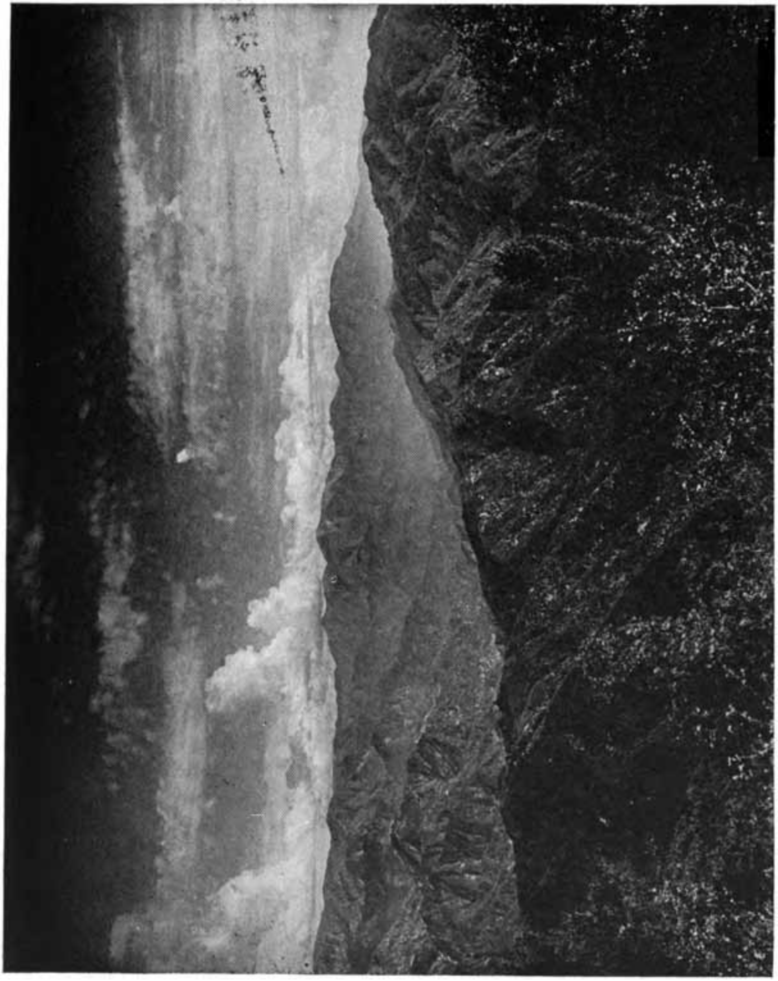
[1] Not every "thin whitish sheet of cloud" is a cirro-stratus formation. The low, white cloud veil of winter days may produce a halo; but it is not a cirro-stratus cloud.



Ellerman, photo.

Turreted alto-cumulus below developing into thunder-heads, curro-cumulus above. Cirro-stratus at right center. Mount Wilson, Cal.

mammillate in the manner of mammato-cumulus clouds. The fibrous alto-stratus is composed of snow crystals. It does not cause halos. The compact form is composed of water droplets and may cause coronas. Alto-stratus clouds indicate varying conditions of moisture and quiet air, rather than definite weather conditions. Nevertheless rain and snow may fall from them.[1]

5. ALTO-CUMULUS (A-Cu).—*Large globular masses, white or grayish, partly shaded, in groups or lines, and often so closely packed that their edges appear confused.* The detached masses are generally larger and more compact (resembling St-Cu) at the center of the group, but the thickness of the layer varies. At times the masses spread themselves out and assume the appearance of small waves, or thin, slightly curved plates. At the margin they form into finer flakes (resembling Ci-Cu). They often spread themselves out in lines in one or two directions.

It is evident that the observer will record alto-cumulus as cirro-cumulus and *vice versa;* many times a description of either will fit the other. Fortunately such an error is harmless.

6. STRATO-CUMULUS (St-Cu).—*Large globular masses or rolls of dark clouds often covering the whole sky, especially in winter.* Generally St-Cu presents the appearance of a gray layer irregularly broken up into masses of which the edge is often formed of smaller masses, often of wavy appearance resembling A-Cu. Sometimes this cloud-form presents the characteristic appearance of great rolls arranged in parallel lines, and pressed close against one another. In their centers these rolls are dark in color. Blue sky may be seen through the intervening spaces, which are much lighter in color. (Roll-cumulus in England, Wulst-cumulus in Germany.) Strato-cumulus clouds may be distinguished from Nb by their globular, or their roll appearance and by the fact that they are not generally associated with rain.

Strato-cumulus clouds usually follow a winter storm, covering the sky during the filling of a low barometer. The foregoing description is sufficiently plain and clear to indicate the character and appearance of strato-cumulus clouds. If they are high enough, however, they may be mistaken for alto-cumulus. In such a case it might be correct to call them alto-cumuli. Close to the horizon, strato-cumulus clouds resemble the normal stratus clouds at times, but they are much higher. Pretty nearly every transition between strato-cumulus and alto-cumulus clouds may be observed.

7. NIMBUS (Nb).—RAIN CLOUDS.—*A thick layer of dark clouds, without shape and with ragged edges,* from which *steady* rain or snow usually falls.

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[1] At Blue Hill Observatory thay are classed as *alto-nimbus* when rain or snow is falling from them.

A bank of cirro-stratus clouds in the west is apt to be the advance of a cyclonic storm. By the time the advancing clouds have reached the eastern sky, the storm is close at hand. Undulated alto-stratus clouds form under the cirrus haze and these very shortly develop into rain clouds, or else are followed by them. A winter cyclonic storm may be likened to a cone with its apex tipped one hundred miles or more beyond its base.

Ellerman, photo.

Thin, undulated alto-stratus forming above a fog, or stratus, Mount Wilson, Cal.

Through the openings in these clouds an upper layer of Ci-St or A-St may almost invariably be seen. If a layer of Nb separates into shreds in a strong wind, or if small loose clouds are visible floating under a large Nb, the cloud may be described as *fracto-nimbus* (Fr-Nb), the "scud" of sailors.

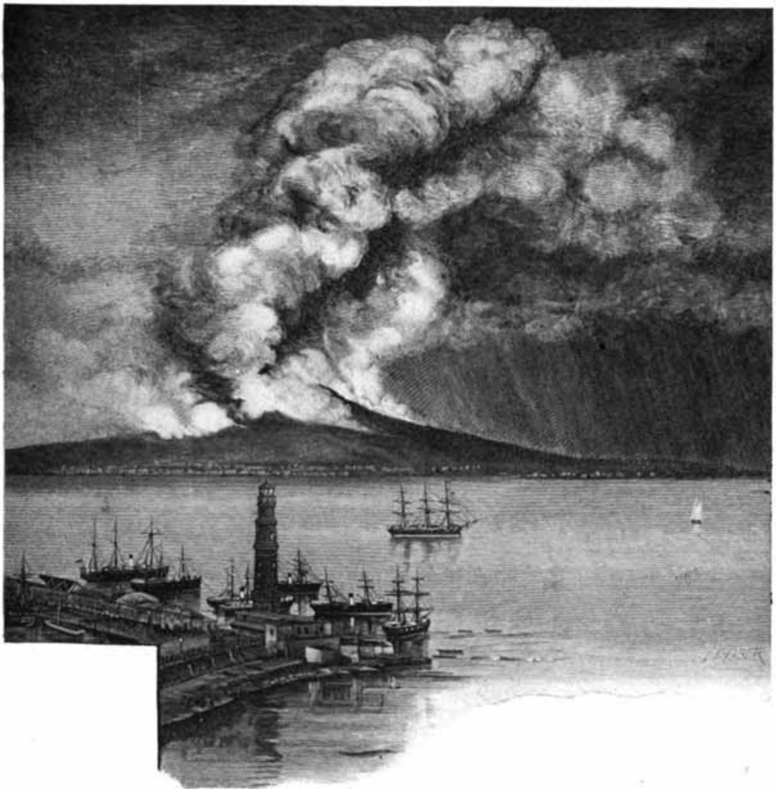
Inasmuch as the sky is almost always wholly overcast during a steady rain or snow, the ragged edges are rarely visible. The foregoing description is hardly true of tropical rain clouds with their sharp, greasy-appearing edges. The observer will not be in serious error in designating any low cloud from which rain is falling as nimbus. The flying scud, its top pointing with the wind, drops no rain. The breaking of a nimbus usually denotes the clearing of a storm; and although the scud is rainless, it is properly nimbus cloud matter though not "rain clouds."

8. CUMULUS (Cu), WOOL-PACK CLOUDS.—*Thick clouds of which the upper surface is dome-shaped, and exhibits protuberances while the base is horizontal.* These clouds appear to be formed by a diurnal ascensional movement which is almost always noticeable. When the cloud is opposite the sun the surfaces facing the observer have a greater brilliance than the margins of the protuberances. When the light falls aslant, as is usually the case, these clouds throw deep shadows; when, on the contrary, the clouds are on the same side of the observer as the sun, they appear with bright edges.

True cumulus has well-defined upper and lower limits, but in strong winds a broken cloud resembling cumulus is often seen, in which the detached portions undergo continual change. This form may be distinguished by the name *fracto-cumulus* (Fr-Cu).

The cumulus cloud with its flat base and rounded dome is so full of character that the foregoing description is ample. It is the summer cloud of the temperate zones and the shower cloud of the tropics. To the unaided eye the constant motion of the cloud matter is apparent; with a field glass the convectional motion is plainly visible in the larger clouds. The cumulus is an "ascensional" cloud, because the water vapor is carried upward until cooling brings about condensation. The condensed vapor sinks until it is again warmed to the temperature of vaporization.

9. CUMULO-NIMBUS (Cu-Nb), THUNDER-CLOUD, SHOWER-CLOUD.—*Heavy masses of cloud rising in the form of mountains, turrets, or anvils, generally surmounted by a sheet or screen of fibrous appearance* (*false cirrus*) *and having at its base a mass of cloud similar to nimbus.* From the base local showers of rain or snow (occasionally of hail or soft hail) usually fall. Sometimes the upper edges assume the compact form of cumulus, and form massive peaks



Cumulo-nimbus cloud resulting from eruption of Vesuvius. Note the heavy rain falling from lower part of cloud.

round which delicate "false cirrus" floats. At other times the edges themselves separate into a fringe of filaments similar to cirrus clouds. This last form is particularly common in spring showers.

The front of thunder-clouds of wide extent frequently presents the form of a large arc spread over a portion of a uniformly brighter sky.

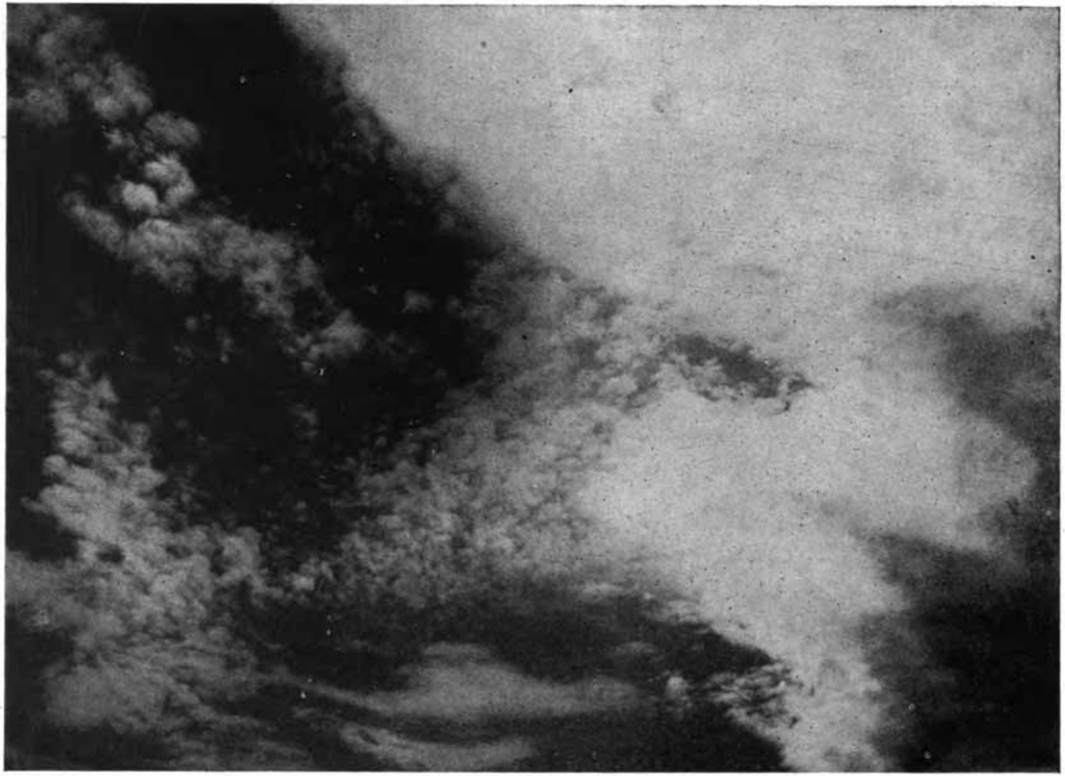
The difference between the ordinary cumulus cloud and the cumulo-nimbus is mainly one of depth and intensity of motion within its mass. If condensation is so intense that its water content reaches the ground, the cloud is cumulo-nimbus. But Humphreys points out the fact that, in arid regions, where the ground is very warm, a well-developed thunder-head sinks until the excessive warmth vaporizes and scatters it. The aborted cumulo-nimbus has been observed by the author. On the other hand, a torrential shower may fall for a few minutes from a tropical cumulus cloud—shallow as to extent and without the angry-appearing cauliflower head of the ordinary cumulo-nimbus.

The fibrous mantle that hovers over the top of the cumulo-nimbus is a cloud of snow flakes. The cloud itself is usually, but not always, a thunder-storm. The observer may disregard all theoretical matters and record it as a cumulo-nimbus if rain is falling from its base. The marvelous photograph of a thunder-storm obtained by Lieutenant W. F. Reed, Jr., U. S. N. (p. 106), surpasses any verbal description of a thunder-storm.

The strong updraught caused by forest fires and burning strawstacks has resulted in the formation of cumulus clouds that still later developed into typical cumulo-nimbus shower clouds. The eruption of Vesuvius in 1872 created a series of cumulo-nimbus clouds with mammoth cauliflower heads. Torrential rains fell on the leeward side of the cinder cone during a considerable time.

Experience has taught the airman that the cumulo-nimbus cloud is an object to be avoided; its beautiful exterior hides a generous accumulation of holes and bumps. The turbulent cumulus cloud has been called "the most treacherous wild beast of the air."

10. STRATUS (St).—*A uniform layer of cloud resembling a fog, but not resting on the ground.* When this sheet is broken into irregular shreds by the wind, or by the summits of mountains, it may be distinguished by the name *fracto-stratus* (Fr-St).



Weed, photo.

Thin alto-stratus (lower middle) merging into alto-cumulus. Dense alto-stratus (right), Mount Weather, Va.

Tradition has made the long, flat cloud-streak near the horizon the type form of stratus cloud. But if that same cloud-streak were overhead it would appear merely as a low cloud covering more or less of the sky. When a fog lifts, it forms a stratus cloud; and if it floats away toward the observer's horizon it becomes a long gray cloud streak. In the first case one is looking at the under side of the surface; in the second, at the edge. The components of a stratus cloud may be fog, smoke or dust—or even all three.

Qualifying Descriptive Terms.—Usage in the matter of descriptive terms is not uniform. The following have been suggested:[1]

Fibrous, characteristic of streaks of falling rain or snow seen from a distance.

Smooth, characteristic of sheet-like clouds.

Flocculent, scaly, flaky, in small tufts (*floccus*, a tuft of wool).

Waved, or in *rolls*, characteristic of waves and windrows observable in billow clouds.

Round-topped, characteristic of the summits of clouds produced by rising currents.

Down-bulged, or *round-holed*, characteristic of the lower sides of clouds produced by down-draughts.

Ragged, characteristic of forming and of evaporating clouds in turbulent wind.

Recording Cloud Conditions.—The International Cloud Committee recommends the following instructions for the guidance of observers:

Kind or character.—Clouds may be designated by name, or by symbol, as Ci-St, for cirro-stratus. Where doubt exists, the number of the picture in the classification scheme should be designated.

Direction.—If the clouds are high the motion may be observed best by noting their position relative to a fixed object—a tree, or a flag-pole. Where the movement of the cloud is very slow, a rest for the head and shoulders may be necessary. The direction is best observed when clouds are near the zenith. The movement and direction of horizon clouds are apt to be deceptive, giving to the observer an imperfect perspective. When possible, a nephoscope should be used if the direction is doubtful.

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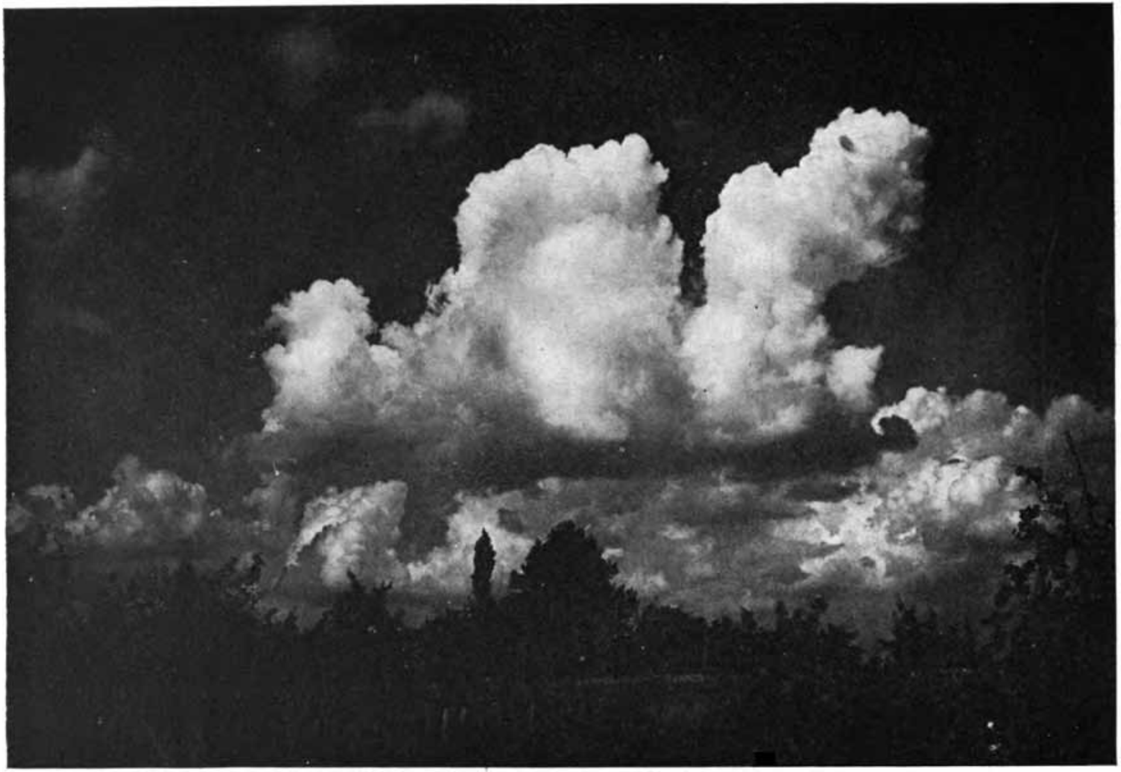
[1] C. F. Brooks, *Monthly Weather Review*, Sept., 1920. Seven terms noted above are used for form; five—transparent, semi-transparent, medium, dense, and very dense—describe *density;* three—coarse, medium, and fine—indicate the degree of fineness. These terms, while they do not alter the International Cloud Committee's classification, add very materially to its clearness.



Atlas Photographique des nuages, Loisel.

Typical cumulus clouds of moist summer weather. The large cloud in the foreground is developing into a thunder-head. Note the wisps of false cirri.

Radiant Point of Upper Clouds.—Though apparently in radial position, streamers of cirrus clouds are actually parallel. The radial form is merely a perspective. The apparent point of convergence should be noted in the same manner as wind direction; as, se, or nw.

Undulatory clouds.—If the clouds show parallel and equidistant striations, such as suggest a succession of water waves, the direction of the striæ should be noted; and if more than one system of striæ appear, this fact should be noted.

Density and position of cirrus forms.—The cirro-stratus haze may become a dense bank of gray in its lower part. It is desirable that its density be recorded by a scale of intensity, 0 to 4; and also that the cardinal direction of the point of greatest density be noted. The gathering of cirrus clouds and the formation of a cirro-stratus bank is closely connected with cyclonic storms.

Unusual Cloud Forms.—Various cloud forms that are not readily classified are noted by every observer:

Billow clouds, or *windrow clouds*, are the same as the undulatory clouds noted in a previous paragraph. The name is derived from their wave-like form. Sometimes they are at cirrus height, and should be classed as cirrus clouds. For the greater part they form at lower altitudes. They are due to cross-winds in plane contact, the two differing in temperature and humidity.

Crest clouds frequently gather about the summits of snow-clad peaks. They are frequently observable shrouding the summits of Mounts Hood and Rainier. On even a grander scale they envelop the summits of Popocatepetl and Ixtaccihuatl, during periods of still air. When a moist wind blows against snow-clad peaks, a stream of condensed moisture flows from the leeward side, forming a *banner cloud.* The so-called "smoking" of Mounts Hood and Rainier is a cloud banner of this sort.

Mammillated, or *mammato-cumulus clouds*, are globular projections from the under side of thunder-heads. They usually accompany thunder-storms, hailstorms and tornadoes. A similar waviness, very strong in character, is sometimes observable in the bands of cirro-stratus clouds near to the horizon.

Scarf clouds are the feathery wisps that sometimes form at the summits of cumulus clouds, especially those of the storm type. They seem to increase in size as the turbulence within the cumulus cloud increases, and sometimes appear like a coverlet over its top.

Observatorio del Ebro, Spain.

Heavy strato-cumulus broken by a strong wind. Note the wisps and curls on lower edges formed by wind eddies.

Various other terms such as *lenticulate*, *maculate*, *flocculent*, and *castellate*, are used by observers. Any descriptive term which conveys a definite meaning is permissible in recording cloud observation.[1]

Cloud Heights.—Bigelow's measurements of cloud heights are somewhat greater than those determined by the International Cloud Committee, due to the fact that the measurements were made in a lower latitude. The table (p.), taken from Hahn's *Lehrbuch der Meteorologie*, shows that the altitudes of the various cloud levels increase from polar to equatorial regions.

The level of each type of cloud is a level of maximum cloudiness; between cloud levels are levels of minimum cloudiness. The airman may find that neither Dr. Bigelow's figures nor those of the International Committee apply to the locality in which his flights are made; but the altitudes of maximum and of minimum cloudiness for any locality are not far from the figures noted and are roughly proportioned. The airman will find also that the various cloud regions are thicker as one approaches equatorial latitudes. The lowest level of minimum cloudiness is that between "scud" cloud height and the base height of stratus clouds—from 300 feet to 1200 feet.

The thunder-head excepted, the lower clouds are shallow; but they vary greatly in depth. A mean of 10,000 feet (3000 meters) may be approximately correct for their depth, but it is unsafe as an estimated depth at any one time. The fact that the highest mountain peaks of the United States are snow-capped shows that precipitation occurs at an altitude of about 15,000 feet; and the fact that observers in mountain regions are frequently above storm clouds is evidence that the cloud blanket may be materially less than 10,000 feet in thickness.

The Distribution of Cloudiness.—In the Pacific Coast region of the United States, cloudiness is more or less seasonal. Practically all the lower clouds are prevalent during the winter months—that is, during the rainy season. During the summer the lower clouds may be absent for weeks at a time. From a

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[1] The student is advised to become familiar with A. W. Clayden's article, "*Clouds*," in the eleventh edition of the Encyclopedia Britannica. Clayden's modification of the International classification is merely the addition of descriptive terms.

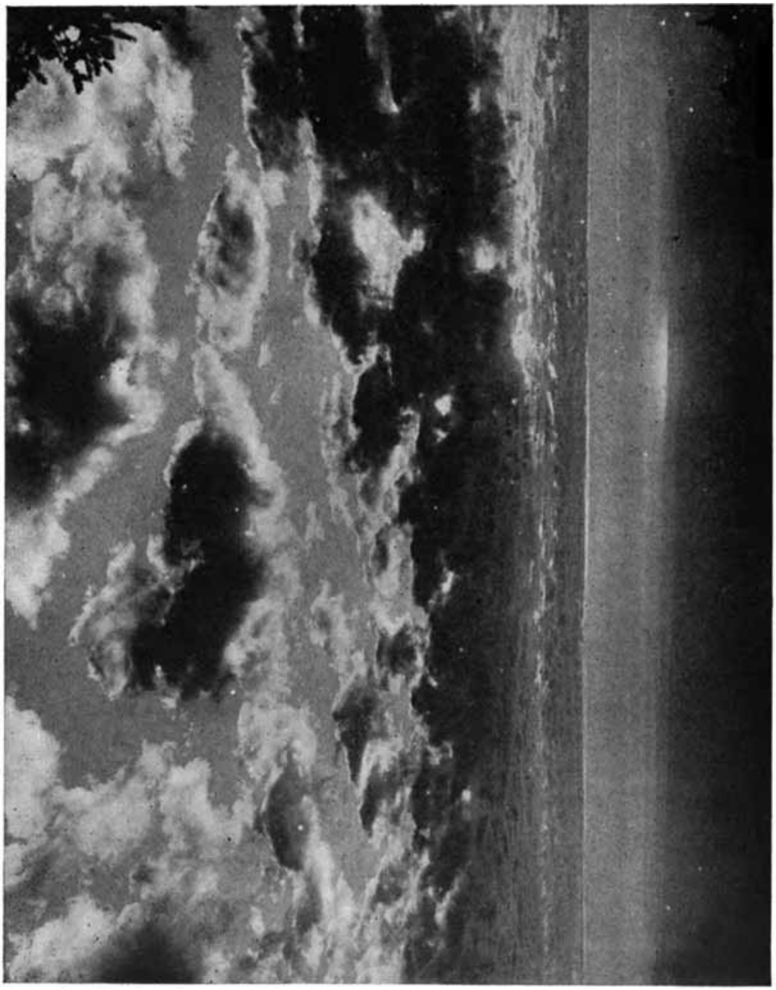
Atlas Photographique des nuages, Loisel.

Mammato alto-stratus in the wake of a thunder-storm. Strato-cumulus in lower left side.

camp in the Sierra Nevada Mountains overlooking the Sacramento Valley, clouds formed by dust, smoke and fog are sometimes the only ones visible for a considerable period.

Along the Atlantic Coast and the Mississippi Valley a cloudless sky for more than one or two days is unusual; for a period of three days it is very rare. During the moist periods of midsummer a very thin cloud veil may prevail for a week or more at a time. The cloud veil, technically a "haze," is too thin to obscure the sun visibly, but it is dense enough to prevent radiation to a considerable extent. During the period when the cloud veil prevails, the night temperature is from 5 to 10 degrees higher than at other times, and the amount of insolation is almost always lowered.

Arizona, southern California and southern Nevada constitute the region of minimum cloudiness in the United States. In this region cloudless skies may persist for a month or more. The observer who watches the hygrometer closely will acquire not a little useful information on clouds and their relation to atmospheric moisture. No part of meteorology is more fascinating than the study of clouds, and none is more important in forecasting weather changes.



Ellerman, photo.

Alto-cumulus clouds. Note the shadows in the center of each mass. At a lower altitude these clouds would be strata-cumulus near the horizon, and fracto-cumulus nearer the zenith, Mount Wilson, Cal.

CHAPTER IX

THE MOISTURE OF THE AIR: PRECIPITATION

Dew and frost are commonly regarded as condensation rain, snow and hail are classed as *precipitation*. So much of the rain and snow results from the adiabatic cooling of the air—that is, cooling by an updraught of warm air—that this may be considered the normal cause of precipitation.

A mass of air composing an updraught is cooled at the rate of 1 degree Fahrenheit for each 183 feet of ascent (about 10.7 degrees centigrade per kilometer) and this rate does not vary much in the first 10,000 feet. When the rising mass has reached the level where it is at the temperature of saturation, condensation begins; rain-clouds form; and, from the coalescence of cloud matter, rain-drops or snowflakes fall.[1]

The most remarkable example of updraught, adiabatic cooling, condensation and precipitation is the equatorial cloud-belt. It is the updraught of the Trade Winds and consists of a zone of cumulus clouds several hundred miles in width. In sailors' vernacular, it is the belt of the *Doldrums*. Throughout most of its width rain is of almost daily occurrence; greasy-appearing clouds, with sharp edges, hover above the horizon about noon, and steadily mount the sky. Wherever they are

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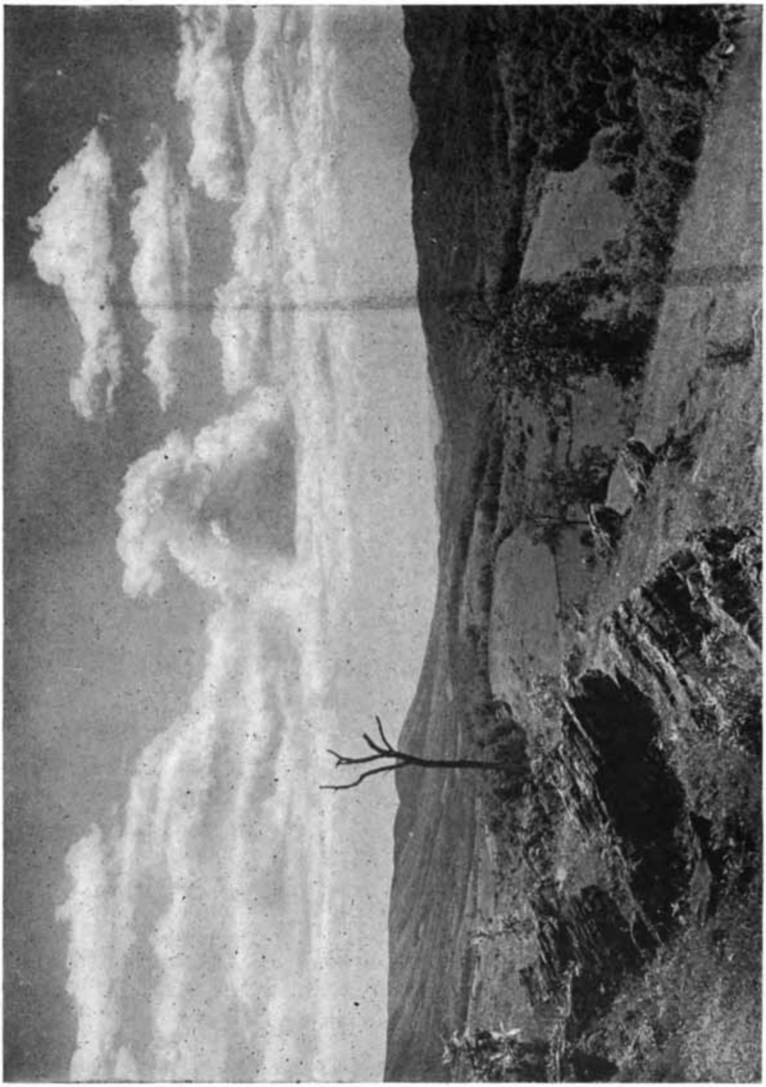
[1] Rain-drops vary in size from approximately 0.0004 inch (0.01 mm.) to about 0.25 inch (6.5 mm.) in diameter. Drops varying in size from very large to very small frequently fall in the course of one shower. Ordinarily the drops are about 0.1 inch (approximately 3 mm.) in diameter. At best, however, these dimensions are only approximate. Large drops are shattered by a stiff wind, and drops a quarter of an inch in diameter are apt to be shattered before reaching the ground. The largest drops occur in connection with thunder-storms. A shower composed of fine drops much diffused is usually termed *drizzle*. Very fine drops—droplets that are heavy enough to fall—are properly called *mist*. These droplets are larger than those of fog, the latter being floating and not falling matter. A thin fog is also called mist, in Weather Bureau nomenclature.



L. W. Humphreys, photo.

Cumulus, fracto-cumulus, and strato-cumulus (right center). Note the typical "anvil" in center.

in an overhead position rain is falling in heavy showers. The passage of the cloud-belt north and south provides an unusual and an interesting distribution of rainfall. Roughly speaking, the cloud-belt halts and turns backward in the latitude of each tropic; in these latitudes, therefore, there is theoretically one rainy season each year. Between the tropical circles the cloud-belt passes twice, resulting in two rainy and two dry seasons—in some localities strongly marked, in others not so distinguishable.

South of the equator the zone of constant rains is not so well marked as it is north of the equator; moreover, the belt of easterly winds at times covers the whole of the Gulf of Mexico. In general, the lands of the Torrid Zone receive an average of about 100 inches of rain per year—rather more in the northern than in the southern part.

In the temperate zones, on the coasts facing westerly sea winds, the rainfall for the greater part is seasonal. Along the Pacific Coast of the United States, it increases with the latitude. Thus at San Diego, California, the annual fall is 10 inches; at Los Angeles, 16 inches; at San Francisco, 23 inches; at Portland, Oregon, 45 inches; at the coast stations of Alaska from 80 inches to more than 100 inches. At San Diego practically all the rain falls between October 15 and April 15; in the seventy-two years from 1850 to 1912, a shower amounting to more than a trace of rain fell only twenty times in July. In San Francisco there is an average of about one rainy day in July; in Portland, Oregon, the July rainfall averages 0.54 inch; in Seattle it is 0.69 inch.

On the west coast of Europe, owing chiefly to higher latitude, the seasonal character of the annual rainfall is not so marked as in California. In Portugal and southern Spain, most of the rain falls in the winter months. At Bordeaux, a little higher in latitude than Seattle, the July rainfall is in excess of 2 inches every month in the year. But while the average of the winter months in Seattle is above 5 inches, in Bordeaux it is about 3 inches.

The thirtieth parallel crosses the northern part of Mexico and also the northern part of Africa. A zone several hundred miles in width along this parallel—in sailors' vernacular, the belt of "horse latitudes"—is the region of high barometric

Weed, photo.

Tufted wind clouds. A typical squall cloud indicating the onset of furious gusts of wind. Note the eddies on the lower side and the direction in which they point, Mount Weather, Va.

pressure, and the belt of descending air. The region covered by it is one of calms over the sea and of light, variable winds over the land. Along the Pacific Coast from San Diego almost to Manzanillo, Mexico, the yearly rainfall is very light and uncertain. Along the Atlantic Coast of Africa, the region of calms is a desert. Eastern Mexico receives a more generous rainfall; and southern Mexico and the Central American states are within the zone of rain-bearing winds.

Southern coasts in general have an abundance of rain. Along the Indian Ocean and the Guinea coast the rainfall is seasonal. On the Gulf Coast of the United States rain falls pretty evenly throughout the year.

The Precipitation of Cyclonic Storms.—Cyclonic storms, or lows, are rather more frequent in the United States and Canada than in Europe. They are much more frequent in occurrence east of the Western Highlands, and they also are much more energetic.

Rather more than half of the storm-whirls of this sort are noted first between the Columbia River and the Strait of Juan de Fuca—not because they do not occur elsewhere, but for the reason that there are fewer weather stations north of Vancouver. When a low is crossing the mountains it is in a region of dry air; therefore it does not possess much energy. When it has crossed the Rocky Mountains it is in a region where both the absolute and the relative humidity are greater. Therefore it is apt to develop a much greater energy; for the latent heat set free by the condensation of water vapor is the fuel of a cyclone. The northerly cyclone usually traverses the Great Lakes, where the increased humidity imparts greater precipitation, finally moving out into the Atlantic. As a rule, the rainfall of such storms is not very heavy. It may drop a little more than 1 inch of rain over the track of its passage, but usually the precipitation is not much greater.

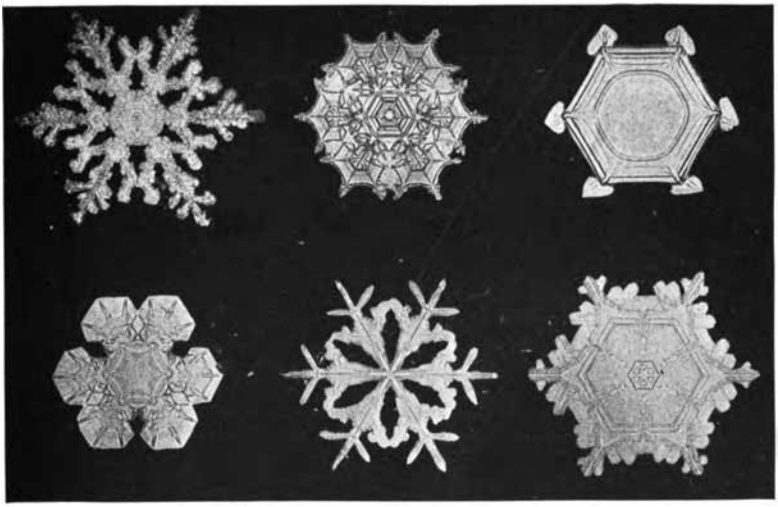
The more southerly cyclones frequently bend towards the Gulf of Mexico, and begin to curve towards the northeast after passing the Mississippi River. They are much more energetic than the northerly storms and drop perhaps as much as 2 inches of rain along their tracks. In various instances a storm first discovered in the plains of Texas finally travels a course between the St. Lawrence River and the coast. In-

Weed, photo.

A summer shower. Cumulo-nimbus belt, the front of an advancing wedge of cold air, overlying warm air next the ground, showing thunder-head (right); strato-cumulus rolls (center), Mount Weather, Va.

asmuch as this track covers a region of great moisture, the rainfall is apt to be very heavy—sometimes more than 3 inches.

The severest cyclonic storms are the West Indian hurricanes and the typhoons of the China coast. Throughout their courses they move through regions of very moist air. In these storms, the velocity of the wind results from a very rapid updraught. The precipitation, therefore, is excessive. In the vicinity of the Gulf Coast of the United States, from 8 to 10 inches of rain may fall during the passage of a hurricane storm, and a downpour of 4 or 5 inches is usual.

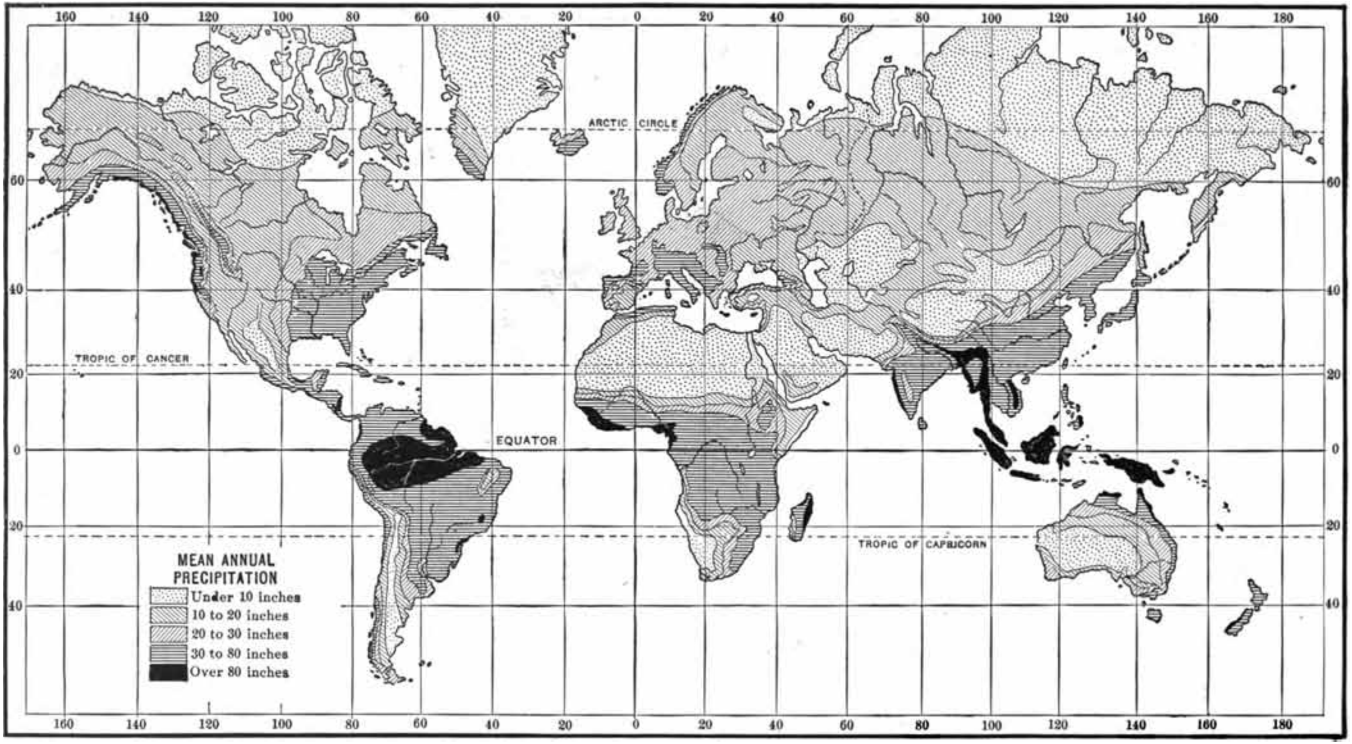


Bentley photo.

Snow crystals, magnified about 50 diameters, Jericho, Vt.

In the United States, cyclonic storms are more characteristic of winter than of summer weather; they are therefore usually described as *winter storms*. The precipitation may consist of rain, sleet or snow—rarely, if ever, of hail.

Snow.—When condensation below 32° F (0° C) occurs, the precipitation takes the form of the ice crystals popularly known as snowflakes. They form in almost infinite variety, but they may usually be classified as tabular (disk-shaped) or colum-



Huntington and Cushing's Principles of Human Geography.

Annual rainfall.

nar.[1] Normal crystals are six-sided or six-pointed; the angles are usually 60° or 120°. The snowflakes of ordinary storms consist of tangled masses of broken crystals. They are at their best when the temperature is not higher than 25° F and the air is still. The flakes should be caught on black cloth. If a microscope is used, it must be used in a place where the temperature is below the freezing point. If photo-micrographs are made, a low power objective—2-inch or 4-inch—gives excellent results.

Occasionally the snowflakes take the forms of soft pellets—the *graupeln* of the German meteorologist. At other times they are half-melted, but retain traces of crystallization. The presence of slowly falling snow crystals during fairly clear weather is common in many localities. It is the greatly-dreaded *poguenib* of the far-western Indian, who associates it with pneumonia.

Snowfalls have been recorded in every state in the Union. They occur occasionally along the Gulf Coast between Pensacola and Brownsville. Snow has fallen in Florida as far south as Fort Myers.[2] A line drawn from Savannah through San Antonio, El Paso, and Yuma to San Francisco marks roughly the limit south of which snow seldom falls. South of the thirty-fifth parallel, snow rarely lies on the ground more than a day or two. At New Orleans a measureable snowfall occurs about once in fifteen years. It is about as frequent in the city of Los Angeles, although the mountain summits in the vicinity occasionally are snow-clad.

In the vicinity of the Great Lakes the ground is covered most of the winter. In the New England and Middle Atlantic states the annual snowfall is 7 to 8 feet. It decreases toward the west, being about 2 feet in North Dakota. In the basin region of the Rocky Mountain States snowfalls occur at long intervals only; in the plateau region they may be expected yearly on the range summits. The heaviest snowfalls occur along the northern Rocky Mountain and the Sierra Nevada

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[1] A remarkable collection of photographs of snow-flakes has been made by W. A. Bentley, and another by J. C. Shedd. The latter is published in the *Monthly Weather Review*, October, 1919. Professor Shedd classifies snow-flakes as first-, second-, and third-growth crystals. They have been classified also as columnar, doublets, and pyramidal crystals.

[2] On March 6, 1843, fifteen inches of snow fell at Augusta, Georgia.

Range summits; from 10 to 30 feet may be estimated as the annual fall. The amount varies greatly from year to year; at Summit, California, 60 feet of snow fell during the winter of 1879-80.

On the Pacific Coast slope the yearly snowfall in the mountains is a matter of great importance. Since the construction of the various irrigation projects in the arid region, humanity is realizing more and more the dependence of productive lands, not only on the yearly amount of snow-fall, but on the conservation of the melting snow, as well. In the arid regions of the United States, the winter snowfall is the moisture of the summer crops.

Except at great altitudes, practically all the snow falls between the first of December and the middle of April in the zone of latitude that includes the New England States and New York.[1] Flurries of snow occur in May as far west as the Rocky Mountains; and at elevations of 2000 feet or more they occur in June.

Sleet; Ice Storms; White Storms.—In Weather Bureau nomenclature, sleet consists of small pellets of ice, apparently formed when rain-drops are frozen in passing through a stratum of cold air next the ground. Usually the pellets are not larger than duck shot; occasionally they are the size of peas. Sleet has been reported as hail so frequently that the Weather Bureau has issued an explanatory pamphlet calling attention to the fact that the ice pellets of sleet differ materially in structure from hailstones. Ice pellets may contain enough air to give them a whitish opaque appearance; therefore they are likely to deceive observers. Sleet storms are very apt to occur in the morning, when the temperature is at its daily minimum, but this is by no means always the case. Sleet may occur when a cold wave flows under warm, moist air; it is likely to result when a warm southerly wind flows over the top of very cold surface air.

Sleet is often mixed with rain; at such times it forms an ice-coating on the ground, making a surface that is more or less pebbly. Frequently it happens that the rain-drops are not

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[1] On the 8th of June, 1816, snow fell in all parts of Vermont; on the uplands it was 5 or 6 inches deep. It was accompanied by a hard frost.—*Thompson's History of Vermont.*

frozen in their fall, but congeal as they strike. In this way, ground, sidewalks, trees and other surfaces become covered with a coating of ice. Weather Bureau practise and popular consent join in designating this form of precipitation as an *ice storm.* The ice storm is apt to be followed by the destruction of tree branches snapped off by the wind, and by an unusual number of accidents in city street traffic.

Several conditions of temperature and precipitation may result in an ice storm. If the rain-drops fall through a stratum of air below freezing temperature and strike an object whose surface is also below freezing temperature a varnish of ice will be formed, and it is likely to increase in thickness so long as precipitation continues. When the temperature is very slightly above the freezing point, and the surface air is dry, it is possible that rapid evaporation may chill the varnish of water below the freezing point and change it to ice. Rain-drops in the air may be chilled to a temperature several degrees below the freezing point; they change to ice instantly as they strike.[1]

Damp snow and snow falling on tree limbs, poles and wires whose temperature is slightly above freezing, is very apt to cling to them. The weight of the accumulated snow may be sufficient to break tree limbs and line wires. Not only is there a considerable material damage; there is also a troublesome and expensive interruption of communication. Popularly, the condition is known as a *white storm.*

A temperature materially below 32° F following a white storm is apt to result in much damage to shade trees and orchards. Branches will bend freely, as a rule, when the temperature is above freezing; but they become brittle under intense cold if coated with ice. The distinction between an ice storm and a white storm is chiefly one of appearance. The Weather Bureau makes no distinction between them.

Hail.—Hail is a product of thunder-storms. The hailstone consists of alternate concentric layers of snow and ice. The manner of the formation of the hailstone is conjectural. About the only thing of which one may be certain is that the hailstone is alternately in layers of moist air below the freezing point and

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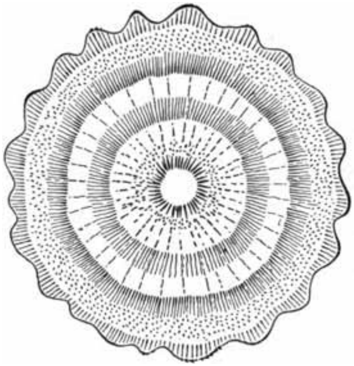
[1] The Blue Hill Observatory reports rain falling when the temperature of the air was about 15° F—a very unusual phenomenon. It is not likely, however, that the rain-drops had reached a temperature much below freezing.

layers of warmer air—that is, it is whirled through alternate layers of snowy air and of misty air. The updraught that occurs during thunder-storms shows that such a movement takes place in cumulo-nimbus clouds; and when the hailstones become too heavy to be carried by the updraught they fall to the ground.

Hailstones usually vary in size from a quarter of an inch to half an inch in diameter. They are very rarely as much as an inch in diameter. In a few instances single stones more than two inches in diameter have been reported. In many instances several hailstones are frozen together, and hailstones "as large as a hen's egg" are formed in this manner. Hailstorms are rarely more than a few minutes in duration.



After Redway.

Hailstone; sectional view.

They occur usually in the southeast quadrant of a cyclonic storm, having the same relation to the area of low barometer as does the tornado. The path of the hailstorm is rarely more than 3 or 4 miles wide—sometimes not more than half a mile—and it may traverse a distance of 25 or 30 miles, or more.

Sometimes the hail is scattered in windrows; and many cases in the United States have been reported where the windrows were several rods in width and more than 2 feet deep. Near St. Quentin, France, a windrow more than a mile long left a mass of ice which did not disappear for several days.

In western Europe hailstorms are very destructive to vineyards and growing crops. For many years the practise of "bombarding the air" was followed. Long-barreled mortars with bell-shaped bores were charged heavily with powder and aimed vertically. At times when storms were expected, thousands of charges were fired into the air with the expectation that the resulting convection of the air might prevent the formation of hail. There is no evidence to show that the practise prevents hailstorms.

In the present state of human knowledge, forecasts of hailstorms cannot be made. The Weather Bureau is making efforts to gain all possible information concerning date, time, duration, extent of area and path of hailstorms. It is pretty well established, however, that hailstorms are more frequent in certain regions than in others; and that in certain limited areas in these regions of greatest frequency they are more destructive than in other areas.

Cloudbursts.—The cloudburst is an excessive downpour of rain, in which the water seems to fall in masses rather than in drops. Cloudbursts are rare; the area covered is small; the duration is a matter of a few moments only.[1] Only in a few cases have trustworthy measurements of the amount of precipitation been made. The ordinary barrel gauge would probably give a result at least 80 per cent true. The majority of recording gauges are of but little use in such storms. Moreover, the cloudburst does not always select for its performance a locality where Weather Bureau stations are in evidence.

The origin of the cloudburst is not certainly known. To call it an exaggerated thunder-storm may express a truth in some cases; certainly not in every case. All the water in an overhead saturated air at a temperature of 70° F over the area covered by the downpour would not make a rainfall sufficient to account for the water dropped by a cloudburst.

[1] A mining engineer in Arizona relates the following: "The day, up to 3 o'clock, had been moist—to the extent that distant objects possessed atmosphere—that is, there was not the illusion of nearness which a very dry air gives. In mid-afternoon there came a sudden darkening of the sky, a light patter of rain, and then a downpour so torrential that further progress along the trail was out of question. The loose rockwaste seemed to be washed out from under the horse's hoofs, and a boss of rock near by seemed to be the only safe place. It was impossible to see anything more than a few rods ahead. The downpour lasted for not more than fifteen minutes. To say that the amount was 6 inches is merely a guess. Much of the trail was washed away and badly gullied. Pinal Creek was a roaring torrent; to have attempted crossing it would have been instant death. Across the summit, on the other side of the range, not a drop of rain fell."

Another traveler wrote: "A heavy cloud had been hovering over Pilot Range for several hours, and we were not surprised to hear a low moan which soon became a roar. So we climbed out of the arroya in quick time. In a very few moments, there came a torrent that would have carried a ton boulder down the course. The cloud over Pilot Knob had dropped its shower and the sink below was full of water—the first time, perhaps, in fifty years."

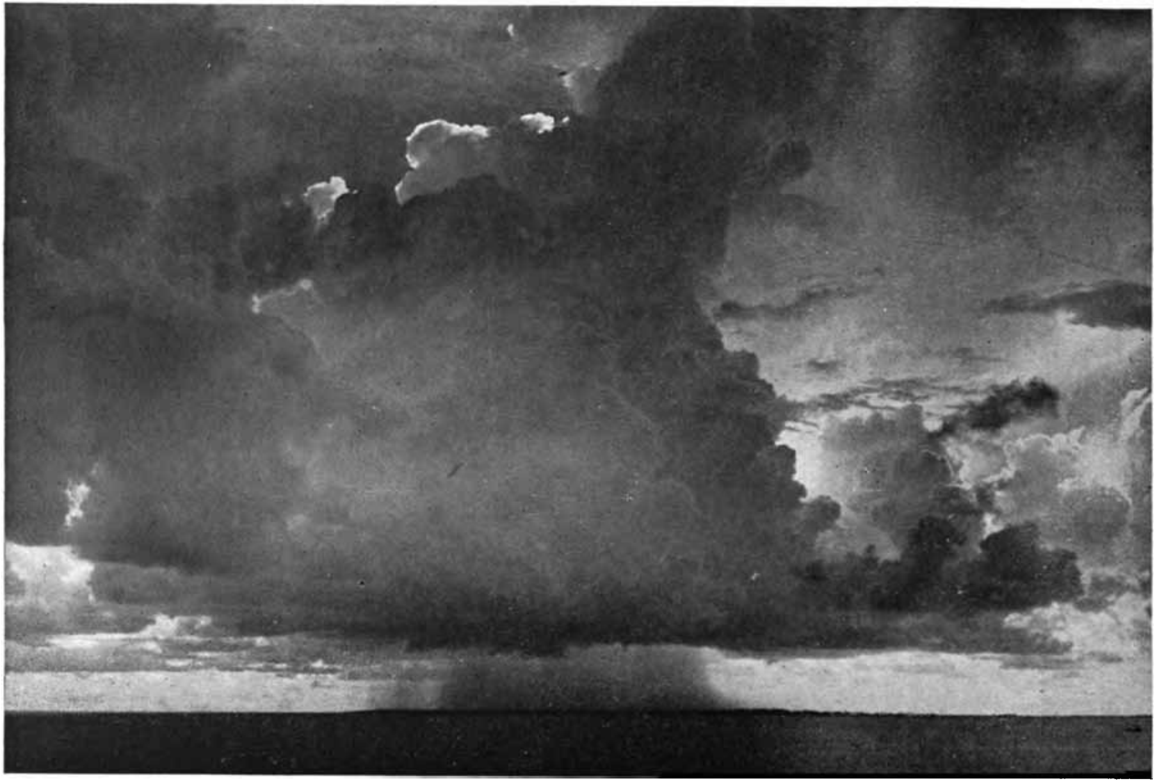


Photo by Lieut. W. F. Reed, U.S.N., near Pensacola, Fla.

Thunder-storm: A typical cumulo-nimbus thunder-head. Note the heavy shower falling from the base of the cloud. Strato-cumulus clouds in lower left corner, and tufts of false cirri in right center.

It has been pointed out that the cloudburst may be derived from the contents of a waterspout carried inland for a long way and dumped upon the nearest mountain crest which has a temperature low enough to chill it. This may be an explanation, but one is not certain that it is the real one. Any explanation must take into account the fact that an ordinary rain cloud cannot hold the moisture that is precipitated in a cloudburst.

Summer Precipitation.—The rainfall of summer months within the United States is rarely a result of cyclonic movements of the air. For the greater part, it is due to the updraughts that result from surface heating; and this also is the cause of most of the tropical rains. Summer showers are apt to be sporadic in character, and the area covered may be small. It is not uncommon to find a rainfall of 2 or 3 inches at one locality while scarcely more than a trace falls at another locality only a few miles distant.[1] Occasionally the daily weather map shows half a dozen areas scattered over the eastern half of the United States in which rain is falling; less frequently, a belt 200 miles or more in width extending from the Gulf Coast to the Canadian border, sweeps eastward from the Mississippi Valley.

In summer the updraught, though strong, is more or less local, occurring over comparatively small areas. In winter the updraught, though weak, may involve an area more than 500 miles in diameter.

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[1] In the past few years insurance against rain has become very common during summer months. Clubs and outing associations thus protect themselves against the losses of revenue which a rainfall might cause. In many instances the serious error of determining the rainfall by the record of a rain-gauge a dozen miles distant has led to expensive litigation. In various instances, heavy showers have occurred at the locality covered by the policy, while merely a trace fell at the station where the precipitation was recorded. Granted that insurance against rain is a legitimate business, it is evident that the installation of a gauge at the locality covered is the only way by which the amount of rain can be determined.

CHAPTER X

ATMOSPHERIC ELECTRICITY: OPTICAL PHENOMENA

ATMOSPHERIC ELECTRICITY

Under ordinary conditions the electricity of the air is positive in relation to the ground and the oceans. Its potential does not vary greatly, being rather higher in winter than in summer—a change which might be considered normal. During rainfall or snowfall the potential usually is unsteady, varying rapidly between positive and negative. The changes are quiet; in ordinary cases they can be detected only by means of sensitive electrometers designed for the purpose.

Ether Waves.—From time to time there are sharp but slight variations in the electric potential both of the earth and of the air. The former are created by the "earth currents" which, in the time when the telegraph was operated by grounded battery circuits, were the bane of the telegrapher. The sharp variations of the atmospheric potential are known as "static waves," or "ether waves"; they are the most common obstacle in radio-telegraphy and telephony.

The ether waves of atmospheric electricity apparently have little or no effect upon the activities of life; they also seem to be unimportant to meteorology, except as their increasing frequency may possibly indicate the approach of a thunderstorm.[1] Ether waves of the Hertzian type, caught at a distance

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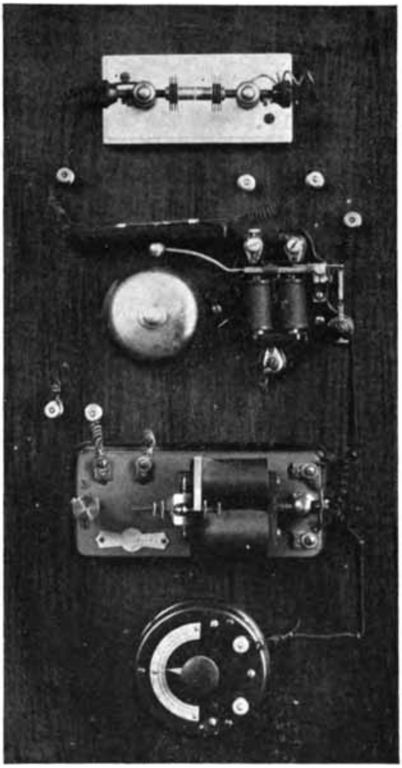
[1] Ether waves are made audible by means of the mineral detectors formerly used by radio-telegraphers, and by the use of the various devices known as audions. The passage of an ether wave caught by the antennæ gives a distinctive hissing sound in the telephone. A strong wave illuminates a Geissler tube placed in the circuit. A more striking result may be obtained by using a coherer and a relay with one or two dry cells. The passage of the ether wave from the antennæ to the ground electrifies the filings in the coherer to the extent that a battery circuit is formed, which closes the relay. The closing of the relay may be used to close a secondary bell circuit, or to communicate any other desired signal. A drop of *clean*

of 50 miles, more or less, from the thunder-storm, may be compared to the ground swell of the sea formed by a distant storm.

Electrical Conditions of the Air.—Humidity may or may not affect the potential of the air materially, but it affects the conductivity greatly. Dry air is a poor conductor; and dust particles, unable to discharge their load of electricity, are strongly repellant and remain suspended in the air, sometimes for several days. The desert simoon is followed by a condition which keeps the air at a high potential, with a highly electrified dust, for several days.

At the trading-posts in the Colorado and Mohave Deserts, after a simoon has passed, metal containers on wooden shelves become condensers of a considerable capacity. Horses' manes and tails stare like fright wigs, and sparks crackle to any ground conductor that may be touched. At such times, strong earth currents may be detected, and their influence may be felt many miles distant.

In a case of this sort the high potential is local—that is, it is confined to the mass of dry desert air, and this mass of air



Ether wave indicator, Meteorological Laboratory. The wire at the upper right of the spark gap leads to the aerial. The lower binding post of the condenser leads to the ground. The coherer is shown above the bell hammer.

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mercury between two iron plugs within a glass tube makes an excellent coherer, when placed in a circuit. Lighting companies sometimes make use of such "storm indicators" to guide them in generating the additional current made necessary by the darkness accompanying summer storms.

is practically a great condenser which has been charged to a potential much higher than that of the air surrounding. In time—from twelve to forty-eight hours—the high electric charge disappears, and the potential sinks to normal. The question—"How can the air, which is composed mainly of gases, become a condenser and hold a charge of electricity?"—is not difficult to answer. The static charge of an electrified body practically is on the surface of the body. Every substance must possess surface and the molecules of the gases composing the air are not an exception; neither are the dust particles floating in the air; therefore they act as condensers, receiving and discharging electrons.

Just as water, by seeking its own level, acquires an even and uniform pressure, so the electricity of the air seeks an even and uniform potential. If a body of cold, dry and highly charged air flows into a region of low potential, or into one oppositely charged, an interchange, or flow of electricity, results. The interchange may be so quiet that it escapes notice;[1] on the other hand, it may be violent enough to produce strong electrical discharges.

The origin and source of atmospheric electricity is still a problem to be solved; so also is the origin of earth electricity. To the best of human knowledge, the earth is constantly giving off negative electricity, and receiving none in return, except that which is brought down by rain, or by snow, or by lightning strokes which pass from the clouds to the earth. The reason therefor is not known.

It has been found that a rainstorm carries to the earth about 3.5 times as much positive as negative electricity;[2] and that positively charged snow falls more frequently than that which is negatively charged. A reason therefor certainly exists, but it is not known. The breaking of large drops of water into spray is accompanied by the production both of positive and negative electricity. Conversely, when fine spray is charged with electricity, the spray immediately coalesces into very large drops of water.

Extra-terrestrial Influences in Atmospheric Electricity.—The fact that rapid movements in sun spots and similar dis-

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[1] The interchange, no matter how quiet, will operate the apparatus described on p. 108.

[2] The records of Dr. C. G. Simpson, London Meteorological Office.

turbances in the photosphere, or envelope of the sun, are coincident with magnetic storms and earth currents leads to the belief that solar influences at times are factors in atmospheric electricity. It is not safe to infer, that because of this fact, the electricity of the earth and its atmosphere are derived from the sun. Practically all evidence is contrary to such an assumption; nevertheless, there seems no reason to doubt that high-frequency waves generated in the sun reach the earth.

The phenomenon known as the *aurora borealis* (*aurora polaris*), more commonly called "northern lights," is most frequently observed during great disturbances in the sun's photosphere. But it is by no means certain that the display, which is electrical, is due to solar causes. The belief that the aurora is of solar cause, however, is held by many physicists.

The height of the aurora above the earth does not vary much from 60 miles. It is rarely visible in the latitude of New Orleans, occasionally in the latitude of New York, and rather more frequently in the latitude of Quebec; its maximum frequency is in the latitude of Norway and the southern part of Alaska.

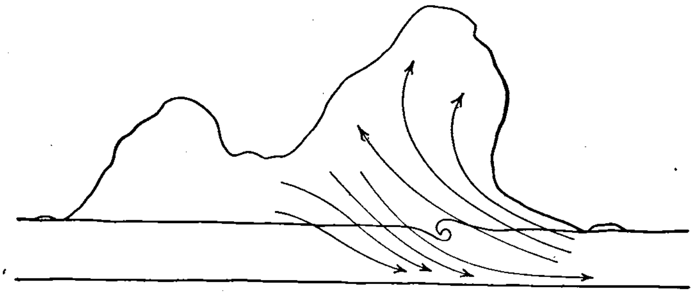
The time of frequency varies. At Hammerfest, Norway, it is not visible during the summer months, presumably because of daylight. In New York, the spring and fall months are the periods of greatest frequency. Records from 1764 show that auroras are much more frequent during the periods in which sun spots are most frequent; this is one reason why the aurora is thought to be due to solar influence.

The work of the observer is to watch carefully and to note faithfully whatever is visible. Information is desired concerning the position, direction and extent of the arch, if one appears—otherwise the position of the patch or patches of light. It is desirable to know whether the arch takes the form of a curtain, a luminous band, or a corona. It is also desirable to note whether the light occurs in rays with dark spaces between them, or is a diffuse illumination without definite outlines, or takes the form of dancing streaks of light, changing rapidly in color, form, and intensity. When possible, it is well to compare the aurora with illustrations in any known publication, especially with those in the Encyclopædia Britannica.

Thunder-storms.—The phenomena of thunder-storms have been known ever since human beings peopled the earth. The cause or causes are still imperfectly known.

Thunder-storms derive their name from the reverberations and crashes of thunder following lightning discharges, which possess an intensity unknown except in nature. These discharges take place between cloud and earth, between earth and cloud, and between cloud and cloud. But the lightning discharges are not the cause of the storm; they are incidents merely in its progress; and except in intensity and volume the thunder does not differ from the snapping of an electric spark.

Several things take place in the formation of a thunder-storm. A strong updraught of air and the shattering of raindrops are among the features necessary to produce free electricity. The updraught of air is almost always a noticeable feature, and this takes place conspicuously in the cumulus thunder-head. Ordinarily the base of the cumulus cloud is less than 1 mile in height; but the updraught that precedes the thunder-storm, and is a potent cause of it, carries the cauliflower head of the cloud to a height of 4 or 5 miles. It is within this head that the potential electricity of the raindrops is changed to kinetic or free electricity.



After Humphreys.

The movement of the wind in a thunder-storm; *A*, base of cumulonimbus cloud; *B*, ground level. A roll scud forms between the wind of updraught and that of a downdraught.

Experiments have shown that a blast of air driven against drops of distilled water, with a force sufficient to blow them into spray, produces both positive and negative electricity—

three times as many negative as positive electrons.[1] It has been found also that a velocity of 25 feet (8 meters) per second, or more, will cause the larger drops to be shattered and beaten into spray.[2] That is, if the drops falling in still air reach a velocity of 25 feet per second, they will be broken into smaller drops; or if the updraught exceeds 25 feet per second, the drops cannot fall against it; they will be shattered and carried upward until the velocity of the updraught is much reduced.

"Clearly," Dr. Humphreys states, "the updraughts within a cumulus cloud frequently must break up, at about the same level, innumerable drops, which, through coalescence, have grown beyond the critical size and thereby according to Simpson's experiments, produce electrical separation within the cloud itself. Under the choppy surges of a thunder-storm, the drops may undergo disruption and coalescence many times, and with each disruption a correspondingly increased electrical charge. Hence, once started, the electricity of a thunder-storm rapidly grows to a considerable maximum. After a time, the larger drops here and there reach places below which the updraught is slight; then they fall as positively charged rain. The negative electrons in the meantime are carried up into the higher part of the cumulus where they unite with the particles of cloud matter and thereby facilitate their coalescence into negatively charged drops. Hence the heavy rain of a thunder-storm should be positively charged—as almost always it is—and the gentler portions negatively charged—which frequently is the case."

The falling rain—and also the hail which occasionally attends a thunder-storm—cools the air through which it passes and the cold air sinks to the earth with a considerable velocity. As it reaches the earth the down-rush plows underneath the warm, moist air in front of the storm, lifting it and thereby aiding the updraught. As the cold air spreads over the ground its velocity is great enough to raise clouds of loose dust that almost always precede the fall of rain.

As in the case of other storms, the latent heat set free by the condensation of moisture is the fuel of the thunder-storm,

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[1] C. G. Simpson, London Meteorological Office.

[2] P. E. A. Lenard.

From Redway's Physical Geography.

Successive lightning flashes. Note the beaded flashes and the scud of nimbus cloud in center.

and the cause of the updraught. Rapid evaporation, on the other hand, together with the expansion of air in the updraught, is sufficient to account for the cold air, still further chilled by rain and hail, which finally culminates in the downrush.

Practically, the cumulus is the parent of the thunder-storm, and when it develops into the cumulo-nimbus stage it is essentially a thunder-storm. Even the apparently quiet cloud is always in motion within itself. Rising currents of moist air, chilled by its own expansion, cause condensation of the vapor into cloud matter. The coalescence of cloud matter into mist and droplets results in their fall to a lower level, where they are again vaporized; and the vapor, in turn, rises in the updraught. All this is constantly changing and disturbing the electric potential. When, however, the updraught is strong enough to shatter the drops into mist, the potential becomes so high that the violent discharges constitute the thunder-storm.

In other words, if the updraught is sufficiently strong to hurl the cloud matter to a height where condensation is very rapid, and also to shatter the falling rain-drops, the cumulus develops into a thunder-head at the top and a thunder-storm at the base.

Thunder.—The distance of the discharge may be found approximately by noting the interval between the flash and the thunder, allowing 1100 feet per second[1] for the velocity of the sound wave. In general, a nearby discharge is followed by an instantaneous report and this in itself indicates that the observer is in the danger zone. It also indicates a probability that the discharge passed between cloud and earth rather than between cloud and cloud. If there is no visible flash, it is likely that the discharge took place between cloud and cloud; and if no thunder follows a discharge, either the discharge occurred at a distance so great that the sound wave became inaudible, or else it was a silent "brush" discharge.

The long-drawn rolling of the thunder may be due to either or both of two causes. If the lightning is a flow or "streak" a mile or more in length, the sound from the farther part requires a proportionately longer time to reach the observer than that for the nearby part. Another factor also must be considered; what appears to be a single discharge may be an

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[1] The rate varies slightly with temperature and density of the air.

oscillatory discharge[1] which does not differ, except in intensity, from the undamped spark of a wireless transmitter, the several oscillations producing separate but interfering sets of sound waves. A more satisfactory theory makes the extreme and sudden heating of the air, with its moisture content practically an explosion with compression waves identical with those caused by instantaneous explosions. The reflection of sound also may be a factor in reverberation.[2]

Forms of Lightning.—The most common form of discharge is shown in the accompanying illustration. The discharge merely follows the line of least resistance. The zig-zag discharge, with sharp angles and saw-teeth points, once patronized by artists in order to give effect to their illustrative work, has never been discovered in photographs of lightning discharges. The most extraordinary effects of lightning are the *dark flashes* occasionally caught in photographs of lightning.

Sheet lightning is generally regarded as the reflection of distant flashes from the surface of clouds. On various occasions the exchange of electricity takes the form of a *bluish glow* between the earth and a low cloud. This form of discharge is rare; probably it does not differ from the brush-shaped discharge visible when a static generator is operated in the dark. The *St. Elmo fire* is a discharge of this sort. During its occurrence, the peaks of roofs, the limbs of trees, flag-poles, church spires, and weather vanes are tipped with coronal circles of electricity. The St. Elmo fire is of rare occurrence. It sometimes follows thunder-storms.

Ball lightning has been observed so many times that its existence seems to be established beyond doubt.[3] It has been

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[1] The oscillatory discharge is regarded as doubtful by some meteorologists. At all events, in traversing a conductor of moderate resistance it is damped practically to a current of unidirectional character.

[2] The electrolytic decomposition of water vapor and its recomposition in the form of successive explosions also has been suggested.

[3] Mr. George Reeder and his assistant Mr. Seaton of the Weather Bureau Station, University of Missouri, describe an instance of ball lightning, as "a pale red, slightly corrugated ball, apparently about 2 inches in diameter, moving across a space of about 6 feet between the telephone and a window. The ball seemed to float as a liquid bubble does, though it seemed solid. It kept a fairly straight line for the window; it rolled over the window sill and disappeared—not into the outer air, but by flickering out as a bubble does. There was no explosion or sound of any kind except a click of the telephone; there was no odor nor mark of any kind on the window sill."

explained as being due to a slowly moving point at which intense discharge is taking place; but this explanation is merely a possibility, not an established fact.

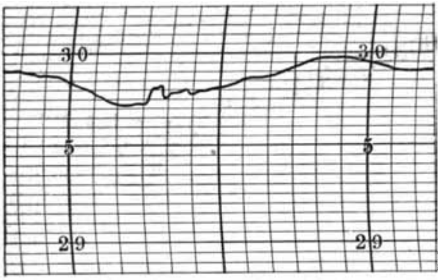
Occurrence of Thunder-storms.—Roughly speaking, the lower the latitude of moist regions, the greater the frequency of thunder-storms. In general, of two regions of the necessary warmth, one having moist air and the other dry air, the former is more likely to be visited by thunder-storms. They are more prevalent in the United States than in Europe; they are more prevalent in the southern part of the United States than in the northern part, so far as the region east of the Rocky Mountains is concerned.

According to A. J. Henry of the United States Weather Bureau, the regions of greatest frequency are in Florida, where thunder-storms occur 45 days in the year; in the central Mississippi Valley, where they occur 35 days in the year; and in the upper Missouri Valley, where the average is 30 days in the year. Thunder-storms rarely occur in the Pacific Coast states, but they are common in the Plateau Region.

Practically all the violent thunder-storms of the United States occur in the warm months. By far the greater number occur in June, July and August, during the hottest part of the day. There is also a period of minor frequency between 9 o'clock at night and midnight. Over the sea, however, the period of frequency is apt to be in the early morning, before daylight.

Occasionally the updraught of the ordinary cyclone may produce a thunder-storm; the thunder-storms of winter are of this sort and they are rarely severe.

Pressure Waves.—The accompanying barogram, recorded at the Mount Vernon Meteorological Laboratory, illustrates pretty clearly the progress of a thunder-storm. The barometer had fallen steadily for more than twelve hours preceding the storm; and this continued until well along in the afternoon. The slight rise of the barometer in the morning is the diurnal pressure wave. The jump in pressure in the afternoon is the characteristic "thunder-storm nose" which usually is found on barograph records of thunder-storms. An expert observer does not need to refer to his daily reports to find the records of thunder-storms; the barograms show them in most instances. The rise in pressure occurs when the descending wind lifts the warmer air above it. A second "nose" appears about 9.00, when clearing gusts marked the end of the storm.



A thunder-storm nose. Barogram of Mount Vernon Meteorological Laboratory, April 21, 1917. The rise in pressure at 6:15 p.m. was caused by the downdraught within the cumulo-nimbus thunder-head.

Forecasting Thunder-storms.—From the nature of the case, the general forecasts made by the Weather Bureau cannot designate the loci of possible thunder-storms, because the general forecasts are made too far ahead, and also because such storms are local.

The meteorologist in charge of the local station is able to forecast more definitely; and, where stations not far apart are fortunately situated, the formation of thunder-storms may be indicated with a fair probability of verification. With warm, moist air on the south side of a low, thunder-storms may be expected; and if one has formed, its path may be predicted with reasonable exactness. In the hands of a trained observer a barograph is a most useful aid. With the aid of the daily weather map, the local conditions of temperature and humidity, and the barogram, at least two hours' notice may be given.

The layman also may forewarn himself with a reasonable degree, if not of certainty, at the least, of probability. An aneroid barometer, if watched closely, may be serviceable; unless intelligently used it is of doubtful service to any but a trained observer. Nevertheless, there are indications that should warn even a casual observer who bears in mind that the thunder-storms disastrous to crops occur mainly in June, July, and August, and also that almost always they occur between mid-afternoon and sunset.

Warm and moist air is necessary to the formation of a thunder-storm; moderately quiet air is also necessary. A thunder-storm is not likely to form where a stiff wind is blowing. Cumulus clouds may be regarded with suspicion; indeed the cumulus is the thunder-storm factory; and when it develops into a cumulo-nimbus, the thunderstorm is probably at hand.

If the air of a warm, moist summer afternoon becomes still and oppressive and if cumulus clouds increase in size, a thunderstorm is very likely to follow; and if a nearby cumulus expands vertically into a thunder-head the storm is pretty certain to follow, somewhere or other in the vicinity. The thunder-head may be visible every where within a radius of 25 miles, but the storm path may be a narrow strip not more than 30 miles in length. The path of the thunder-storm, like that of the tornado, is determined by the circulation of the cyclone in which it is formed. Its forward movement, except in the extreme southern part of the United States, is from a westerly to an easterly direction.

Safeguards Against Lightning.—The destructive effects of lightning in the United States are chiefly loss of life and loss from fire. Loss of life occurs usually when lightning strikes trees under which people and animals have taken shelter. Trees are the objects most frequently struck. Wooden buildings when struck are apt to take fire instantly, but cases are on record which show that wet shingles and weather boards may be ripped off without further damage. Among structures, oil tanks stand first in the likelihood of destruction by lightning. Church spires and large barns are frequently struck, and isolated buildings are regarded as a far greater risk than city buildings; indeed, in the compactly built areas of a city the risk from lightning stroke is negligible.

Lightning rods afford the best protection against lightning. J. Warren Smith of the United States Weather Bureau found that in many thousand insurance risks, the destruction of rodded buildings was negligible. Other authorities regard the safety afforded by lightning rods at from 90 per cent to 97 per cent. The Bureau of Standards [1] points out the necessity of connecting all exposed metal surfaces such as metal roofs, gutters and tanks with the lightning rods. Sir Oliver Lodge recommends iron in preference to copper as a material for lightning rods for the reason that its greater resistance tends to damp the oscillations of a discharge, practically converting them into a one-way current.

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[1] *Bulletin* 56.

Atmospheric Optical Phenomena

A ray of light may pass through a solid, such as glass; a liquid, such as water; or a gas, such as oxygen, nitrogen or water vapor—that is, the air—without much apparent loss. Such substances are *transparent*. In passing through different substances the ray is likely to be bent out of its course, as is apparent when a stick is thrust obliquely into a body of water. The bending of the ray is called *refraction*. Or if it is turned back, as when it impinges upon a mirror, it is said to be *reflected*.

A ray of light impinging upon a piece of black cloth is said to be *absorbed*. If only a part of the ray is absorbed, the rest being reflected, the parts of the ray reflected produce the sensation of color.

If a ray of light is passed through a wedge-shaped prism the component parts of the ray are unequally bent or refracted, and reach the eye in a series of colors. Red is the least refracted; violet suffers the greatest refraction. A ray of white light, therefore, is not of a "bundle" of wave-lengths of the same magnitude, but a bundle of an infinite number of rays of different wave-lengths.

In passing by the edge of an opaque body, or in passing through a very narrow slit, a ray of light is deflected slightly, and alternate fringes of light and dark bands are produced. The deflection and interference constitute *diffraction*, and diffraction is also a factor in giving various color tints to the sky.

The various atmospheric optical effects of the sky are produced mainly by refraction, reflection, diffraction, and absorption of light by the constituents of the air. The color of the sky itself is due to the irregular scattering and dispersion of light as the sun's rays glance from the gaseous molecules and minute dust motes of the air. The most common incidents of atmospheric optical phenomena are coronas, halos, rainbows and mirages.

Corona.—A corona consists of a ring—sometimes several rings—rarely more than 4 degrees of arc measurement in diameter, surrounding the sun or, more commonly, the moon. The corona is a case of diffraction, the deflection of rays passing by water droplets.[1] The inner border of the ring is brownish-

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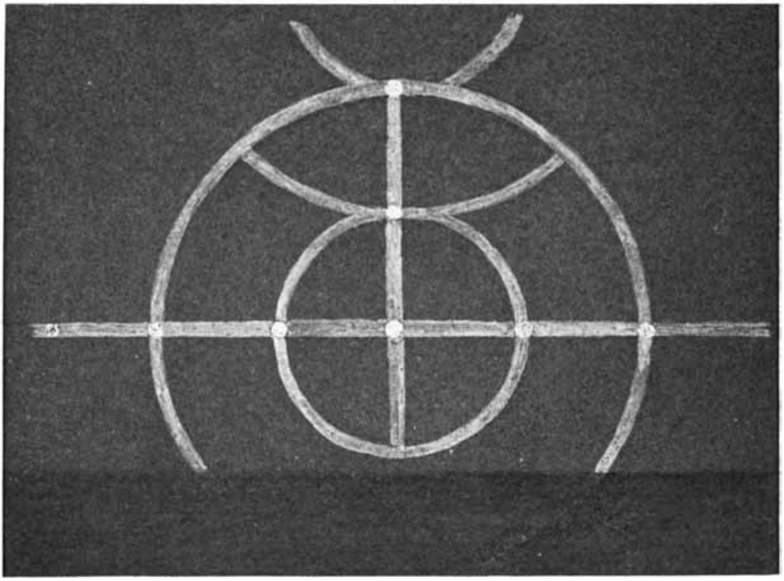
[1] In a foggy atmosphere, an observer with his back to the sun sometimes sees a dim, colored ring surrounding his shadow which is cast upon the fog. This phenomenon, known as a "glory halo," is probably a corona.

red. Within the ring is a bluish-white surface, the *aureole.* If spectrum colors other than the red are observable, they follow each other in order from violet to red, reversing the order of halo colors. This sequence of color sometimes is repeated several times in the case of the corona but not with the halo.

Halo.—The most common form of halo is the ring around the sun or moon. It has a radius of about 22 degrees of a great circle. At times, however, the halo is a complex arrangement of concentric tangential and independent arcs of circles. The simple halo is practically a rainbow, red inside the ring, with colors on the outer side ranging in spectrum order. Unless the halo is strong, however, the impression to a casual observer is that of a white ring. Occasionally another fainter and incomplete ring of 46 degrees radius may be observed. Still more rarely a white ring parallel to the horizon and passing through the sun is observable. At or near the intersection of this circle with the halo, mock suns, *parhelia*, or mock moons, *paraselenæ*, appear as very bright spots, with red predominating. Mock suns and mock moons are seen at times in other positions. The



From a drawing made by himself.

Lunar halo observed by Gen. A. W. Greely at Fort Conger.

mock suns at the intersection of the 22-degree circle are usually bright and decidedly red next the sun; those at the intersection of the 46-degree circle are faint. Occasionally a white spot is observed on the sky opposite the sun. This is the *counter sun*, or ant-helion.

As a rule, the various circles, with the exception of the halo circle, are only partly visible; and in many cases the unusual arcs seem to have no connection with the halo. Many interesting illustrations of complex halo circles have been published. Usually these have the circles of 22 degrees, 46 degrees, and the mock-sun circle in common; otherwise they are unlike.

Occasionally a vertical column of sheen extends above and below the sun—perhaps more frequently the moon; it is known popularly as the *pillar of light*. Rather infrequently a horizontal bar of sheen may be seen forming the popularly named "heavenly cross."[1] *Sun pillars*, varying in color from white to red are occasionally seen at sunset or at sunrise. Patches of color occasionally are observed in cirrus and cirro-stratus clouds at a considerable angular distance from the sun. They may be due to causes similar to those which produce halos, but the causes are not known.

Cirrus or cirro-stratus clouds, or ice mist, in front of the sun or the moon are necessary to the production of halos. Some of the ice crystals are tabular; others are columnar and prismatic in shape. It is thought that both reflection and refraction of light are involved, each depending on the character of the crystals. Spectrum colors which abound in halo phenomena are explainable as a result of refraction; white-light surfaces may be due to reflection.

Rainbow.—The rainbow against a dark gray background of cloud is one of the most beautiful objects in nature. It may be seen as a full circle against spray thrown into the air, or against a mist. The rainbow of the summer shower consists of a bright arc near the horizon and usually a fainter arc above. The radius of the bright, or *primary bow* is about 42 degrees of arc; that of the upper or *secondary bow* is not far from 52 degrees of arc.

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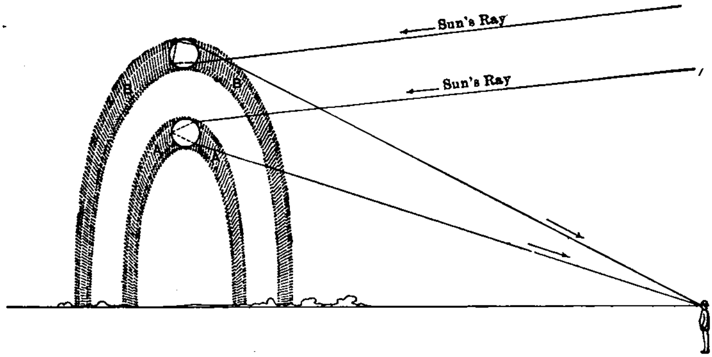
[1] This effect may be produced by looking at the moon through a piece of polished copper screen-netting held at a distance of 20 feet. It is an effect of diffraction.

The rainbow is best observed when the sun is not more than 45 degrees above the horizon; it forms in the side of the sky opposite the sun. On rare occasions a tertiary bow may be seen between the observer and the sun.

The colors of the rainbow vary in intensity and in quality. Red is always in evidence outside the primary and inside the secondary bow; orange, yellow and green are commonly though faintly observable; blue is sometimes seen; but violet is rarely if ever observable. The strength and the sequence of the colors depends mainly on the size of the drops, but partly on their distance and the number of them.

Each observer sees his own rainbow, and each rainbow is practically a series of hollow concentric cones, the vertex being at the eye of the observer. The rainbow moves forward, backward or sideways as the observer moves. A shower in one part of the sky and sunshine in another, the observer being between, are requisite for rainbow formation; and this condition, in most parts of the world, is confined to summer showers.



Refraction of light passing through rain-drops.

Mirage.—Owing to changes in temperature the density of the air varies almost constantly at different heights. Rays of light passing through air of varying density are bent differently with each change of density. An observer looking at a distant object sees the object with distorted outlines. An elliptical sun at sunset is very common; and sometimes one sees it with greatly distorted outlines.

When a layer of air rests quietly on another the plane of contact, if below the observer, reflects the sky in much the same manner as does a body of water. An object at this plane is seen both upright and inverted, thereby forming a *mirage*. If the plane of contact is materially above the eye of the observer the inversion occurs in the air. Occasionally inverted images of the shipping in the harbor are formed.[1]

The *looming* of objects—that is, bringing to sight objects that normally are below the horizon—is clearly a case of refraction. The rays of light which should pass above the observer are bent within reach of his vision.

According to legends a fairy named Morgana hovered around and about the southern coasts of Italy. This sprite used her powers romantically rather than maliciously to change the commonplace shoreline across the straits of Messina to a most wonderful landscape of turreted embattlements and castellate fortifications. Hence the name, *Fata Morgana*. The phenomenon apparently is produced by a horizontal layer of air, denser at the center than at its surface. It therefore becomes practically a cylindrical lens which magnifies in a vertical but not in a horizontal direction. It may be considered as a form of looming.

It is probable that the Brocken spectre is produced in part by a mass of air which acts as a lens. The traditional "heiligenschein," or halo, is an example of diffraction, however.

[1] Many physicists hold that the inversion in such instances is due to refraction. In one popular textbook of physics a diagram graphically describes the method of refraction; but the diagram illustrates reflection. The mirage is considered in detail in Chapter XII.

CHAPTER XI

THE DUST CONTENT OF THE AIR

Dust is usually classed as "foreign matter of the air." Such a view of the shell of wind-blown dust is permissible. It might also be considered logical as regards the finer dust particles which do not reach the ground except by means other than their own gravity. It is hardly logical to consider the dust of the stratosphere as foreign matter of the air; for, as a matter of fact, it is permanently and not temporarily there. Moreover, cosmic dust seems to pervade every part of the universe which the solar system traverses, and the earth is constantly gathering dust from space.

"Invisible" Dust; Characteristics.—Practically nothing is known of the dust of the stratosphere, except that its presence is revealed in various ways. The particles themselves are too small to be discerned by any mechanical method at present known. *En masse* they reflect enough sunlight to reveal their existence, but not their form nor their constitution. In part, and probably to a great extent, they constitute the overhead effect noted by observers for more than six thousand years—the sky. An estimate of the size of such dust particles cannot be made with any degree of accuracy. It is safe to say that they are much smaller than the smoke particles that escape from the burning end of a cigar. It safe also to say that they are smaller than the particles which constitute the "blue haze." As a matter of fact, rapid changes in sky polarization indicate about the only thing that can be authoritatively asserted—namely, that the invisible particles behave much like the molecular constituents of the air.

Measurements.—Under the stratosphere, the dust particles of the air are of every possible size, from those of the blue haze to the coarse rock waste of the simoon. The micromillimeter, practically the twenty-five thousandth part of an inch, is a convenient unit of measurement. It is convenient because of the fact that dust particles of this dimension are very near to the size of the permanently floating dust motes of the air.

The research work of Dr. John Aitkin, the highest authority on the subject, has shown that clean air contains from 3000 to 5000 visible dust particles per cubic inch. The air of schoolrooms and public buildings with undressed wood floors carries from 60,000 to 80,000 particles which are visible under the high power of a microscope, and an unknown number which can be counted only when amplified in size by the condensation of moisture upon their surface.[1] Dr. Aitkin found the cleanest air at snow-clad heights in the Alps, and not over the sea, as one might expect.

Electrification.—To the best of knowledge, the invisible dust, both in the stratosphere and the sphere of convection, does not depend on winds for its distribution. The particles themselves behave as do other ionized bodies, and it is not impossible that their suspension in the air is due to electrification.[2] There seems to be no reason why the ionization of minute dust particles should not occur in the same manner as the ionization of the molecular constituents of the air.

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[1] The dust-counter used by Dr. John Aitken consisted of a chamber or receiver, into which a measured portion of air was drawn. The receiver contained a small amount of water—enough to keep the air pretty nearly at saturation. A slight reduction of temperature by means of an air pump causes almost instant condensation. By counting the droplets condensed on a ruled silver plate within the receiver, using a magnifying lens therefor, the number of droplets per cubic centimeter, or per cubic inch, may be estimated. Dr. Aitken obtained the best results when the dust content of the air was small. In practice he therefore mixed the air to be examined with a measured quantity of air made dustless by filtration. A modified dust-counter, the "koniscope" is a more practical instrument, though not so accurate.

[2] A solid of 1 inch cubic measurement, weighing 1 ounce, has 6 square inches of surface. If it be shaved into slices one one-thousandth of an inch in thickness, each slice loses 999 parts of the original weight but only a little more than 4 parts of the original surface. That is, in subdivision, a substance loses weight much more rapidly than surface. The weight of a dust particle one twenty-five thousandth part of an inch in dimension is less than one fifteen trillionth of an ounce. The surface is almost infinitely great in comparison. Now, the electric charge of a dust particle, condensed on its surface, is of the same kind as that of the earth. Therefore they mutually repel. It is only fair to add that the theory of the electrification of dust is not fully substantiated.

Dust and Condensation.—The experimental work of Dr. Aitkin showed conclusively that the moisture of the air condensed with difficulty in dustless air even when the temperature was several degrees below saturation; in normal, or dust-laden air, condensation took place readily. The repetition of Dr. Aitkin's experiments under widely diverse conditions has left no doubt that the dust particles of the air, including sulphur gases set free by the combustion of fuel, are the most important factors in condensation. The research of C. T. R. Wilson brought to light additional knowledge; Wilson found that the passage of a beam of ultra-violet light through air caused condensation, even when its temperature was slightly below that of saturation. Saturation temperature, however, is not wholly necessary to condensation; a certain but small amount of condensation goes on below the temperature of saturation. Condensation goes on more freely when the humidity—both absolute and relative—is high.

Dust particles differ greatly as nuclei of condensation; they may be "good," "indifferent," or "poor." The reason for the difference is not known with certainty. It may be that quickly cooling particles are better condensers than slowly cooling particles; it may be that a high degree of ionization favors rapid condensation; or that the more hygroscopic a particle the more freely it condenses. Each is a reasonable hypothesis that remains to be substantiated.

Barus and Pierce have shown that the dust particles over Providence, a manufacturing center, are far more favorable to condensation than those observed contemporaneously at Block Island. The reason therefor may be a difference in the chemical character of the dust particles; it may be due to a difference in the degree of ionization; it may be due to other and unknown causes.

One thing, however, is certain: The dust particles belched from the stacks of manufacturing districts are such excellent nuclei of condensation that the prevalence of fogs over such districts has given rise to the term "city fogs,"[1] as distinguished

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[1] It has been pointed out that sulphur dixoide molecules in themselves are not "good" nuclei. Sulphur dioxide is a gas and is not to be included in the dust content of the air. But the intense heat of combustion has separated it from the combination in which it existed. The chemical affinity

from the ordinary advection fogs. The distinction is a practical one. It is pertinent to add also that a city fog forms usually under a lid. But while the city fog condenses on particles that are hygroscopic, the fogs of swamp lands, rivers, and ponds condense on particles that are materially different. Condensation does not take place so readily—in other words, the dust particles are indifferent nuclei. A thick fog condensed on nuclei of an indifferent sort may be "eaten up" by a slight rise in temperature; it may rain itself to pieces by a drop in temperature.

Sources of Atmospheric Dust.—Aside from the dust picked up and carried by the winds, there are well-defined sources of floating dust that must be considered. Cosmic, or meteoric dust, is not born of the earth; it is gathered by the earth from space. Large particles fall to the earth; but those materially less than a micromillimeter constitute the floating dust of the air. The character of this dust can be recognized only when the particles fall to the earth or are trapped while floating near to its surface.

Many of the particles thus caught are tiny meteorites. These, in many instances, are metallic globules or floating metal bubbles. They are essentially different from the metallic particles of smeltery dust, emery-wheel dust, and brake-shoe dust, which also are metallic. The cosmic dust of non-metal character cannot be recognized with any degree of certainty; indeed, recognition of any sort of dust whose particles are less than a micromillimeter is difficult. The gathering of cosmic dust seems to be constant rather than sporadic.

Additions of volcanic dust to the floating dust of the air are made irregularly, but they come in enormous quantities. Much of the ash [1] falls to the ground, but a very large part consists of particles fine enough to constitute floating matter. The eruption of Krakatoa,[2] in 1883, projected so much floating

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of the nascent gas is strong, and in the air it is apt to enter into combination again with dust particles of basic character, the resulting combination forming nuclei favorable to rapid condensation.

[1] Volcanic "ash" is not a product of combustion. It is the convenient name applied to lava blown into fine dust by the expansive force of steam, or by other forces.

[2] The eruption, which threw the ash into the air, had proceeded for several

dust into the air that the trail, which girdled the earth several times, was visible at sunset for nearly two years. The blood-red sky [1] at times rivaled the northern lights. Less marked red sunsets followed the eruptions of La Soufrière and Mont Pelée in 1902. The explosion of a great quantity of munitions in New York Harbor was followed for several days by red sunsets observable as far west as the Weather Bureau station at Ithaca, N. Y. The dust mantle of the Greenland glacier is apparently of volcanic origin. Indeed, volcanic dust is always an important constituent of the floating dust of the air; at times it is the chief constituent.

The floating dust of the air has a marked effect upon its temperature. Benjamin Franklin noted this fact. During several months in 1783, the air was filled with floating volcanic dust. "The sun's rays were indeed rendered so faint in passing through it that, when collected in the focus of a burning glass, they would scarcely kindle brown paper." The heating power of the sun was so feeble that freezing temperatures began nearly a month before their normal occurrence. "Delaware River was closed in November and remained ice-bound until late in March." [2]

The years 1812-1816 were years of great volcanic activity, and the air was loaded with floating dust. As a result, the year 1816 has gone into history as the "year without any summer"—the year of "eighteen hundred and froze-to-death." In Vermont snow fell and frosts occurred every month of that year. On the 8th of June, snow on the uplands was 5 or 6 inches deep.[3]

Humphreys has shown that, with a blanket of volcanic

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days, during which time the coarser dust fell on the nearby islands and into the sea. This, a normal eruption, was separate and distinct from the explosion which shattered the island.

[1] By reflected light, fine dust particles tend to a whitish color, and to a bluish tint if very fine and fewer in number. The purity of the tint depends, to a certain degree, on the size of the particles. By transmitted light, especially when the sun is near the horizon, the blue and the violet rays are absorbed and scattered and the red rays reach the eye of the observer. When the air is full of floating dust, the scattering of blue and violet rays is very great.

[2] The Philadelphia Inquirer.

[3] Thompson's History of Vermont.

dust in the air, while the earth is receiving a lessened amount of heat from the sun it is radiating into space about thirty times as much.[1]

The products of combustion must also be taken into consideration as having a similar effect on absorption and radiation of heat. The world's fuel consumption each year is the equivalent of about 1,500,000,000 tons of coal. Forest fires and grass fires add to the total of combustion whose products in part escape into the air. By their means an enormous number of dust particles are projected into the air and distributed through it. As a rule, the dust particles of fuel combustion are nuclei favorable to condensation. One cannot estimate even broadly the extent of air pollution from this source; it can be measured chiefly in terms of city fogs.

The suspended matter of combustion products has been measured at times. Systematic measurements both of suspended matter and of matter which is brought to the ground by rainfall have been made in various parts of England, at regular stations. The insoluble matter caught in gauges consisted chiefly of smoke carbon, a mixture of free carbon and heavy hydrocarbons, minute globules of liquid tar and insoluble ash. The soluble matter consisted of various sulphates, chlorine, ammonia, and soluble ash. The amount varied from a few hundred tons per year on each square mile to nearly 6000 tons per square mile. Measurements in several manufacturing districts of Pennsylvania showed an average of about 1900 tons per square mile per year falling to the ground.[2]

In regions where smokeless fuel is used there practically is no smoke problem, and the pollution of the air is confined almost wholly to wind-blown dust and to local sources of pollution. In localities swept by sea winds, salt derived from wind-whipped spray is usually a factor in the floating dust. In most of the large seaports of the United States the chlorine content from this source is made a matter of systematic measurement. The tendency of tools and polished steel articles to become rusty in the vicinity of the sea is probably due as much to the chlorine content of the air as to the presence of excessive moisture.

[1] Physics of the Air.

[2] H. H. Kimball.

Wind-blown Dust.—In regions of sparse vegetation, where the ground is bare, enormous amounts of loose rock waste are moved hither and thither by the wind. The increase of the carrying power of the wind with increment of velocity is almost beyond belief. When the velocity of the wind is doubled its carrying power is increased sixty-four fold. In regions of loose rock waste the wind becomes a wonderful physiographic factor. The broad, intermontane valleys of the plateau region have been filled with rock waste, much of which is wind-blown; and the floors of the deeply filled valleys have been made level by wind-blown dust. The plains to the eastward of the Rocky Mountains are deep with wind-blown dust. More dust and rock waste is deposited in the rivers of this region than they are able to carry. Platte River, popularly described as "a mile wide, an inch deep, and bottom on top," is an instance of a river drowned by the rock waste which it cannot carry.

Winds blowing steadily for centuries have carried fine rock waste from the Gobi far into eastern China, choking the gorge of the Hoang in places with wind-blown dust more than 100 feet deep. The loess deposits in the lower course of the Hoang are also of wind-blown dust, which has been dumped into the river in quantities greater than the river could carry. In 1851 the channel had become clogged to the extent that the river broke its banks near the city of Kaifeng, abandoned the old channel to the delta of the Yangste, and made a new channel to the Pechili. The sediment with which the river had clogged its channel was wind-blown dust. In general, the action of the wind in unswarded regions is one of leveling. It wears away the high spots and fills the low spots.

In regions of generous rainfall, the surface is covered with vegetation to the extent that very little rock waste is exposed to the action of the wind. About the only physiographic action consists of the formation of sand dunes to the leeward of ocean and lake shores. In various instances these have gradually traveled a distance of several miles inland, ceasing to advance when growing vegetation has anchored the sand in place.

In cities and much-traveled rural districts, the wind-blown dust is picked up mainly from dirt streets, school playgrounds, and other unswarded areas. The wind-blown dust from these consists chiefly of loose dirt, paving material, garbage, finely pulverized horse dung, and foliage dust. The dust carried by winds blowing over areas of orchard and shrubbery usually contains the spores of fungi, pollen in season, the spores of various moulds, the eggs of insects and the dust scales of moths. Winds blowing over swampy areas are apt to have a generous content of the micro-organisms common to swamps. Dry air contains the spores of micro-organisms; moist air is often rich in the organisms themselves.

Bacterium Content of Dust.—Dr. T. M. Prudden exposed Petri dishes, each varnished with a gelatine culture medium, for five minutes in different parts of New York City. The dishes were set aside for several days. Each micro-organism falling on the plates developed into a "colony." The colonies were counted with the following result:

1. Ball ground, Central Park, a westerly wind	499
2. Union Square, at fountain	214
3. A private library	34
4. An uptown dry-goods store, near Broadway	199
5. Broadway and 35th Street, small park	941
6. A cross street, after sweeping	5810

Examination of dust collected by the author in school rooms and from the book shelves of a public library yielded results similar to those obtained by Prudden.

The foregoing presents general principles worth noting: micro-organisms may fall to the ground and become a part of the dust of a public street. They also float a long time—some of them permanently—in the air. Exposures 1, 5, and 6 show that, when the air is in motion, the bacterium content is much greater than when the air is still. Measurements made at the direction of the Transvaal Chamber of Mines showed that dust particles 1 micromillimeter in dimension required about five and one-half hours to fall a distance of 7 feet. At the Mount Vernon laboratory, particles of the same dimension required from six to ten hours to fall 9 feet.

Equally important is the fact that, when the air is stirred by sweeping, the tramp of footsteps, or the passage of vehicles, its bacterium content—and also its dust content—is much greater than when it is still.

CHAPTER XII

THE PRINCIPLES OF ATMOSPHERIC VISIBILITY

The transparency of the air is a matter which affects every organization engaged in transportation; the impairment of visibility has led to wrecks without number upon land and sea. Within the past few years wrecks from this cause have become a serious menace to air transportation.

Standards for testing the transparency of the air and for measuring the impairment of visibility are used here and there, but there is no uniformity among them; for the greater part they are local as to usage. A few, such as the visibility of the sun's disk, the variability of certain stars, and the sharpness of a shadow cast by a rod on white paper, are pretty general so far as overhead observations are concerned.[1] Seamen all over the world are pretty apt to judge visibility by the clearness of the horizon; and the principle of camouflage is not so much to conceal a vessel as to blend it with sea and sky so that its outlines are indistinguishable. The locomotive engineer gauges visibility according to the plainness with which he can see semaphores during the day and signal lights by night. The marine pilot must be able to distinguish the colors of code flags and smoke stack markings, as well as colored lights. The air pilot must be able to discern the condition of the atmosphere by the refraction of the light passing through it or reflected from it. For almost all purposes, the problems of visibility must be determined along horizontal lines. The impairment of visibility along vertical lines becomes a danger when an airman cannot see his landing place.

Good visibility is safety; poor visibility is danger.

Several factors are concerned in the change from good to poor

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[1] Sir Napier Shaw suggests the degree of visibility of the Zodiacal Light, during the season when it is visible, as a test of the clearness of the air. In many laboratories observers note the degree of clearness.

visibility, and these are all contained within the air itself. The factors which impair visibility are:

Fog.
Thickly falling snow.
Dust storms in arid regions.
Very fine rain—many drops per cubic foot.
Heavy rain—large drops.
Dust storms in swarded regions.
A smoke pall held down by a "lid."
Moisture haze in a smoky air.
Moisture haze or dust in clear air.
Refraction caused by the mixing of warm air and cold air.

Experience and judgment have taught pilots how to avoid dangers that confront them. It remains for meteorologists to fix definite standards and to express varying visibility in terms that are comprehensible and intelligible to all. Moreover, in many instances, changes in visibility may be forecast with a high percentage of verification.

Fog is generally regarded as the chief factor in the impairment of visibility, but the various other factors cannot be arranged in an inflexible order. A desert simoon may impair visibility quite as much as the worst fog; but simoons are rarely in the van of transportation, while fog is practically coincident with every line over which commerce is carried. On the other hand, though the blurring of outlines by refraction, and the slight discoloration of the air by a dust haze may reduce transparency, neither one is a menace to safety. Not even a moisture haze is disconcerting unless it conceals the horizon.

In general, the impairment of visibility is due to various movements of the air within itself. Except as the wind picks up fine dust, nothing is added to or taken from the air to make the difference between transparency and opacity. The great planetary movements of the air need not be considered here. The cloud belts incident to them and the conditions which produce precipitation are fairly understood; they are regular and periodical. Such movements as are not planetary—the cyclones and the anticyclones are understood as to cause and effect, and the forecasting of them has become a science. But there are other movements, more or less superficial and local, that are not so well understood. The causes of them may be known, but the effects cannot always be forecast. These movements are commonly grouped under the generic name of *turbulence*, and much of the impairment of visibility is due to them. Air in convectional equilibrium as to temperature and humidity may be clear and transparent at one time; a mixing process may cause it to be opaque a few minutes later. The change may be due wholly to turbulence.

Turbulence.—Sudden and local movements of the air are due usually to changes of temperature. A change of temperature produces a change in pressure; a flow of air results, and the flow—that is, the wind—continues until equilibrium is restored. But the moving of the mass of air does not always produce a mixing; indeed, the plane of contact where it meets another body of air differing in temperature and humidity sometimes is sharply defined. The friction between the two masses frequently causes the condensed vapor to be rolled into long windrows or billow clouds. The airman has learned that visibility is impaired in this plane of contact and, that in passing from one mass to another, he is likely to experience a sharp bump.

As a matter of fact, most of the turbulence which results from the mixing of air begins at the ground. The "skin friction" of the wind dragging over water reduces its velocity along the plane of contact about one-third; over the ground the reduction is roughly twice as great.[1] The drag rolls great sheets of air into volutes. These, as they are pushed upward, bend into fantastic shapes, but continue to rotate upon many axes of many angles. Sometimes a volute bends into a ring, and the ring itself rotates on a constantly changing diameter in irregular librations. The movement, however, is upward as well as onward.

Now, this process of mixing is wholly different from the ordinary convectional movements of the air. A knowledge thereof is important to the marine pilot because it is the chief cause of sea fog along the Atlantic steamship lanes. Thus, a warm, moist wind blows into a region of the drift of a cold current. The chilling of the water vapor quickly condenses it to fog, and the churning movements of turbulence carry the process of condensation higher and higher.

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[1] G. I. Taylor, Meteorological Office, London.

To the pilot, the result is not merely impairment of visibility; it may be almost obscurity. The airmen who crossed the Atlantic emerged from the sea fog with plane wings thickly covered with ice.

The upward movement of turbulence, "the railway of the air" continues until resistance balances initial force—that is, to an altitude which practically is a lid. At this plane the fog spreads out, forming stratus clouds.

Convectional Movements.—A similar movement takes place when air is warmed. An ascending movement occurs at the focal area of warmth; descending air flows in to take its place. To a certain degree, these movements are planetary; in the tropics, ascending currents are the rule, and these are balanced by descending currents in higher latitudes. Planetary convectional movements are pretty well known and the limits of their procession and recession with the apparent motion of the sun are also known. The time, limits and location of the impairment of visibility resulting from these movements are also pretty well established. Indeed, the Coast Pilot Charts of the Hydrographic Office afford the information by which the loci of impaired visibility may be determined.

There are other examples of convectional movements which may be regional but are not planetary. The cyclonic movements are ascending convectional currents; the anticyclones are descending currents. The cyclone is very apt to be an area of impaired visibility, especially on the southeastern half, in which rain, snow and fog may be expected. The anticyclone may sweep snow or dust in blinding quantities up to a distance of a few hundred feet above ground; but it generally brings the conditions of best visibility.

Various causes bring about local updraughts of small area. Thus, during hot weather, a large area of bare rock surrounded by greensward becomes a local radiator of heat, and a sharp updraught results. Vision through such an updraught may become blurred, but it is not greatly impaired. The airman entering it gets a bump that rattles his plane, however. Descending currents in the shape of downdraughts of small area if rather strong are apt to be dust-raisers; they are "woollies" over water. There may be a slight blurring of outline due to refraction, but there is otherwise but little impairment of visibility.

The obscuration of outlines of objects at ground level may warn the airman in some cases that he is nearing a downdraught. The obscuration may be a dust storm; if under a cumulo-nimbus cloud it is pretty certain to be a dust-storm; in snow-clad regions it may be due to wind-blown snow.

In any case, although they do not materially impair visibility, such local convectional movements are more disconcerting than the cyclones and anticyclones. The forecasting of these and the charting of their tracks has become a science. Small local convectional movements cannot ordinarily be predicted along with general forecasts; but in various cases they may be predicted locally. Thus, during abnormally hot days in the valleys east of the Coast Ranges of California, the updraught is so great that strong sea winds prevail along the coast. The air is clear until after sunset; then, because of rapid cooling, fog billows roll in through the Golden Gate and cover much of the lowlands.

The Ceiling or "Lid."[1]—The paradoxical epigram, "air to be warmed must first be cooled" and *vice versa* is strictly true. If a body of air, having been thoroughly mixed, comes to rest, the temperature is not the same throughout its mass; it is cooler at the approximate rate of 1 degree Fahrenheit for every 183 feet of ascent (about 10 degrees centigrade per kilometer). It may be defined as being in convective equilibrium while in such a condition. Now, if a body of air at the top be cooled a few degrees, it contracts and becomes relatively heavier. Because it is heavier, it begins to drop. It is warmed by compression as it descends, but it is always surrounded by warmer air; so it drops until it reaches a plane which it cannot penetrate—sometimes a layer of colder air; sometimes the ground.

Similarly, if a mass of air at the ground be warmed ever so slightly above the surrounding air, immediately it begins to ascend, being floated upward because it is lighter. It is chilled by its own expansion as it ascends, but as its temperature remains higher than that of the surrounding air it continues to rise until it reaches a layer of air as warm as itself. At that level it ceases to ascend, and spreads out instead. This plane therefore becomes a "lid." Perhaps it may reach the stratosphere,

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[1] This term was adopted by Sir Napier Shaw in a monograph on atmospheric transparency. It would be difficult to coin a more appropriate name.

for the stratosphere is a planetary lid that envelopes the convectional air; but a lid may form anywhere between the ground and the stratosphere. Wherever a layer of warm air rests on one of still, cold air a lid is formed. Smoke, dust, and other fine foreign matter spread out to form stratus cloud when it reaches such a lid. If the two air layers are not turbulent there is little or no mixing.

Low stratus clouds indicate the height of a lid near the ground—half a mile or more; but the stratiform appearance is seen to best advantage when the clouds are not higher than 30 or 40 degrees above the horizon. Near the zenith they lose their stratiform shape, being then seen in "elevation" and not in "plan"; but frequently they indicate themselves to the practised eye of an observer. The strato-cumulus clouds that follow an anticyclone also indicate a lid. The high fog that completely covers the sky at heights varying from 7000 to 10,000 feet—practically a stratus or an alto-stratus cloud—is a lid. Cross-winds at a very considerable height likewise may indicate a lid.

The presence of a lid has much to do with the comfort of the airman. In penetrating a lid the plane is apt to get a sharp bump. If lightly ballasted, a free balloon may rebound after descending upon a lid and shoot upward several hundred feet. Sir Napier Shaw has called the attention of aeronauts to this possibility.

A low lid affects visibility to a marked degree. Under the lid, fine floating dust, smoke and the various gases of combustion spread out in stratus cloud and greatly impair visibility. The famous London fog is due to the persistence of a low-lying lid.

The impairment of visibility depends partly on the height of the lid and partly on the character of the content of the air underneath it. In open, swarded regions where the air is free from pollution, not much impairment of visibility is likely to exist. In regions where soft coal is used as power fuel, chimney products may accumulate to such an extent that impairment becomes a very serious matter; and the lower the lid, the greater becomes the impairment. Obscurity is apt to grow until increasing pressure breaks the lid and brings about a.clearing of the air.

Pressure is an important factor in visibility. When the air is misty and the seeing generally is poor a very slight increase in pressure clears it up at once. As a cyclonic depression ad-advances the seeing becomes poorer, because of rain or snow, until the trough passes. Then the seeing at once begins to improve, with increase of pressure.

The foregoing, turbulence, convection, and inversion—that is, the formation of a lid—are the principal movements of the air which impair visibility. The factors themselves are moisture, dust, smoke and refraction of light. The dust and smoke differ merely in origin; the moisture may appear in the form of fog, mist, rain, or snow.

Fog, Cloud, Mist.—In marine transportation, fog is the worst factor in the impairment of visibility. Practically it is the only one. If the temperature is brought below the dew-point, fog results from condensation of the water vapor. The brisker the wind, the thicker the fog blanket. A convectional updraught does not destroy the turbulence; convection merely carries it higher.

The thickening of a sea fog is an illustration. If the sea water is colder than the air, which is the case when polar waters intrude within lower latitudes, warm air blowing over it will give up its vapor in the form of fog. So long as the eddying movements of the air are constantly bringing warm air next the cold water, fog condensation increases. The fog blanket thickens; its upper part marks the height at which the temperature of the air is above that of saturation.

The fogs of the Newfoundland Banks have been the terror of the sailing route between American and British ports. They will prove a much greater hazard to air transportation unless a circuitous southerly route is followed. An Arctic current and a southwest wind laden with water vapor constitute the working machinery of this fog factory. Radio-telegraphy now forewarns the sailing master when and where he will encounter the fog blanket that hovers over an ocean graveyard. Times and positions of these fogs are approximately known, but definite forecasts cannot now be made.

During summer, fog along the steamship lanes in the vicinity of the Banks averages between ten and twenty per cent of the time; in winter it may be expected about one-third of the time.

If an iceberg is sighted dead ahead during foggy weather it is usually so near that avoidance is difficult. A steamship can stop or it may back. An air plane can do neither.

From time to time experiments in oiling the area of fog-covered waters have been tried; but the oil film has no effect on the fog. The fog comes from the air and not from the water and the oil film does not warm either one.

The fogs of the Pacific Coast occur usually in early evening and may continue after sunrise. In southern California the coast fog may be high above ground. It is then the "velo," or veil. The fogs of the middle Atlantic Coast are usually associated with cyclonic movements. To a certain extent they are of the nature of city fogs, being encouraged by the smoke and dust incident to city industries. In the larger harbors fog may be forecast, but not with a high degree of verification. Even a light fog ties up shipping pretty effectually.

A light fog may be more opaque than a heavy rainfall. Direct rays of light do not penetrate a dense fog more than a few rods. The light is scattered by reflection. The amount of water contained in a cubic foot of saturated air at 67° is 6.2 grains. If the temperature be reduced to 42°, approximately one-half the vapor, 3.1 grains, will appear as fog, and this amount is sufficient to produce a very dense fog.

In practise, a single rule must guide a pilot; when the limit of visibility is less than the distance required to make a stop, there is danger. In traversing sea fogs, where other vessels are not likely to be encountered, sailing masters have expressed the opinion that quite as much danger exists at half speed as at full speed. Perhaps this is true if one considers a collision. Nevertheless, at full speed an average of twice as many chances of collision will occur, for the vessel will meet an average of twice as many other vessels in a given time.

To the airman there is no difference between fog and cloud, so far as the impairment of visibility is concerned. For the greater part, a pilot may fly above stratus clouds if the air is not clear below them; and airmen usually can find plenty of room under the alto-stratus clouds of an overcast sky. But an airman who has once encountered a cumulo-nimbus cloud, or even large masses of low cumulus clouds, is not apt to repeat the experience. In many cases both fog and cloud may be avoided; but one cannot avoid a fog when it shrouds a landing place. And while fog turbulence is slight, cloud turbulence may be very great, and this is notably the case with cumulus, and cumulo-nimbus clouds.

It is not easy to draw the line between fog and mist. Inasmuch as the droplets of mist are much larger than those of fog, they do not scatter so much light; moreover, measured per cubic unit of air, there are not so many of them. At times one may see a gray moisture haze in the direction of the horizon. A little experience enables one to distinguish it from a dust haze. It is never thick enough to impair seeing materially.

Humid air is not quite so clear as dry air, but it rarely loses transparency to the extent that it impedes transportation. Nevertheless, the impairment of visibility by air that was merely very moist has been the critical point of several suits in which railways were involved.

Rain and Snow.—It is not often that rain, *per se*, falls so fast that the seeing is badly impaired; but now and then this happens. Very heavy downpours may limit the vision to less than a few rods. But downpours of this sort are not common, and if the seeing is passable for 1000 feet ahead, danger is largely avoidable.

Some of the light passing through raindrops is refracted; some is reflected and otherwise scattered. The outlines of an object which normally is distinct may be obliterated, but its mass is likely to be seen. In this respect rain differs from fog. Even if the combined surface of the drops next the observer is sufficient to form a screen, the screen is partly transparent, but a fog screen is practically opaque. If a rain-drop be broken into water particles of fog size, their aggregate surface is several million times that of the rain-drop. The screening power of the fog, therefore, is vastly greater than that of the rain-drop and so also is the amount of light scattered.

A fast-falling snow is about as bad for visibility as an ordinary fog. If blizzard conditions prevail, the snow may be broken into a fine ice dust quite as opaque as a thick fog. The airman may avoid a snow squall of small area by flying around it; the locomotive engineer and the marine pilot must push through it. The danger point is reached when a snowfall hides semaphores or obscures signal lights.

Dust Storms.—In arid regions winds of the simoon type are not uncommon. Frequently they carry heavy clouds of dust far beyond desert boundaries into fertile regions. The Santa Ana of southern California is an example. Dust storms originating in the plains states sometimes carry their content as far east as the Mississippi. So far as the impairment of seeing is concerned their effect does not reach more than a few hundred feet above ground. The haze of fine and highly electrified dust which commonly hangs in the air after a dust storm is not very opaque, but it extends much higher above ground. It may persist for several days. The airman may fly above a dust storm, but if it blankets a landing place it becomes a positive danger.

The ordinary dust haze, a bluish tinge observable against a dark background, does not impair seeing. Frequently it has the density which the landscape artist terms "atmospheric effect." The sea haze, on the other hand, may be disconcerting because it may hide the distinctive marks of nearby vessels. The sea haze has been an interesting factor in naval strategy because of this fact. Frequently it is dense enough to interfere with signaling, even with helio-apparatus. Calmness of the air is a condition necessary to the formation of the blue dust haze and the sea haze.

The Smoke Pall.—The smoke that hovers over manufacturing districts differs materially from that of forest fires, being composed largely of free carbon and hydrocarbons. In moist weather water drops varnished with tarry matter are mixed with smoke carbon. Mixed with stack products are sulphur gases—sulphur trioxide and sulphur dioxide. These are chemically active and in the presence of moisture become very effective nuclei of condensation.

In manufacturing districts where soft coal is extensively used as power fuel the smoke pall may be dense enough to hide the outlines of large objects at a distance of 4 or 5 miles. A low-lying lid holds the smoke pollution close to the ground and impairs seeing very materially. The airman may fly above the lid into a region of clear air; the marine pilot, except in harbors, is out of the way of smoke; the locomotive engineer, who cannot avoid the smoke pall, sometimes finds it disconcerting. It rarely interferes with signaling.

Under ordinary circumstances the diffusion of smoke is so rapid that it is rarely visible at a distance of more than 40 or 50 miles from the source of pollution. At this distance a dirty-appearing horizon is about the extent of the impairment of seeing. From Chicago to South Bethlehem the region is one of almost continuous manufacture; nevertheless, the combined smoke pollution of the wide region is rarely discernible at the Atlantic Coast.

Refraction of Light.—Rays of light passing through bodies of air differing in density are bent from their original direction. The outlines of objects therefore reach the observer more or less distorted. The blurring of outlines one notices along a railway track is an example. At a distance of half a mile an approaching locomotive appears as a dark mass without outline. The imperfect mixture of warm air and cold air causes the scattering of light. A boss of rock projecting from the coast, or surrounded by greensward, produces a similar effect noticeable to the air pilot.

Refraction of this sort is a menace to safety whenever it conceals the outlines of objects which should be recognizable beyond stopping distance. A locomotive engineer who loses time in order to make certain of semaphore signals, and is censured therefor, is in about as bad a position as one who is disciplined for running past them for the same reason. Usually the judgment that comes with experience enables the engineer to observe the necessary precautions.

The mirage of arid regions, especially of the desert, is disconcerting at times. It hides landmarks which are necessary to the safety of the traveler; along the railways of arid regions it may disconcert trainmen. When it is below the eye of the observer it has the appearance of a distant body of water which reflects the sky.[1] It is observable only when the eye is not more than 4 or 5 degrees above the level of the apparent surface. The angle is so critical that a change of level of 2 feet on the

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[1] Trained observers in arid regions are of the opinion that the ordinary desert mirage is due to the reflection of light from the plane of contact of two layers of air resting one upon the other. The experience of the author, covering many years in the desert region of western North America, favors this explanation. In his "Light," Professor Hastings explains it as a case of refraction, and this view is held also by Humphreys.

part of the observer may destroy the illusion. Such a mirage may be apparent to a man, and not to a child standing beside him.

The desert mirage is disconcerting as well as deceiving. Surveyors occasionally are compelled to suspend work, and locomotive engineers are sometimes deceived concerning the locations of sidings and signals. A cattleman who unwisely attempted to drive a herd of several thousand cattle across the Colorado Desert lost the entire herd. The cattle, becoming thirsty, grew very nervous. The mirage deceived them and they stampeded to their death. During a battle between British troops and Turks in the arid plains of the Tigris, a desert mirage concealed the Turks so effectually that fighting was temporarily suspended.

From the nature of the case, forecasts of the impairment of visibility due to refraction are out of the question. However, it may be safely assumed that when a light wind is blowing there will be no trouble from this source. In desert regions the whirls, sometimes known as "sand spouts," indicate the absence of surface winds. They indicate the breaking up of a lid, but their effect on visibility is slight.

Forecasting Conditions of Visibility.—Some of the fundamental conditions of visibility have been discussed in detail. Fogs cannot be forecast with any degree of certainty, but local conditions may indicate their probability, especially in the case of the coast fogs already noted. Along the steamship lanes between American and British ports, time and place are indicated, not by forecast but by probability. City fogs, which are due largely to pollution, cannot be forecast. They are indicated when the humidity is high and the smoke pollution great. They disappear with a slight rise of temperature. It is well to bear in mind that, with temperature close to the dew-point, a fall of a very few degrees may fill the air with a dense fog; a rise in temperature ever so slight may change foggy air to clear air. Impairment of visibility due to smoke pollution cannot be forecast. When due to a lid, a rise of barometric pressure indicates a clearing of the air, which may take place in an hour. In other words, a lid indicates suspended convection.

The best seeing comes with an anticyclone, the forecasting of which is pretty certain to be verified. Other highs indicate good seeing if the air is dry, and dryness of the air, when not polluted, is fundamental to its clearness. Rain or snow, and mist are pretty certain to accompany a cyclone. A cirrus haze at the eastern horizon and a white sky overhead are followed by gathering clouds which increase in thickness, and by precipitation. These changes can be forecast, both as to time and place, with a fair degree of certainty. The advancing half of a cyclonic depression is an area of increasing impairment of seeing; the receding half is one of improving visibility. The same is true of the V-shaped depressions of western coasts in high latitudes. On the front of the V the seeing grows worse; at the rear, it constantly improves. In each case the decreasing pressure brings foul vision; the increasing pressure, good seeing.

Stagnation of the air almost always brings haziness, but rarely to an extent that interferes with good seeing. In some cases, such as the "stranded Bermuda high" it may be roughly forecast. The haziness resulting from stagnation may interfere with the long-distance helio-signals occasionally necessary, or with the long-distance sighting in geodetic surveys; otherwise, the impairment is not of consequence.

CHAPTER XIII

THE DAILY WEATHER MAP: STORMS

THE DAILY WEATHER MAP

The daily weather map is a bird's-eye view of the United States with respect to temperature, pressure, wind, and storm at 8 o'clock in the morning, seventy-fifth meridian, standard time. A few minutes before 8 o'clock more than two hundred observers are busy recording all weather conditions covering the various stations. These observations are completed by 8 o'clock, morning and evening, and are promptly telegraphed to the Weather Bureau at Washington in coded form. So carefully and thoroughly is the work done that a few code words from each station contain all the necessary information concerning temperature, pressure, direction of the wind, rain or snow, cloudiness, moisture, thunder-storms, fog, and other phenomena.

Making the Daily Weather Map.—At the central office, and also at certain other designated offices, the figures and other information are charted on a base map containing the name and position of each station, the boundaries of the states, and the outline of the United States. For the sake of clearness, all other features and names are omitted. Blue lines are drawn to indicate isotherms; red lines similarly indicate isobars. When the isobars are completed it will be found that some of them are roughly concentric, inclosing irregularly shaped ellipses. In some of these the pressure is highest at the center; in others, the center is the point of lowest pressure. These are the *highs* and the *lows* that indicate storm centers—that is, *anticyclones* and *cyclones*.

In order to give the forecaster additional information, the direction of the wind and the sky condition must be noted. These are shown in each case by a circle pierced with an arrow.

The arrow points the direction of the wind. If the sky is clear, the circle of the arrow is left clear; if partly cloudy, half the circle is blackened; if cloudy, all the circle is blackened. An *R* in the circle indicates rain; *S* means snow; and *M* means that the report for that particular station is missing. All localities in which rain or snow is falling are shaded. The map thus finished is the daily weather map, and from it the forecasts of the following twenty-four to thirty-six hours are made. These also may include information discovered by the long-distance forecasts.

Distributing Weather Information.—The base maps on which the information is to appear are distributed to such stations as issue daily weather maps. As soon as the matter described in the preceding paragraph has been placed graphically on the map, it is reproduced by a quick process in the form of a printing plate. The matter for the plate is usually ready by half-past nine o'clock, and is printed on the base maps which are usually folded, wrapped, and addressed within a short time. At the New York City Station about 3000 maps are required for the daily issue. They are sent to shippers, railroad offices, merchants, newspapers, educational institutions, post offices, and public places of various sorts. Almost every daily paper publishes a *résumé* of the weather map; some reproduce the map itself. All told, the daily forecast is so widely published that it is within almost instant reach of everyone within the main body of the country.

Features of the Weather Map.—The chief desire of the public is to learn whether the weather during the succeeding few hours is likely to be pleasant or stormy, warmer or colder, clear or cloudy, quiet or windy. These are features that affect all people; and the daily weather map answers the questions correctly a little more than four times in five. The verification of rain or of snow practically is four times in five; of temperature and wind direction, rather better than four times in five.[1]

A study of the weather map will show the area or areas in which rain or snow was falling at the time of observation; it will show where freezing temperatures may, or may not have ex-

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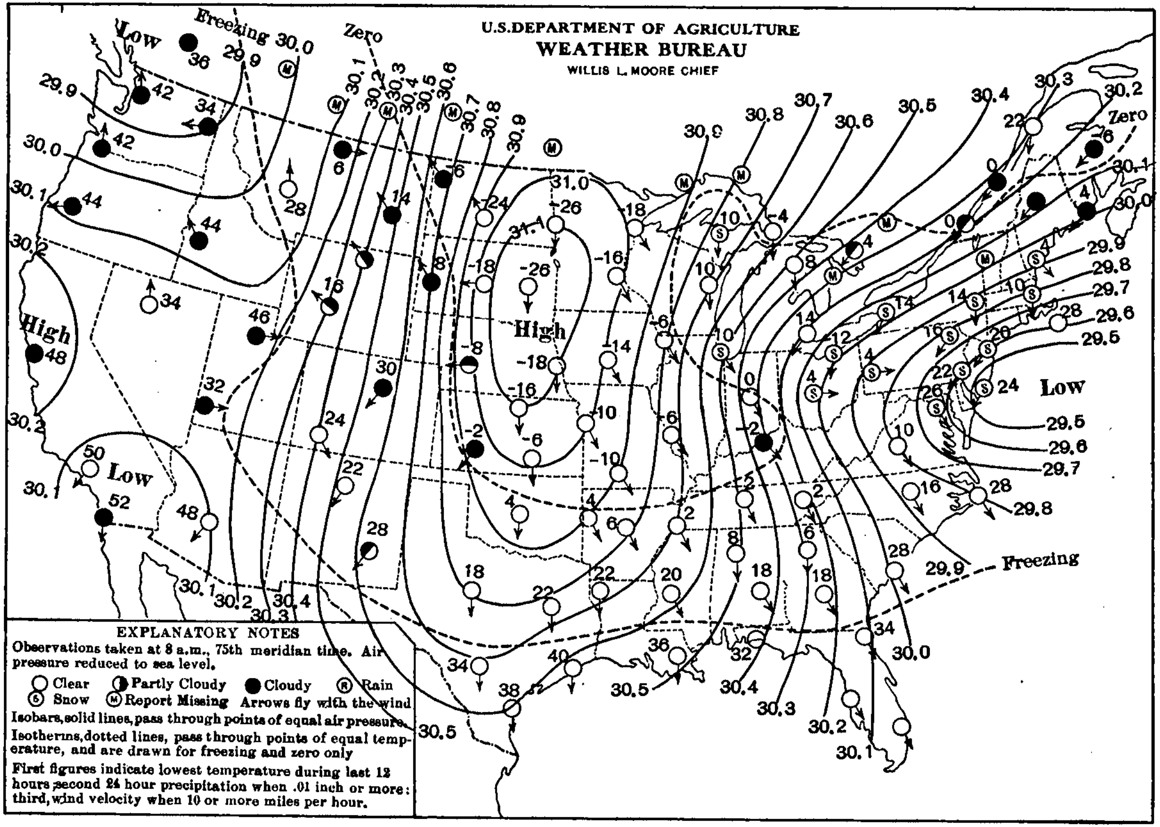
[1] The percentage of verification varies with locality. In California, where the rain and temperature conditions are seasonal, the percentage of verification is high.



After Bliss.

A winter cyclone (low) followed by a cold wave (high). The daily weather map of Jan. 25, 1905.

isted; it will show the areas of clear, cloudy and windy conditions. The man in Chicago may learn at a glance the weather conditions at Los Angeles, New York City, Winnipeg, Key West, Bermuda, or Havana. A merchant who has shipped perishable goods may learn whether or not his consignments are threatened by washouts, snow blockades, or cold waves. In other words, the daily weather map is very much more than a mere bird's-eye view of the air and its conditions; it is a survey—a topographic map—with measured values.

STORMS

The Movement of Weather Conditions.—The ripples, whirlpools, and waves of a river are carried along in its flow; so also the waves and whirlpools of the air are carried along with the great streams of the air. Throughout the greater part of the United States, this movement is from a westerly to an easterly quadrant—that is, the greater part of the main body is in the belt of Prevailing Westerlies. The Gulf Coast, together with the Florida Peninsula are in the Trade Wind belt in summer, but not in winter. Therefore, such movements as cyclonic areas or lows will move from a westerly to an easterly quadrant with the velocity of the general movement of the air.

The paths of the principal types of cyclonic storms which have already been described are shown on the accompanying map. They are discovered by means of the isobars. That is, somewhere in the middle western part of the United States an isobar of 30.00 inches will be found to inclose an elliptical area. Within this area isobars are drawn for every tenth of an inch of decreasing pressure. This area is a *low*, and probably an area of updraught; if the pressure is below 29.50 inches it is pretty certain to be a strong updraught, and the arrows which indicate wind direction are pointing toward the center of the low.

If the pressure at the central part of the low is only two- or three-tenths below 30.00 inches, the updraught is not very strong and the winds blowing into the low are light. Rain or snow may or may not be falling. On the other hand, if the pressure within the low is 29.50 inches or less, rain or snow, followed by heavy winds, is pretty certain to occur, mainly on the east and south sides of the cyclones; if the pressure falls below 29.00 inches a violent storm, with winds from whole gale to storm strength, is certain.

The various types of cyclonic storms differ but little in character, and their names apply to the locality where they originate or are first observed. Thus, they are variously known as "Alberta," "North Pacific," "Northern Rocky Mountain," "Colorado," "Texas," "Central," and "West Indian." Other names occasionally are used in designating the storms. The system employed by the Weather Bureau is one of convenience rather than of scientific value. About a third of the storms that cross the continent are of the Alberta and North Pacific type.

Redway's Physical Geography.

Wind, cloud, and precipitation in a cyclonic storm.

The map, p. 148, shows the isobars of a cyclonic storm. The low pressure at the center indicates a storm of unusual intensity; this is indicated also by the closeness of the isobars. In other words, the pressure gradient is steep, when the isobars are close, and this also indicates the degree of violence of the storm.

Observations covering more than twenty years show that winter storms of the United States advance at the rate of a little more than 700 miles per twenty-four hours; summer storms cover about 500 miles. These figures differ from the values obtained by the British Meteorological Office, 576 miles and 474 miles per day respectively. The progress of the cyclone is merely the velocity of the general drift of air, and this varies in different latitudes, and at different times.

Inasmuch as the storm tracks of the different types are fairly regular in position, and the velocity of progress is known, it is not difficult to forecast the position of a storm from day to day; that is, a storm center which is over Cincinnati may be expected to reach Philadelphia or New York at about the same hour on the following day. Fast express trains run at a rate of speed that rarely varies; the cyclonic storm moves also at a fairly uniform speed. The express train does not ordinarily leave its steel-bound track; in this respect it differs from the cyclonic storm which occasionally does swerve from its expected track to the confounding of the forecaster. This is likely to happen about once in five times.

Let us suppose that a storm of the Alberta type, after reaching the Great Lakes, takes a dip southward and passes off the coast somewhere near Cape May, instead of following a predicted course across New York. In the eastern part of the United States practically all forecasts north of Cape Hatteras will be upset. Instead of rain, central New York and Massachusetts will have clear or partly cloudy weather. Baltimore and Washington will have cloudiness, easterly winds and rain, instead of clear or partly cloudy skies.

Not only may a cyclonic storm swerve from its predicted track; it also may fail to produce the rain or the snow which, according to popular tradition, constitutes the storm. As a matter of fact, the rain and the snow are merely an incident in a cyclonic movement. The essential feature of cyclone mechanics is the updraught. Now, in its progress if the cyclone invades an area of very dry air, the updraught may not be cooled to the temperature of condensation; in such a case there will be no precipitation. All lows are not rain storms or snow storms in the ordinary meaning; but practically all the rain and snow that fall on large areas accompany winter lows.

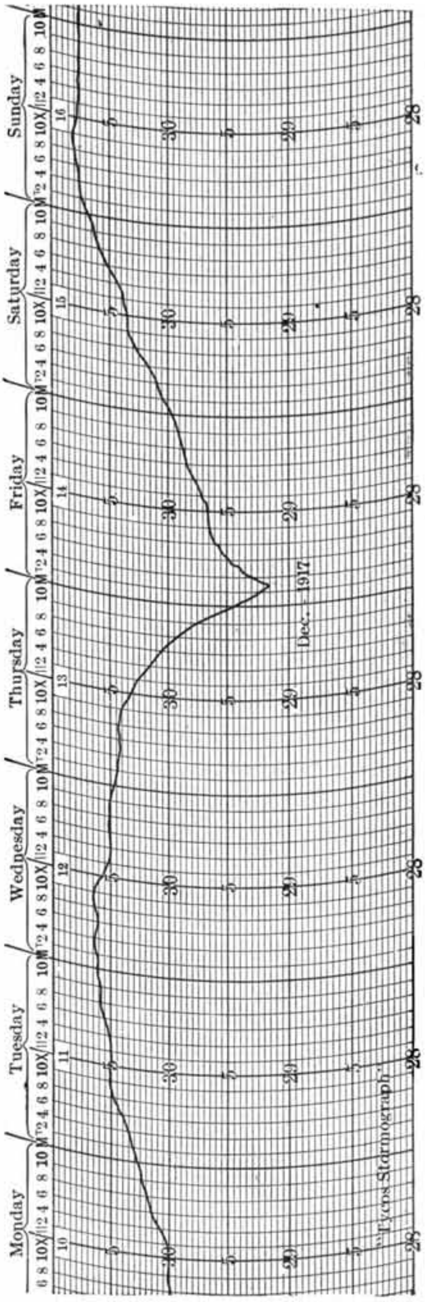
Let us take a low which is central in Illinois. The wind is blowing into it from all quadrants, to fill the updraught. The storm is preceded by a wind from an easterly quadrant and clears with one from a westerly quadrant, which is apt to settle in the northwest. Within the storm area the winds acquire a spiral motion, whirling upward contra-clockwise as they approach the updraught. The whirl brings warm and moist air from a southerly region to the easterly side of the low, where the air is colder and the temperature nearer to the dew-point—that is, to condensation. For this reason, most of the precipitation is on the east and south sides of the low. On the west side colder and drier air is blowing from the west and the northwest and, being colder, is drawn into the updraught to a less extent or perhaps, not at all. Westerly and northwesterly winds, therefore, usually are clearing winds.

Just as the trough of a wave is followed by a crest, so a low is pretty apt to be followed by a high; and cyclonic storms of the Alberta type are frequently followed by crests or waves of cold air from high latitudes. If a winter high pressure area lies over the northwestern part of North America, and a low forms anywhere in the vicinity of this area, a flow from the high to the low will naturally follow. This means that, in order to fill the low, the clearing northwest winds must also be descending currents; and, as a matter of fact, they flow along the surface, lifting the warm air above them. In their flow into lower latitudes and their descent, they, too, acquire a whirl. But the whirl is clockwise, or the reverse of the whirl of the cyclone; hence it is known in Weather Bureau cant as the "anticyclone." The winter anticyclone, therefore, is usually a cold wave.

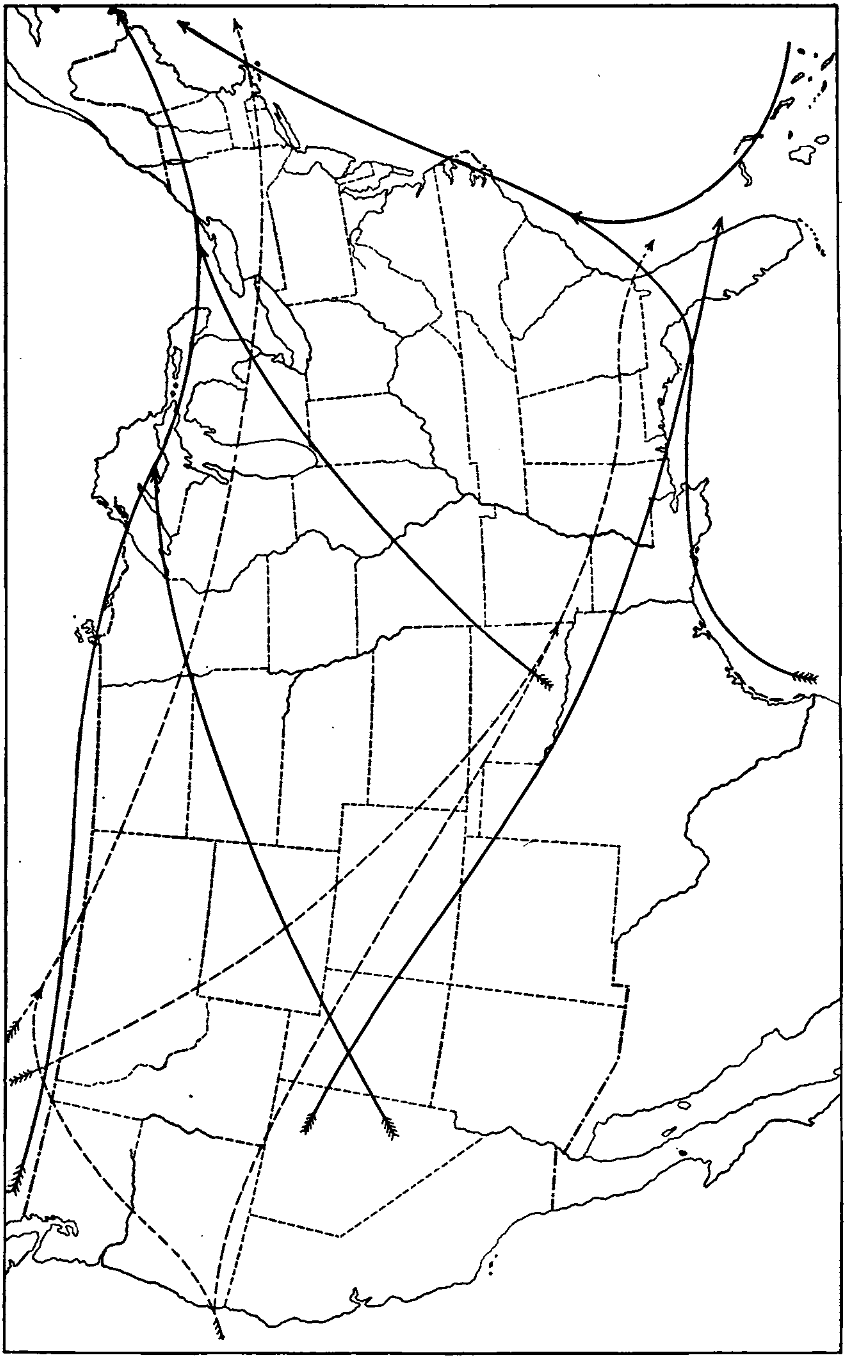
The high of the winter cold wave is an area of considerable pressure. Usually the barometer stands above 30.50 inches; occasionally it mounts nearly to 31.00 inches. For this reason the cold air spreads far south—sometimes carrying freezing weather far into Florida, to the detriment of the semitropical orchards. The southern part of Florida is the only part of the United States which escapes freezing weather.

In many respects, the cold wave is one of the most valuable health assets of the United States. Should the ground be covered with snow, so that gale winds pick up no dust, it brings the purest air that mortals on land ever breathe. Even if the ground is bare, the high pressure invades the nooks and crannies where foul air and putrefaction lurk, and drives them out. The cold wave with its stinging wind is the greatest scavenger in existence.

West Indian Hurricanes.—The West Indian hurricanes do not differ materially from other cyclonic storms in general principles, and they differ from the typhoons of the China Sea in name and place only. They are cyclonic storms of very great violence and, with the exception of tornadoes, they are the most destructive storms that reach any part of the United States. The wave that covered Galveston, the floods that many times have swept the Sunderbunds of India, and the storm that caused Isle Dernier to melt away were hurricanes of the cyclonic type — whirling up draughts toward which the surface wind blew from every direction.



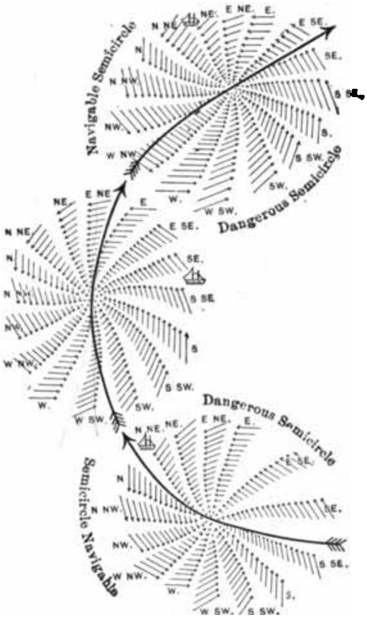
A winter storm barogram; record of the Meteorological Laboratory at Mount Vernon. N. Y.



Storm tracks of the United States: Heavy arrows, cyclones; broken arrows, anticyclones.

The West Indian hurricanes originate in tropical latitudes, somewhere north of the equator. They move in a northwesterly direction until they reach the latitude of westerly winds; then they recurve and move in a northeasterly course. In some instances a hurricane recurves before reaching the Florida coast; in others it advances until the recurve crosses the Gulf of Mexico. In the first instance it is not likely to cover anything more than the coast plain; in the second the storm center may sweep the eastern United States from the Gulf to the St. Lawrence valley. After recurvature, hurricanes move more rapidly—occasionally as much as 50 miles per hour.

These storms are called West Indian hurricanes from the fact that they are first noted at a West Indian weather station, frequently at Barbados. They sometimes originate far to the eastward of the West Indies, sometimes in the Caribbean Sea. Since vessels are now fitted with radio-telegraphic apparatus, hurricanes are commonly reported before reaching a land weather station. Once discovered, their movements are closely watched and are made known to shipping until they disappear in the North Atlantic.



From Redway's Physical Geography.

Storm cards showing movement of wind in West Indian hurricane.

The dead calm of tropical seas is the real beginning of the West Indian hurricane. The air, moist almost to the dew-point, is heated next the surface until it becomes more buoyant than the colder air above it. Finally the unstable equilibrium is overcome and an updraught occurs. The warm air of the updraught is chilled by its expansion and its moisture is condensed. The latent heat thus set free adds to the strength of the updraught, and the cyclonic movement quickly develops into a hurricane of tremendous energy. Hurricane winds at Galveston were estimated to have a velocity of 125 miles per hour; 100 miles per hour was registered before the anemometer was blown away.

According to Chief Forecaster E. H. Bowie, U. S. Weather Bureau, if a West Indian hurricane, moving westward in the longitude of eastern Cuba, is north of the island, it will recurve east of Florida, provided an area of high pressure covers the northwestern states. But if the hurricane is moving westward over Cuba or the western Caribbean Sea when an area of low pressure 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.

Form and Dimension of Cyclonic Storms.—Extended measurements of the areas of low and of high pressure, made by Loomis and based on the isobars of the daily weather map, showed them to be elliptical in form, the longer axis usually pointing a little east of northeast. The average dimensions were found to be 1600 miles on the long axis by about one-half of that extent along the short axis. The average dimension of anticyclones is about the same. These values apply pretty closely to the dimensions of the cyclonic storms of western Europe.

The low of the West Indian hurricanes is very much smaller in area. Even after its existence has been discovered it may not be more than 100 miles in diameter; and by the time it passes a West Indian weather station it may not be more than 200 or 300 miles across. After it recurves and enters the United States, its area is much less than that of the ordinary cyclonic storm; the isobars are usually regular and more nearly of circular shape than those of ordinary storms.[1]

Storm Probabilities.—Before storm forecasts were sent to vessels by radio-telegraphy, the sailing master of the vessel was obliged to rely upon himself for weather predictions. He based his forecasts on his barometer, clouds, and the wind. A close study of these enabled him to make forecasts that were

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[1] It is not unlikely that the eccentricity of the ellipse of the cyclonic storm depends on the velocity of the whirl—the higher the wind-velocity, the more nearly it approaches a circular form.

marvelously good. With intelligent study of wind, clouds, and moisture, one should be able to forecast most ordinary weather changes from eight to twelve hours in advance, without the aid of barometer or weather map. This does not apply to such local disturbances as tornadoes, thunder-storms and hail, nor to such conditions as ice storms and sleet.

Throughout the greater part of the United States easterly winds indicate the approach of a cyclonic storm. If the wind is from the south or the southeast, the storm is probably approaching along a path to the north of the observer; if the wind has settled to a quarter between east and northeast, the track is somewhere south of the observer; if the wind is due east, the observer is probably in or near the track of the storm center.

If the sky remains clear with an easterly wind the rain area is likely to pass some distance from the observer; but if the sky becomes gray, and then white, and the air perceptibly damper, rain is not likely to be far away. When cirro-stratus clouds appear in the easterly sky, rain or snow is pretty certain at hand within a few hours.

The position of the storm center may be determined by watching the wind closely and noting any change that may occur. Standing with the back to the wind the area of low pressure is on the left hand, and the area of high pressure on the right hand. During the passage of the storm, if the wind shifts from the east through north to northwest—that is, if it "backs in"—the cyclone center is passing to the south of the observer. If it veers through the south to the west or the northwest, the storm center is passing north of the observer.

The cooperative observer can do much to aid in establishing definite facts on which predictions may be made. Among them and of first importance is establishment of the direction of rain-winds. These, as has been shown, are easterly winds, but conditions of topography may change the real direction to one that is apparent. The apparent direction should be established for each month in the year. In every community there are weather-wise people who possess valuable information that they have not recorded. Such information should be considered carefully and accepted or rejected as the case may be.

The number of days in each month on which 0.01 inch or more of rain has fallen should be noted, tabulated, and compared with the map of rain frequency published by the Weather Bureau. From this table a coefficient of the probability of rainfall for the particular station may be deduced by dividing the number of rainy days by 365, or 366, as the case may be. In a similar manner, the probability of rain for each month may be established. It is pertinent to add, however, that forecasts made from such coefficients are by no means certain; often they are disappointing.

The average duration of rainfall may be deduced by dividing the total number of hours during which rain has fallen for the month by the number of rainy days. If the duration is to be based on the average length of storms, the number of storms may be taken as the divisor. In the northeastern part of the United States the average duration of rainstorms is five hours; in the southeastern part, four hours; in the western highland region, including the plains, about three hours; and in the basin region probably not more than one hour. The intensity, or rate of rainfall per hour, is a matter of great importance. It is tabulated at regular intervals at Weather Bureau stations.

It is well to bear in mind that the artificial production of rain is a delusion. No appreciable fall of rain will occur unless a continued updraught of air is produced, and neither cannonading nor explosions at a considerable height has accomplished this. Possibly the conjunction of planets may affect the movement and the formation of storms; if so, however, the connection has not been established.

Secondary Storms; Tornadoes.—When a whirlpool forms in a stream, smaller whirlpools almost always occur near its edge. These secondary whirls result from the formation of the larger whirl. Similarly, secondary whirls of the air are very apt to accompany the cyclonic storms which pass over the Great Lakes and down the St. Lawrence Valley. In the winter the secondary storms thus formed appear along the Virginia coast, or perhaps to the north of it, and move north or northeast with heavy snow squalls and high, gusty winds. In the summer they are attended by hailstorms, thunder-storms and tornadoes. These occur usually on the south or the southeast side of the low.[1]

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[1] In the southern hemisphere they form on a northerly quadrant.

Tornadoes are less frequent than thunder-storms, but they are the most violent and destructive storms that come into the experience of humanity. The term is loosely applied to almost every violent wind; it is incorrectly applied to any secondary storm that is not a true whirlwind, or "twister." There are no definite conditions known by which tornadoes may be forecast; but when the path of a northerly storm dips southward and increases in intensity, tornadoes are likely to occur.

The tornado is a whirling storm, and the whirl becomes so rapid that the vortex develops into a black funnel-cloud. The funnel is usually observed first in the air. As the whirl increases, the funnel gradually extends downward to the ground. No measured velocity of the whirl is known to have been made; but calculations based on the weight and the surface of bodies moved by the wind show that the velocity, in various instances, has exceeded 500 miles per hour.[1]

The first visible warning of the tornado is the gathering of a bank of very dense cloud, usually in a westerly quadrant—southwest, west or northwest. The color of the cloud bank varies. Not infrequently it appears much like the smoke from a burning hay barn, or a strawstack; quite frequently it is a dark greenish gray. The color depends on the position of the observer with reference to the sun. The cloud bank is always in tumultuous commotion within itself.

It is in this cloud bank that the funnel of the tornado forms. In some instances, as the tip of the funnel approaches the ground, an inverted funnel is formed at the ground, quickly joining the funnel hanging from the cloud. The funnel is the destructive part of the tornado. It uproots trees, or twists their trunks to the breaking point. Wherever the tornado passes through woodlands its path is marked by uprooted, shattered and twisted trunks of trees. When the funnel strikes a building the latter bursts outwardly. In various instances a roof has been carried in fragments a distance several miles away. Wooden railway bridges have been dismembered and splintered beyond repair, and steel bridges have been torn from their abutments and crumpled into shapeless heaps. Chickens have been almost completely plucked; straw and twigs have been driven

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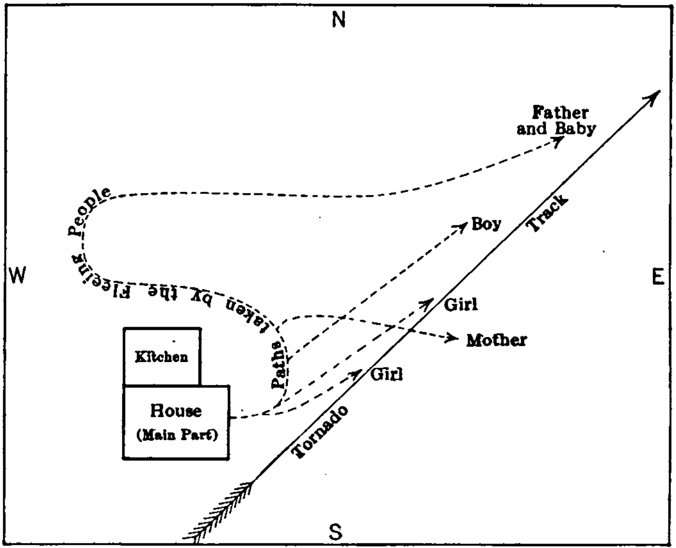
[1] This was computed by Bigelow in the case of the Missouri tornado of May 27, 1896.

Koester, Photo.

Lake Gervais tornado, July 13, 1890, as seen from St. Paul. Note the mass of cold air as shown by the upper cloud overrunning the warm surface air.

endways into boards; and large animals have been lifted and carried considerable distances. In one case a cow was lifted out of a high corral and deposited, not seriously injured, several hundred feet away.[1]

The cause of the tornado cannot always be determined; in a few instances it has been assumed by reason of strong circumstantial evidence. During the passage of a northerly cyclone that has bent its path into the south, great volumes of dry, cold air are sometimes whirled into regions where the air is



The graphic story of a tornado.

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[1] The accompanying diagram illustrates a gruesome story. When the funnel cloud approached the house, the family fled. At first they ran northward, a direction of safety. Then, one after another, they turned eastward and ran into the whirl. The younger of two girls ran directly into the tornado path and was instantly killed. The mother had reached a place of safety; then she turned into the tornado path and was crushed to death against a tree trunk. The older girl and a boy also turned toward the storm track; their clothing was stripped from them and they were torn and bruised. The father, with the baby in his arms, had reached a place of safety; then, in fright, he too ran back into the storm track where both were killed. This is one story that illustrates many. As a rule, the path of safety is toward the northwest or the southeast if the direction of the tornado track can be determined.

warm and moist. Now, if the heavier cold air rests at the surface of the earth no disturbance follows. On the other hand, if the cold air comes to rest on the top of a thick layer of warm air, an unstable condition results. Sooner or later an updraught of warm air takes place and tornado conditions are established. The rapid whirl creates a near-vacuum, and this accounts for the fact that buildings struck by the funnel-cloud burst outwardly.

The air movement of tornadoes is three-fold—the updraught, the whirl, and the progressive movement. The destructive path of the tornado is as wide as the funnel-cloud, rarely more than a few rods. The entire whirl is not much more than half a mile in diameter; the extent of the path varies from a few miles to about 200 miles. The tornado progresses along its track at a rate varying from 10 or 12 miles an hour to express-train speed. The funnel-cloud is formed at a height of about half a mile.

From the nature of the case, the best values concerning the dynamic force of the tornado are only approximate, but even these are instructive. Normal air pressure is at the rate of 2117 pounds per square foot. Now, if the air pressure within the funnel is only three-fourths normal when the funnel involves a building, the air pressure inside the building will be 530 pounds per square foot greater than on the outside. Such a difference in pressure is sufficient to burst the walls of almost any building.

Tornadoes are most prevalent in May, June and July; the average of these months exceeds that of the rest of the year. They are more common in the United States than in Europe. The regions of greatest frequency are the lower Ohio and Missouri valleys and the Central Mississippi region. Very few occur in the arid region west of the one-hundredth meridian and fewer still are reported north of the fiftieth parallel.[1]

Hail and electrical discharges frequently accompany tornadoes, but they have nothing to do with the cause of them; and although the updraught occurs in thunder-storms—and probably a cyclonic movement of the air within it—one is

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[1] Sir Napier Shaw, of the Meteorological Office, London, does not even mention tornadoes in his "Forecasting Weather." They are unknown in the British Isles, the line squall being its nearest approach.

hardly warranted in considering the tornado as an exaggerated thunderstorm.

Desert Whirlwinds.—Dust spouts are common in desert regions. A little after sunrise during warm weather, the still air next to the ground becomes very much warmer than the air at the distance of a few hundred feet above the ground. In time the unstable equilibrium is upset and chimneys of updraught are formed here and there, carrying columns of fine dust to a height of several hundred feet. At a distance the dust columns are strongly outlined. When the cold air has settled to the ground the whirl and its dust column ceases. Later in the day, the setting in of a steady wind puts an end to the unequal warming of the air.

Apache Indians have made use of the desert whirls as signals, creating them by setting fire to the spines of a columnar cactus that is common in the southwestern states. The burning of the spines at the right moment made enough heat to start the updraught. When the warm air at the surface has been pressed upward the descending air is perceptibly colder at times.

Waterspouts.—If the whirl of the updraught over water increases to a velocity whereby the skin friction of the wind overcomes the cohesion of the water, a waterspout is formed. The whirl of the updraught is strong enough to whisk the water into the air, at the same time whirling it into a mist. Undoubtedly some of the water drawn into the air is vaporized. When the spout breaks, a considerable part of the water in the air drops in a torrential deluge. Popular tradition has it that sea water drawn into a spout falls as fresh water—a tradition that is contrary to the facts of the case.

White squalls are fair-weather whirlwinds over the water. In many instances there is not enough condensation in the air to form a cloud; occasionally, however, a bit of misty cloud, the "bull's eye," is visible. At the surface, the wind is strong enough to whisk the water into white spray, but the whirl is not strong enough to draw it into the updraught.

CHAPTER XIV

FORECASTING THE WEATHER: WEATHER FOLKLORE

Two classes of people criticize Weather Bureau forecasts, the public and the Weather Bureau. Probably the Weather Bureau itself is the severer critic of the two. Its rules for purposes of verification are inflexibly definite. The practise is definite as to the character of the forecast, the time of occurrence, and the place of occurrence.

Rain—Fair.—By *rain* in this connection is meant any kind of precipitation in season. The general term precipitation is used to embrace rain, snow, sleet or hail; but in forecasts, "rain" may be used to cover any or all. To verify a "rain" forecast, precipitation must occur to the amount of 0.01 inch or more. The forecast may designate "rain," "showers," "thunder-storm," "snow," "sleet," etc., but the meaning for verification does not vary. Even the term "clearing," when used in connection with a rain forecast, means that rain will fall during a part of the time covered by the forecast.

For purposes of verification, *fair* means only the absence of precipitation. The forecaster may differentiate the kinds of fair weather to be anticipated as partly cloudy, cloudy, unsettled, overcast, or threatening—these are all variations of the forecaster's "fair." If precipitation occurs to the amount of 0.01 inch or more, by the rules of the Weather Bureau the forecast fails.

Warmer—Colder.—The rules concerning temperature forecasts are also equally definite, but with certain limits in verification. If the forecast is "warmer," any rise of temperature is a verification; so also is "cooler" if lower temperature is forecast. But if a change is not forecast, or if the words "not much change," "slight change," "continued warm," (or cool), or "stationary temperature" are used, a definite number of degrees (6 in summer and 10 in winter) is required to vitiate the forecast. Modifying words, "slightly," "much," "probably," etc., do not relieve the forecaster of the failure of his verification.

Time of Occurrence.—The forecasts most generally sent out for publication are based on the 8:00 A.M. observations and reports. The terms designating time are "to-night" and the name of the following day. "To-night" covers the twelve-hour period from 8:00 P.M. of the current day to 8:00 A.M. of the following day. Therefore, whatever is forecast for "to-night" must occur within these time limits. "Rain to-night" would fail of verification if none occurred until after 8:00 A.M. the day following, even though a heavy downpour set in immediately thereafter. "The following" day begins at 8:00 A.M. and ends at 8.00 P.M. after the current day—that is, for purposes of verifying the 8.00 A.M. forecast on Monday, "Tuesday" covers only that portion of the day between 8.00 A.M. and 8.00 P.M.

Place of Occurrence.—Most forecasts are made to cover individual states. The larger states are subdivided into "north," "south," "east" and "west" sections. The daily forecast may be for the whole of a state or for any of its sections. If rain is forecast, say, for New Jersey, and none is reported from any of the stations in the state, the verification fails, even though showers may have occurred at nearby stations in Pennsylvania and New York.

The Value of Safety.—Measured by their effect on commerce, production, and transportation, some weather changes are of no particular effect; they are neither beneficent nor hurtful. Other changes are classed as "critical"; if they occur unexpectedly—that is, without forewarning, they may result in loss by damage, or by destruction; they also may cause human suffering.

The "unexpected" may be unseasonable rains, snowstorms, floods, frosts, cold waves, hot spells, tornadoes, or other severe weather. These are the weather conditions to which the forecaster must be keenly alert; they are the possibilities that demand his chief care. Forecasters realize that it is wiser to warn against a killing frost that does not materialize than to fail in warning against one that does appear. The unverified forecast of frost may cause some trouble and some loss, but the killing frost that comes without warning is likely to result in loss infinitely greater.

In the raisin-growing regions of California, a shower on the fruit curing in the open air causes very great damage. The fruit grower, therefore, is closely observant of the forecast of showers. The expense of stacking his trays, however, is small compared with the loss of his crop or the impairment of its quality, resulting from a shower. It is to the credit of the district forecaster that in many years not a shower has occurred of which timely warning was not given.

Recently a West Indian hurricane threatened the Gulf Coast and warnings were duly issued. Precautions were taken as indicated; but, by the time the hurricane reached the Gulf Coast, not much energy was left in it. But what would have been the result had the warnings been omitted and the hurricane had possessed the violence of the storms which destroyed Galveston and Corpus Christi?

It is the desire of the Weather Bureau to prevent loss by forewarning. The district forecasters do not strain points for high percentages of verification. A row of failures may be discouraging; a mistake against the forecaster may make him a target of derision; but a mistake which results in loss of life is irreparable. Therefore, in making forecasts, it is "safety first."

Those who make intelligent use of Weather Bureau predictions realize that forecasts are not insurance policies. They merely are expressions which represent the experience and judgment of the best-trained meteorologists. In one particular the dissemination of weather forecasts might be made even more valuable—namely, by issuing a map and forecasts based on the 8:00 P.M. reports, to be published in the morning papers. When the public decides that it really wants this information, the information will be forthcoming. As a rule, the public gets what it deserves, but not always what it needs.

POPULAR WEATHER PREDICTION—FOLKLORE[1]

Weather prediction is probably as old as human history and some of the sayings popular to-day passed current more than three thousand years ago. They survive because they are true. Mariners at sea and shepherds on land learned their lessons

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[1] The material for much of this chapter is inspired by Professor Edward Garriott's Weather Folklore, published by the U. S. Weather Bureau.

well; neither the one nor the other was possessed of a daily weather map. The wind was a fair barometer; the blinking of the stars was an excellent hygrometer. The discovery of the underlying principles of barometric pressure was the beginning of modern meteorology. The use of the barometer quickly appealed to sailors, and practically every deep-water vessel in the world is equipped with one. Transportation companies, lighting companies, farmers and manufacturers find it a necessity. The invention of the aneroid barometer has popularized its use tremendously.

In the hands of one without experience, or without training in the use of it, the barometer is usually a disappointment. To the trained observer, or to the observer who has gained wisdom by experience, it is an instrument of the highest value. To be serviceable in forecasting weather conditions it must be watched—not casually but systematically. The experience that comes from intelligent study of pressure changes will enable an observer to command most gratifying results.

General Pressure Indications.—As a rule, pressure changes should not be considered by themselves; they should be studied in conjunction with changes in temperature, humidity and wind direction. There are, however, certain general weather conditions indicated by changes in barometric pressure which hold good:

A gradual rise of the barometer indicates settled fair weather.

A rise from a very low pressure indicates wind and clearing weather—the more rapid the rise, the stronger the wind.

Rapid changes in pressure indicate early and marked changes in the weather.

A sudden rise in pressure indicates as great a change as a sudden fall.

The wind is apt to blow hardest when, after having been very low, the barometer begins to rise.

Should the pressure continue to remain low after the sky has cleared, expect more rain within twenty-four hours.—PRINCE.

If the pressure falls two or three tenths of an inch in four hours or less, expect gale winds.—PRINCE.

In summer a sudden fall in pressure indicates a thunder-storm; if it does not rise when the storm ceases, unsettled weather may be expected.

A fall in pressure not accompanied by stormy conditions indicates a severe storm at a distance.

A steady but very slow fall in pressure indicates that the low and its storm conditions is moving slowly. "Long falling, long last; short notice, soon past."—FITZROY.

During a period of low pressure, fine weather may be regarded with suspicion; a change may be expected at any time and most likely it will be sudden.

The barometer falls lower for high winds than for rain, but torrential rains may accompany a very low pressure. In winter, if high temperature accompanies very low pressure, heavy rain followed by a cold wave may be expected.

A rising barometer usually indicates winds having a westerly element—southwest, west, or northwest. A falling barometer usually indicates winds having an easterly element—southeast, east, or northeast. The rule is not infallible, however. Occasionally there occurs a dry east wind with a rising barometer.

A gradual but steady fall of the barometer indicates unsettled weather, increasing moisture and rain. A slow fall from a very high barometer indicates unsettled and rainy conditions rather more certainly. A sudden and rapid fall indicates a sudden downpour and high winds, or both. In summer a thunder-storm is preceded usually by a drop in pressure.

Wind Indications of Weather Conditions.—Throughout the eastern half of the United States[1] winds with a westerly element—northwest, west, and southwest winds—indicate fair weather. Winds with an easterly element—northeast, east, and southeast winds—indicate unsettled weather, rain or snow.

A straight north wind is apt to be a clear-weather wind. "The north wind driveth away rain."—PROV. XXV, 23; but this is not always true, especially if it veers into the northeast.

Straight south winds along the Atlantic and Gulf Coasts are apt to bring unsettled weather, inasmuch as the south wind blows from the sea, it usually brings warm air and excessively humid weather. Occasionally it brings storm conditions.

West winds are dry winds; in the eastern half of the United States they are apt to be dust-laden also. In midsummer they blow many miles over sun-heated ground and they are therefore apt to be hot winds.

East winds almost always precede rain and snow by twenty-four hours or more. Along the Atlantic Coast the east wind is pretty certain to be a storm-breeder.

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[1] The narrow strip along the Gulf Coast should be excepted from the general rule. In summer it is within the Trade Wind belt.

Northwest winds are the prevailing winds of the greater part of the United States. They are also the clearing winds for most of the cyclonic storms that sweep the country; they constitute practically all the cold-wave winds.

Southwest winds are the prevailing winds during the summer months in the eastern part of the United States. With a falling barometer, they bring rain.

Northeast winds are storm-winds; almost always they are cold and raw.

Southeast winds are rain winds along the entire coast and much of the interior of the United States, for the greater part of the year. The time varies from twelve to eighteen hours in winter and from eighteen to thirty-six hours in summer.

Barometer and Wind Indications.—When pressure and wind-direction are both considered and interpreted according to their mutual relations, local forecasts can be made with a much greater degree of certainty. During the colder months, throughout the United States, the western highlands excepted, precipitation begins with falling pressure. In the summer months, and in the western highlands it is apt to begin with the rising barometer. The following indications have been compiled for the Weather Bureau by Garriott.

29.80 or below, rising rapidly....	w	Clearing and colder.
30.00 or below, rising slowly.....	s to sw	Clearing within a few hours; fair for several days.
30.10 to 30.20, rising rapidly....	sw to nw	Fair, followed in two days by warmer and unsettled weather.
30.10 to 30.20, steady..........	sw to nw	Fair, with stationary temperature for one or two days.
30.20 and above, steady........	sw to nw	Continued fair; steady temperature.
29.80 or below, falling rapidly...	e to n	Severe northeast gales; heavy rain or snow.
29.80 or below, falling rapidly...	s to e	Severe storm probable, followed by clearing and colder weather.
30.00 or below, falling rapidly...	se to ne	Rain with high wind, followed within 24 hours by clearing and colder weather.
30.00 or below, falling slowly....	se to ne	Rain likely to continue 48 hours.

30.10 or above, falling rapidly...	e to ne	Rain or snow probable within 12 to 24 hours. In winter, snow and high winds.
30.10 or above, falling slowly....	e to ne	In summer, light winds and rain after 48 hours; in winter, rain within 24 hours.
30.10 to 30.20, falling slowly....	se to ne	Rain in 12 to 18 hours.
30.10 to 30.20, falling rapidly...	s to se	Increasing wind; rain in 12 to 24 hours.
30.10 to 30.20, falling slowly....	s to se	Rain within 24 hours.
30.10 to 30.20, falling rapidly...	sw to nw	Warmer; rain in 18 to 24 hours.
30.10 to 30.20, falling slowly....	sw to nw	Warmer; rain in 24 to 36 hours.

Barometer and Temperature Indications.—The following are noted by P. R. Jameson. They apply chiefly to that part of the United States and Canada east of the Rocky Mountains, approximately from the latitude of the Ohio River to that of the Saskatchewan River.

PRESSURE RISING

Below 30° F...............	Cold wave
Between 30° F and 40° F....	Freezing temperature
Between 40° F and 50° F....	Frost or freezing temperature probable
Between 50° F and 60° F....	Cooler
Above 60° F..............	Warm; cool nights

PRESSURE FALLING

Below 30° F...............	Overcast; snow
Between 30° F and 40° F....	Rain, sleet or snow
Between 40° F and 50° F....	Unsettled; rain
Between 50° F and 60° F....	Heavy rains
Above 60° F..............	Showery conditions; unsettled

Humidity Indications.—The gathering moisture of the air or, technically, its increasing humidity, is an indication of unsettled weather. Ordinarily, the air which may be at the dew-point at daylight becomes relatively dry at midday because its higher temperature gives it what is popularly termed "a greater capacity for moisture." But if the relative humidity remains high in the middle of the day it is evident that the absolute humidity has increased, and unsettled weather may be expected.

A hygrometer is useful in detecting increase of moisture, but it is not wholly essential. Where a hygrometer is available it is apparent that the less the difference between the wet bulb and the dry bulb the greater the moisture content of the air and the greater certainty of unsettled weather.

The effects of increasing moisture in the air are so well known that the literature of them is great, and popular sayings concerning them are found in all ages.

When the locks turn damp in the scalp house most surely it will rain.—INDIAN TRADITION.

If metal plates sweat it is a sign of foul weather.—PLINY.

The tightening of cordage on ships is taken by sailors as a sign of approaching rain.

A red sun has water in his eye.—NEW ENGLAND TRADITION.

When it is evening, ye say it will be fair weather, for the sky is red; and in the morning it will be foul weather, for the sky is red and lowering.—MATTHEW XVI, 2-3.

Rainbow in the morning, shepherds take warning;
Rainbow at night, shepherds' delight.

Circles around the sun or the moon indicate increasing moisture.

Salt absorbs moisture quickly. Its becoming coherent is a sign of increasing moisture.

The sunflower lifts its head when the moisture of the air increases.

The perfume of flowers becomes stronger when the air becomes damp; so also does the odor of a tobacco pipe.

It is well to bear in mind that these traditions apply to a more or less sudden change from dry to moist air, and not to the long-continued spells of moisture that come with steady sea winds.

Moist weather of long duration may be clear, as is commonly the case along the Atlantic Coast in summer; but a rapid change from dry to moist air almost always brings hazy conditions, and this is the sort of change that precedes rain.

> And if through mists Sol shoots his sullen beams,
> Frugal of light in loose and straggling streams,
> Suspect a drizzling day and southern rain
> Fatal to fruits, and flocks and promised grain.
> —VIRGIL.

The foregoing are only a few of the traditions and folklore sayings concerning the humidity of the air. Nearly all of them may be reduced to one or the other of two general principles—

the hygroscopic character of many common substances, or the mistiness of the air which tends to scatter all but the red rays of the sun.

The varying conditions of humidity usually afford indications more or less characteristic. These are more noticeable at morning and evening when the humidity is high. They are apt to be most pronounced on the horizon when vision penetrates a layer of air of greatest density. The following are proverbs of seamen:

A whitish-yellow western sky indicates rain.

Unusual hues of the sky forming a background of sharply edged clouds indicate heavy rains and gusty winds.

A white, yellow or greenish-yellow sunset indicates a storm.

A diffuse or hazy sunset indicates a coming storm.

A purple sky foretells continued fine weather.

A blur or haziness at the horizon indicates unsettled weather.

This may be correct if the haziness is due to misty air; but it is not true if the hazy or distorted outlines are caused by the refraction of air currents.

If the sun draws water in the morning expect rain by night.

This may be true in some localities, but it is not generally true. The appearance is due to the reflection of straggling rays of sunlight from dust motes or from mist.

Red evening sky, a fine to-morrow.
A red morn betokens a tempest.

Cloud Indications.—Cloud matter is the first step in condensation. If precipitation is feeble in energy and slow in process, only cloud is formed; if it is more energetic the cloud matter forms rain or snow.

Because cirro-stratus clouds, higher than others, consist of the first precipitation on the advancing low, they are among the best indications of an approaching storm. In a majority of instances they are the overflow from the upper part of the approaching cyclone; they may be more than one hundred miles in advance of the storm center.

Not all cirrus and cirro-stratus clouds are storm clouds, however. If they rise to a higher altitude, or if they disappear, fine weather is likely to follow. If they accompany a rising barometer, fair weather is likely to continue.

Cirro-stratus clouds covering the western horizon to a height of 30 degrees or more indicate rain within twelve hours as a rule. This is a still more certain indication if the lower edge of the cloud is wavy. A cirrus patch with streamer edges, which increases in size, indicates snow.

Clouds moving apparently against a surface wind in reality are moving with an upper current of the air. That is, cross-winds are blowing, and cross-winds very commonly precede rain or snow; a departing storm may also clear with cross-winds.

When ye see a cloud rise out of the west, straightway ye say: There cometh a shower; and so it is.—LUKE XII, 54.

The greasy, gray clouds which are characteristic of tropical skies during the rainy season are sometimes seen during summer in northern latitudes. They are pretty certain to indicate a heavy downpour.

Greenish-tinted masses of cloud collecting in the southeast indicate heavy rains.

A mackerel sky—twelve hours dry.

Rain from high clouds or from thin clouds does not last long.

If detached clouds increase in size the moisture of the air also is increasing; if they decrease in size and disappear the moisture is decreasing. While the former condition in itself does not indicate an approaching storm, it is instructive in connection with other local indications.

A sky overcast with high clouds does not indicate stormy conditions if the clouds remain high. If the pressure falls and the clouds lower, stormy weather may be expected.

Rapidly increasing cumulus clouds indicate thunder-storms. A *thunder-head* or high cauliflower top to a cumulus cloud denotes a rapid updraught, which in itself is the beginning of a thunder-storm.

Still and very slowly moving cumulus clouds indicate a continuance of fair weather.

A cloud layer against the side of a mountain range, if rising to a greater height, indicates increasing pressure; if dropping lower, decreasing pressure.

Cirro-stratus together with alto-stratus clouds indicate precipitation with a probability of about 90 per cent.—MCADIE.

Animal and Plant Indications.—To assert that four-footed animals, birds, and insects sometimes foretell approaching weather conditions is to make a very radical claim which cannot be established. But to assert that they do not recognize existing conditions and respond to them, and to weather changes in progress, is to fly in the face of the experience of four thousand years.

To most animal life weather conditions are of even greater importance than they are to humanity. If the experience of naturalists, and of those who are in close contact with herds and with bees is worth anything, one must admit that nature has provided them, not with "prophetic instinct," but with keener sensitiveness to changes in weather conditions than is possessed by human beings. The bison is especially sensitive to weather changes.

All shepherds agree that before a storm, sheep become frisky, leap and butt one another.—FOLKLORE JOURNAL.

When horses and cattle become restless and uneasy, a change to unsettled weather may be expected.

When fowls oil their feathers and are unusually noisy, unsettled weather may be expected.

A bee was never caught in a shower.

When bees hover about their hives and refuse to take flight, unsettled weather may be expected.

When house flies bite, expect rain.[1]

When spiders strengthen their webs rain may be expected.

The song of the robin bringeth rain.

The odor of plants of the nightshade family becomes very rank with the approach of rain.

Milkweed closing at night indicates foul weather.

The convolvulus derives its name from the fact that its flower closes when a rapid increase of moisture occurs. This is true also of the pimpernel. The pitcher plant, on the other hand, opens to receive the coming shower. The leaves of the sugar maple, the cottonwood and the sycamore turn so as to show the under side on the approach of a shower. Occasionally this is noticeable in the case of clover.

Experience will teach the observer the value of popular weather signs and traditions. The experience of out-of-door men whose employments are affected by weather conditions should not be tossed lightly aside. Perhaps the explanation of their reasoning may not bear critical analysis; the results,

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[1] This is not true of the house fly. The biting stable fly, however, seeks shelter indoors on the approach of stormy weather.

on the other hand, are apt to have a high value. Weather science now has treatises of inestimable value, but no book from which weather knowledge may be obtained surpasses wind and sky.

Indications of Heavenly Bodies.—It is hardly necessary to note that such indications are due to the effects of the varying moisture content of the air, together with slight refractions and diffractions caused by the moisture of the air.

Red sun in the morning, let the shepherd take warning.

A circle around the sun foretells foul weather.

The circle of the sun wets the shepherd.

A mock sun brings rain.

The moon with a circle brings water in her beak.

A lunar halo indicates rain; the larger the halo the sooner may rain be expected.

A large ring around the moon, and low clouds, rain will follow in twenty-four hours; a small ring and high clouds, rain in several days.

The halo around the sun or the moon is neither more nor less than a very faint rainbow caused by the refraction of light rays as they pass through mist or very thin cloud matter. It is therefore a phenomenon of humidity.

Before the rising of a wind the fainter stars are not visible, even on a clear night.—PLINY.

Mixed air currents cause so much refraction of light that feeble points of light are not perceived. With clear, still air the stars are very bright. In astronomical observatories, observations made on windy nights have but little value, so great is the blurring from refraction. The higher the power of the telescope, the greater the impairment of visibility.

PART II

CHAPTER XV

THE MEASUREMENT OF TEMPERATURE: THERMOMETERS

Quantitative measurements in temperature, based upon the calorie, have a definite place in physics; and those based on the British thermal unit have a broad application in various economies. Human sensitiveness to heat does not pertain to quantity but to intensity. A large block of ice at 30° may contain more heat, quantitatively considered, than a red-hot horseshoe. If carried into a room whose air was far below freezing, the ice might warm the room to a greater degree than would the horseshoe. Humanity, and indeed, all living things require the intensity of heat that enables living organisms to function naturally and properly. The vital questions therefore are—"How warm is it?"—or, "How cold is it?"—or, "Is physical comfort satisfied?" These conditions depend upon intensity of heat—that is, upon *temperature.*

Temperature.—The term temperature has a broad application. It is an expression of the varying warmth of earth, air and water, with relation to life.

The unit of temperature is a *degree*, a measured part of the expansion which a column of mercury within a tube undergoes when heated from the melting point of ice to the boiling point of water at sea level.[1]

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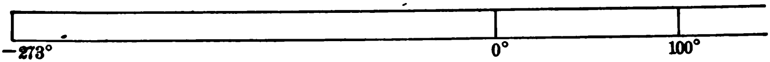
[1] The standard conditions are somewhat complex. The real test in thermometry is a comparison of a thermometer in the process of manufacture with an accurately made standard. A standard thermometer is a part of the equipment of the manufacturer.

Three scales of degree measurements are more or less in use. In the Réaumur scale, now rarely used, the expansion is divided into 80 parts; in the centigrade, into 100 parts; in the Fahrenheit, into 180 parts. In the Réaumur and the centigrade scales the zero, 0°, of temperature is at the melting point of ice; in the Fahrenheit, 32 degrees below it. The centigrade scale is used chiefly in Continental Europe. The degree values are inconveniently large and, in many cases, fractional units of the degree must be expressed. Winter temperatures require the use both of positive and negative quantities, and this adds to the labor of computation and to the likelihood of error.

Absolute Temperature.—The fact that neither the centigrade nor the Fahrenheit scale *per se* expresses the relation of the volume of a gas to its temperature has led to the establishment of a theoretical *absolute zero* of temperature. The following demonstration and the accompanying cut explain the method of its determination. A glass tube about 50 inches long and closed at one end contains a free-moving piston of mercury, resting about 20 inches from the open end of the tube. The tube is first placed in a container filled with melting ice. When the piston has reached the low point its position is marked. It is then transferred to a container of boiling water, and the position of the mercury piston is again marked. The amount of expansion is divided into 180 equal parts or units. If, now, the distance between the first mark and the lower end of the tube be measured, it will be found to contain almost precisely 459 of these units. Each unit corresponds to 1 degree Fahrenheit. Hence from this experiment absolute or natural zero would be −459.4°. On the centigrade scale it is −273.13°. Absolute temperature is commonly expressed as A°; or 459.4°A.



The empiric determination of the absolute zero of temperature.

The *natural zero* deduced from an investigation of the pressure of a gas at constant volume has the same scale value as the absolute zero. It is inferred, in consequence, that the absolute or natural zero is the temperature at which molecular motion ceases.

The Thermometer.—The ordinary thermometer consists of a bulb or reservoir fused to the end of a glass tube or stem. The tubing from which the stem is drawn is a wedge-shaped prism with a strip of white enamel fused to the convex surface. When the prismatic tube is drawn out into thermometer stems the wedge angle becomes a lens which magnifies the fine thread of mercury; the enamel becomes an opaque, white background against which the thread of mercury is plainly visible. The bulbs of ordinary thermometers are commonly blown at the end of the drawn tube. Those of the best thermometers are made of a specially constructed glass and are fused to the end of the drawn tube.

Most solids, in cooling from fusion or from intense heating, suffer what is known as "hysteresis"—that is, molecular changes continue for a considerable time. These changes alter the size of the bore of the tube. In order to overcome them, the tubes of thermometers of the highest grade are laid away to "season" or "temper" for a period of two years. The shrinkage of an unseasoned tube is likely to cause the readings to register as much as 6 degrees too high.

The bore of the thermometer is microscopic in diameter; in thermometers graduated to fractions of a degree, it may be less than 0.001 inch; ordinarily it is from 0.002 inch to 0.005 inch. In the construction of precision thermometers the bore is measured under the microscope, and a bulb of hard glass of the required size is fused to the end of the tube. Cylindrical bulbs are preferable to spherical bulbs; they present a greater surface and therefore are more sensitive. The expansion and contraction of the glass with changes of temperature is somewhat greater than with spherical bulbs, but thermometer scales are compensated for this correction.

The bulb of the thermometer is usually filled with mercury at the time it is fused to the stem. While hot, the open end of the stem is inserted in a vessel containing pure mercury. As the air in the bulb cools, its contraction causes a small quantity of mercury to be forced through the bore of the stem into the bulb. The mercury in the bulb is then heated to its boiling point and the open end of the stem again dipped into the mercury. This process is repeated until both bulb and steam are completely filled.

The mercury and the tube are apt to contain a minute quantity of moisture. If this remains it is pretty certain to cause a broken column of mercury in the tube, thereby rendering the thermometer imperfect. To prevent this, the filled tube is kept for some hours at a temperature above the boiling point of water. The "roasting" requires care and experience.

When the roasting process is completed the bulb is again heated and as soon as the mercury is expanded to the top of the stem the latter is sealed, leaving an angle or "hook" at the top. The hook holds the tube fast to the scale.

The tube is now ready to be graduated. For this purpose it is placed successively in brine at 2°, melting ice at 32°, and water baths at 62° and 92°. The position of the top of the column is marked for each temperature and usually for each tenth degree of the scale. An engine ruling machine divides each division into 30 parts. The division marks are also scaled below 2° and above 92°. The metal scale is subdivided according to the marks on the stem.

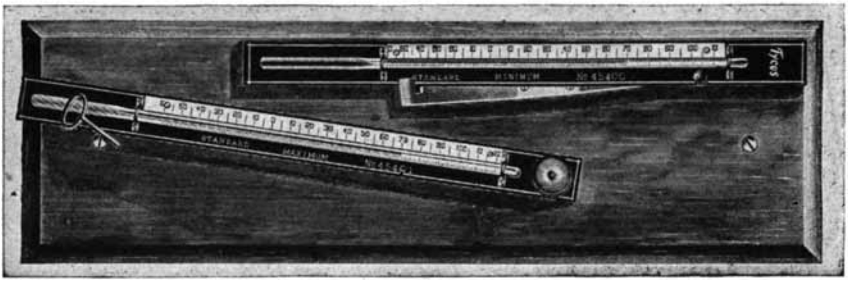
Several manufacturers produce three grades of instruments. On those of the first class minute spots may be found at the various testing temperatures. If the marks do not appear, the thermometer is not trustworthy for precision purposes. Weather Bureau thermometers are specially tested, and a certificate showing the error for each 10 degrees accompanies each instrument. A thermometer which does not comply with these requirements is not a standard instrument.

Thermometers of the second grade are not engraved on the stem; the divisions are on the metal scale to which the tube is attached. The tubes are seasoned; but trifling inaccuracies unfit them for use where precision is required. They are sufficiently accurate for ordinary uses.

Thermometers of the third grade are "rejects" and rarely bear the maker's name. The inaccuracy is always more than 1 degree, and it is likely to vary in different parts of the scale. In many instances these thermometers are sold to jobbers and retailers who stamp fictitious names on them. Experience and practise will usually enable one to discover the maker. The scope of thermometer scales varies greatly. Practically every industry employs temperature measurements which require specially constructed thermometers.

Weather Bureau Thermometers.—Several kinds of thermometers are necessary for the requirements of a weather service; and these are practically the same in all parts of the world where a weather service is maintained. In weather stations the daily maximum and the daily minimum are required; a continuous graphic record is desirable, but the instrument for this purpose is supplied to stations of first-class equipment only.

A *standard thermometer* of the ordinary type, that is, one which shows existing temperature at any time, is desirable. A minimum thermometer can be used for this purpose, but a standard instrument is preferable. The scale, divided to single degrees, should be engraved on the tube and on the metal strip as well. Readings are made to the nearest degree mark. If the fraction is exactly half a degree the preceding figure, if odd, will be increased by 1 degree; if even, it will remain unchanged.[1]



Maximum and minimum registering thermometers.
Weather Bureau patterns.

The *maximum thermometer* is so called from the fact that the mercury in the tube is not drawn back into the bulb when the temperature lowers. The expansion of the mercury in the bulb forces the flow into the bore, as with ordinary thermometers. A slight constriction of the bore at the top of the bulb prevents a backflow, thereby leaving the mercury in the bore at the maximum temperature since its last previous setting. Usually the maximum temperature of the day occurs between 2:30 P.M. and 4:00 P.M. and the thermometer should be set late in the

[1] This rule applies in all Weather Bureau computations.

evening or early next morning so as to record the maximum for the next day.

To insure accuracy of readings the thermometer should not be higher than the eye of the observer; and to avoid error of refraction by the lens front, the observer should stand squarely in front of the end of the mercury column. An error of refraction may amount to half a degree.

The "setting" of the maximum thermometer is accomplished by whirling it around a stud and bearing at the end opposite the bulb; centrifugal motion forces the mercury past the stricture, and back into the bulb.

The maximum thermometer of the Weather Bureau type should rest in a nearly horizontal position, the bulb slightly higher than the farther end of the tube. Ordinarily this will prevent any back flow. Occasionally, however, a maximum thermometer fails to leave the mercury in the bore at the point of maximum expansion; for reasons not fully explained the column of mercury is drawn back toward the bulb as the temperature falls. A maximum thermometer of this sort is known in Weather Bureau cant as a "retreater." The retreating of the column of mercury may be overcome by a slight increase in the elevation of the bulb. When, however, it is discovered that the retreating is habitual, the thermometer should be returned to the maker.

Some maximum thermometers set easily; others require to be whirled vigorously. Observers differ in their likes and dislikes. If the column of mercury moves very easily there is always danger of error. If the tube is held in a horizontal position there is the possibility of a slight retreat of the column. And if the bulb is elevated there is always the possibility that it may slide toward the far end of the tube. The maximum thermometer readings are not trustworthy for any except maximum temperatures. When set, it should agree with the reset minimum thermometer.

It is advisable to bring the thermometer very carefully to a vertical position when the reading is made. This corrects at once any sliding of the column that may have occurred. But there is always danger that a part of the mercury in the tube may flow into the bulb when the thermometer is brought to a vertical position; this is most likely to occur in hot weather when the column is long.

Taking everything into consideration, a maximum thermometer that requires a moderately vigorous whirling is preferable. The instrument with which the observer can work to best advantage is the one with which he should be provided.

The *minimum thermometer* is for the purpose of registering the lowest temperature between settings. It is exposed in a nearly horizontal position with the bulb slightly higher than the opposite end of the tube. Inasmuch as winter minima are sometimes lower than the freezing temperature of mercury, and because the instrument here described requires a transparent column, minimum thermometers usually contain alcohol instead of mercury. The alcohol of American Weather Bureau thermometers usually is colored; in most foreign made instruments it is uncolored. In the matter of visibility the gain of a colored liquid is material, but coloring matter is not essential. In spite of care, a precipitation of the coloring matter occasionally may occur, and this is likely to cause a slight constant error. The space in the tube above the alcohol contains air, more or less saturated with alcohol vapor.

The essential feature of the minimum thermometer is a small black index within the bore and also within the liquid. As a lowering temperature contracts the liquid column, the cohesion of its surface drags the index toward the bulb. When the liquid expands, however, it flows around the index without moving it. The index therefore shows the lowest temperature between settings. The minimum temperature is read at the end of the index farthest from the bulb. The temperature may be read from the minimum thermometer at any time, reading from the end of the column of alcohol, and not from the index.

The minimum thermometer is usually attached to a strip of brass, bent so that the instrument is held about an inch from the board support. It is fastened so that the end containing the bulb may be swung to an inverted position. The maximum thermometer is fastened to the same support. The stud on which it whirls is about 2 inches long. The free end rests on a pin which is removed when the thermometer is set.

Instead of the fasteners described above, clamps, sometimes called the Townsend supports, may be used to hold the thermometers. The clamps are fastened to the board support and permit the setting of the thermometers. The clamps are issued as a part of station equipment.

Care and Adjustment of Thermometers.—The thermometers, being exposed to the weather, accumulate dust; the metal parts may become tarnished or even rusty. It is advisable to use a soft camel's hair brush for removing the dust, and this should be done two or three times a week. When occasion requires, a polishing brush may be used on the metal parts. It is more desirable to prevent than to remove rust and tarnish.

Unless the maximum thermometer becomes a retreater, it is not likely to get out of order. Even if drifting snow blown into the shelter incrusts it, no damage is likely to result. It is better to allow the snow to melt off than to attempt to remove it by force.

If a maximum thermometer has not been set for a long time, a break in the column which refuses to unite may result. The same may occur if the moisture has not been wholly expelled during the roasting process. In such a case it is usually possible to drive the space to the small chamber at the end of the tube. It may be driven into the bulb; if this is done the break is likely to work back into the column again. If the instrument is held in a vertical position, bulb down, at a distance of 1 or 2 inches from a table, and is allowed to fall with vertical blows so as to hit a thickness of blotting paper placed on the table, the broken space gradually displaces the mercury until it reaches the top of the column.

A break in the column of mercury in the tube is not necessarily a defect; it is only when the break will not close—that is, when it leaves an open space—that error in the reading results. In such a case the thermometer should be discarded, or else returned to the maker for repair.

The minimum thermometer is usually out of order when it is received at its destination. The index may be fast at the top of the tube, or in the bulb; most likely the alcohol column is broken, a half dozen or more bubbles occurring; possibly some of the alcohol is lodged in the chamber at the farther end of the tube.

To loosen the index, tap the edge of the metal scale with a small piece of wood—say, a clothes pin—until it becomes free.

With bulb end down, let the thermometer fall vertically an inch or more so that it strikes endways on the table or the shelter floor. Little by little the alcohol will flow along the tube; the broken parts of the column become shorter; and the bubbles disappear.

If this fails, hold the thermometer at its upper end and bring it down forcibly as though striking hard blows with a hammer —being careful, however, *not* actually to strike anything. It may require vigorous exercise, but the centrifugal force will finally bring the broken parts to the rest of the column. It usually requires from a quarter to half an hour to put a minimum thermometer with a broken column in order. Great care must be used that no part of the alcohol remains in the chamber at the farther end of the tube.

Thermometer Shelter.—Maximum and minimum thermometers should be sheltered from the sun and from direct contact with precipitation of every sort. They also must be placed so that they are in contact with free air. They must be sheltered from heat radiated from buildings, metal roofs, and pavements. The board support should not be attached directly to the wall of a building; if on a porch it should be attached to an outrigger that leaves a space of a few inches from the building. A wide, covered porch with a northerly or an easterly exposure is the best position about a building.

The daily maxima on the south side of a house, within 3 feet of the wall will be from 2 degrees to 6 degrees higher in clear weather than those on the north side, close to the house. The minima will vary but little. If only a window exposure is available, a north-facing window should be selected, and the thermometers should be screened from the window if the room is heated. There should be several inches of space between the shelter front and the window.

In cities, the flat roof of a building frequently offers the best position for thermometers. A graveled roof reflects less heat than a metal roof, and should be preferred when possible. In any case the shelter should be placed where the thermometers are not affected by heat reflected from nearby walls. The best position on the roof must be determined by judgment and experience.

In open country and sparsely built localities, the shelter built after the plans recommended by the Weather Bureau should be used. This consists of a miniature house, 3 by 2 by 2 feet, with louvered sides and a removable top. The front may be let down when readings are made. The front should face the north. The shelter rests on braced legs which should be anchored firmly to the ground. The top of the shelter is likely to become hot enough to radiate heat to the thermometers. This may be prevented in part by a double roof with an air space, or by covering the roof loosely with asbestos cloth or with linoleum. There can be no objection to placing the shelter in the shade of a tree that shields it from the afternoon sun, provided it is not less than 8 feet from trunk and branches.

A Thermometer Shelter.
It is placed in the shade of tall trees, and receives direct sunlight a few hours in the morning only.

In locating a place for a shelter it is a good plan to use a second thermometer in various positions, checking and comparing maxima and minima. Reflection and absorption sometimes bring about unexpected results. Observers with experience are alert to these possibilities; the inexperienced observer must learn them. In general, if the shelter is distant twice the height of an object there will be no errors caused by reflection or by absorption from that object.

Anomalies of Temperature.—As a rule, minimum temperatures—and they usually occur just before sunrise—are less apt to be affected by unusual conditions than are maximum temperatures. The minimum temperatures on the south side of a building are usually the same as those on the north side. In prolonged hot spells, however, this does not always hold true. The walls of the southerly exposure may absorb so much warmth during the day that not all of it is radiated at night. As a result, a minimum registered under such conditions will be too high.

The prevalence of a stiff wind, especially the northwest wind of cold waves, equalizes temperatures to a remarkable extent; the minima of stations covering considerable areas rarely vary more than 1 or 2 degrees. On the other hand, on very still nights the minima of stations only a few miles apart may vary several degrees.

On very cold, still nights cold air tends to settle by gravity into low spots. This condition is so marked that the minima of localities only a few rods apart may vary as much as 2 or 3 degrees. This difference is very noticeable in mountain valleys where the cold air is apt to flow down the valleys at night. Frosts occur much more frequently along valley floors than in the foothills and the benches higher up.

City and suburban temperatures usually have about the same daily means, and their monthly averages should not vary more than a degree. The daily maxima and minima not infrequently vary several degrees. This is due chiefly to the fact that the less amount of smoke and dust in suburban localities favors absorption of heat in the day time and permits radiation at night.

In early fall and also in late spring, frost may be observed in sheltered places on the ground when the thermometer registers several degrees above freezing. An observer may therefore conclude that his minimum thermometer is not registering correctly. It is not likely than an error has occurred; ground surface temperature, especially on northerly exposures, may register several degrees—on occasions, as many as 10 degrees—lower than the thermometers 6 feet or more above the surface.[1]

Thermometers on the business streets of cities, especially those in which the blocks are solidly built, register from 3 degrees to 6 degrees too high as a rule, owing to radiation and reflection from nearby buildings. They indicate the temperature of the street, but not of the free air.

The Six Maximum and Minimum Thermometer.—A maximum and minimum thermometer of the Six pattern consists of a glass tube bent in two or three sections as shown in the accompanying figure. The tube in the center is a cylindrical bulb about 0.1 inch internal diameter; the bulb at the top of the right-hand column is large enough to have a volume of about 1 cubic centimeter. The bore in the U part of the tube is about 0.02 inch in diameter; it is filled with mercury. The central bulb is completely filled with a solution of creosote, or with alcohol. The expansion of the liquid in the central bulb pushes the mercury down on the left side of the U and up on the right side; it also pushes liquid into the air bulb on the right side, slightly compressing the air and vapor in the bulb. Lowering temperature causes a contraction of the liquid in the central bulb, thereby drawing back the mercury in the U. This is made more positive by the compressed air and vapor in the right-hand bulb. The scale reads downward on the left and upward on the right side. These are marked respectively "cold" and "heat," or "night" and "day."

Maxima and minima are recorded by separate indices within the bore of the tube. The indices are pieces of steel wire coated with glass—in some thermometers they are plain wire—each armed with two appendages. On one end the appendage points upward; on the other, downward. Their object is to hold the index lightly to the place in the bore to which the mercury pushes it. Pushing the indices is the only work the mercury in the U tube performs. Rising temperature pushes the index in the right-hand tube upward; falling temperature pushes the index in the left-hand tube upward. The

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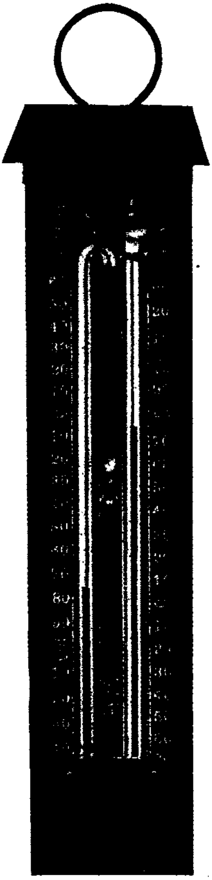
[1] In the latitude of middle England Sir Napier Shaw notes that thermometers on the grass register lower by 20 degrees than those in the shelter, a difference of 8 degrees being very common.

indices are set by the use of a small magnet which accompanies the thermometer. The poles of the magnet are hollow-ground, so as to fit closely to the tube.

In many respects the Six thermometer is preferable for ordinary uses. It is not so likely to be broken as the regular Weather Bureau thermometers; it is very readily set; and it is more nearly "fool-proof" than the delicate Weather Bureau instruments. It is not so sensitive as the Weather Bureau thermometers; it is slow in registering; and the indices are occasionally caught in the mercury from which they are separated with difficulty. A violent jar may break the hair-like appendages that cause the indices to register. If this happens to the index in the right-hand tube its repair by a thermometer maker is possible; if in the left-hand tube the case is hopeless.



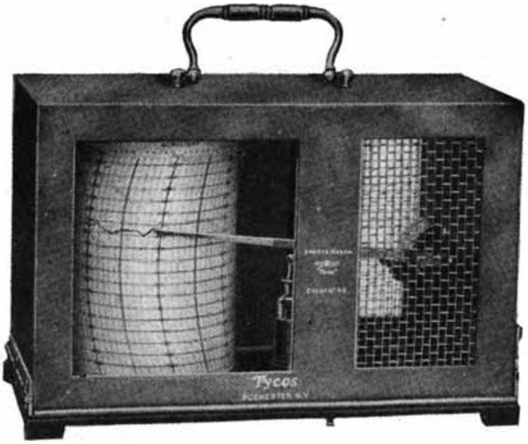
Maximum and Minimum Thermometer. Six's pattern

In selecting a thermometer of this type one should note first whether or not the readings of the two tubes are the same. When a thermometer has lain edgewise, or on its side, for a number of days—and this may occur when it is in transit on a railway—a flow of the liquid past the mercury, from one tube to the other, may take place. As a result the readings on the two sides do not coincide. An expert in the mechanics of thermometry can make the necessary adjustment, but it should be done by an expert and not an experimenter. In selecting a Six thermometer, a comparison of the readings of the two sides should be the first care.

The Six thermometer may not be quite up to the standard of accuracy. If the error is small the thermometer needs not be condemned, however, for an allowance can be made therefor.

The Thermograph.—The thermograph is both a registering and a recording thermometer. The essential part of the mechanism consists of two thin strips of metal having different coefficients of expansion. The metal strips are brazed or soldered surface to surface, bent to a quadrant or curled into a coil, and annealed. The type used by the United States Weather Bureau consists of a curved flat tube filled with mercury or with alcohol. In either type of thermograph expansion causes a warping of the metal which is communicated to a lever, whose long arm is a recording pen.

The recording part of the thermograph is a drum containing a clock. The clock is geared so as to cause one nearly complete revolution of the drum in a week. The slight shortage of a complete revolution is an allowance for the margin of the fastening of the paper on which the record is made.



Thermograph—nigh drum.

The paper strips upon which records are made are about 12 inches long. They vary in width according to requirements. Horizontal lines lithographed from engine-ruled plates divide the width of the strip into degree spaces. Arcs of circles, whose radii are the length of the pen, divide the length of the strip into day spaces, each of which is subdivided into two-hour intervals. High drum record sheets are ruled for temperatures varying from −50° to 120°; low drum strips are usually ruled from 0° to 100°.

High drum thermographs are used very generally in meteorological work. Low drum strips have all the temperature range necessary for greenhouses, refrigerating establishments and freight cars containing perishable goods. They are used in many Weather Bureau stations where the yearly range does not materially exceed 100 degrees. For most stations, and for general military use, a high drum thermograph is advisable.

Thermographs are not so accurate as standard thermometers. In very damp weather the expansion and swelling of the paper on which the record is made affects the accuracy. Inasmuch as the paper rests on the lower collar of the drum, the upward expansion of the paper may render the record of the maximum 2 or 3 degrees too low. In any case, the maxima and minima should be compared with those of the registering thermometers, and the corrections, plus or minus, noted on the record sheet.

If the thermograph record does not coincide with the thermometer readings an adjustment screw will bring the pen to the proper position. It is a good plan to adjust the pen so that the minimum coincides with that of the minimum thermometer. The time of the minimum may always be determined from the thermograph sheet, and this is one of its important uses. As a rule, the minimum temperature occurs a short interval before sunrise. During the progress of a cold wave there may be a steady fall of temperature covering a period of two days. Frequently the fall of temperature continues from 12:01 A.M. to 11:59 P.M.[1] The "lowest this morning" is therefore not the minimum of the day; and though this fact may escape the notice of the observer, it will not escape the record of the thermograph.

The recording pen of the thermograph may lag anywhere from five minutes to forty-five minutes behind the actual temperature. In very damp weather the lag is usually the greatest, and, in fixing the time at which a given temperature occurred, this fact must be taken into the calculation. An observer who studies the vagaries of his instruments—and they are many—will learn how to master them.

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[1] These figures are generally employed in weather bureau and in meteorological time to avoid the confusion that results from the use of the term "midnight."

High-air Thermographs.—High-air temperature observations are usually obtained by thermographs secured to kites or balloons. In manned balloons a very sensitive thermograph is contained in a tube through which a current of air is forced. This instrument, the Assmann aspirator, is far more convenient than an ordinary thermograph. Experience has shown that unless the air is in rapid motion, registration is too slow to be trustworthy. A mechanical fan moves the air through the tube at the rate of about 12 feet per second.

In another form of instrument decreasing pressure moves a plate in one direction while the stylus of a bi-metallic thermometer records with a motion at right angles thereto. A clock is not required in this type of instrument; it is therefore lighter and more convenient.

The Black-bulb Thermometer.—This instrument, now little used, consists of a maximum standard thermometer, the bulb of which is covered with a coat of lampblack and encased in a vacuum tube. Originally it was designed for the measurement of solar radiation. A thermometer of this sort, exposed to direct sunshine, registers a temperature many degrees higher than does an ordinary thermometer, but the degree varies according to the thickness and the quality of the lampblack. It is therefore a very imperfect instrument for the purpose designed.

The black-bulb thermometer roughly measures the temperature which popular tradition terms "sensible" heat; exposed to direct sunshine, the temperature registered is from a few degrees to 60 or more degrees higher than the temperature registered by the ordinary thermometer. With a high humidity, or in smoky, dusty or foggy air, the black-bulb thermometer registers much lower than in clean air.

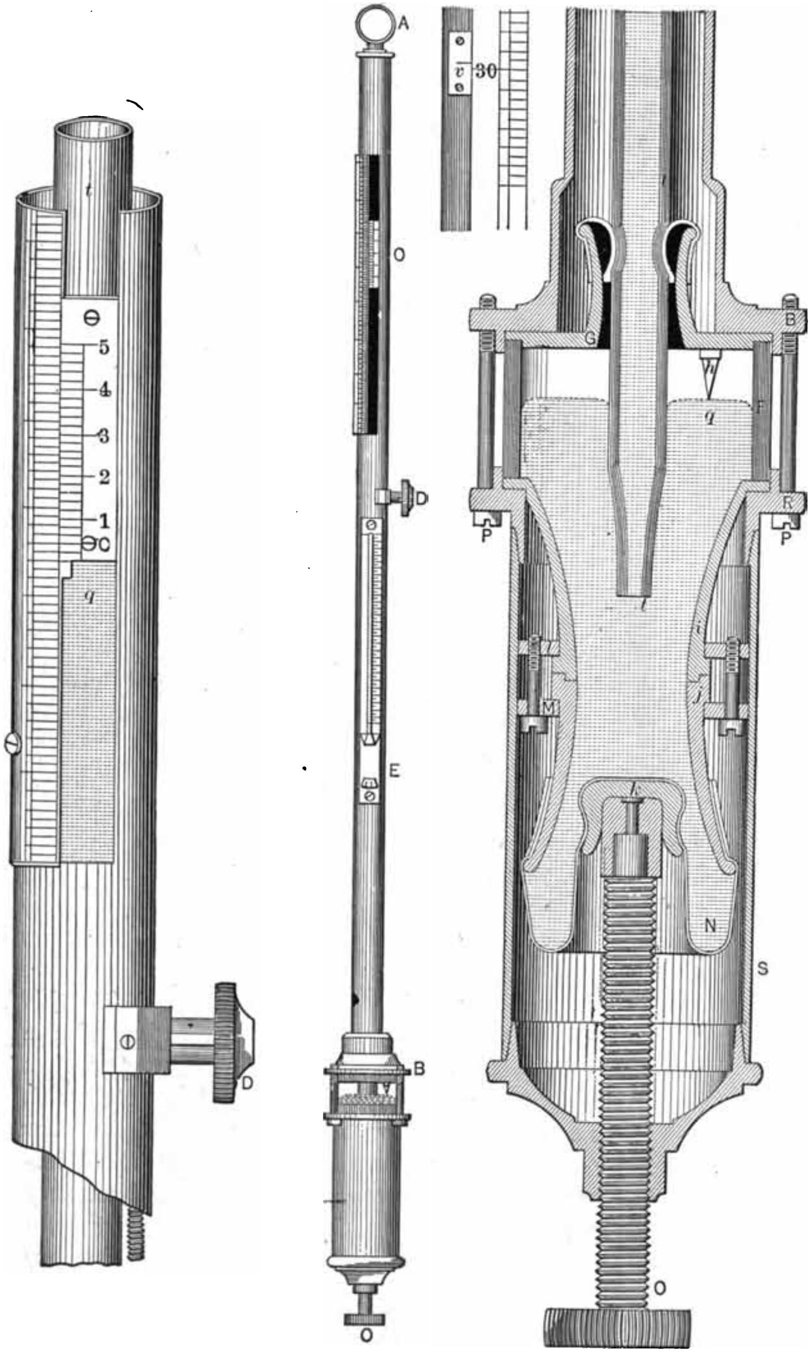
CHAPTER XVI

THE MEASUREMENT OF PRESSURE: THE MERCURY BAROMETER

Two terms may be used to express the gravity of the air—weight and pressure. The weight of air is used more properly to express the gravimetric force of a given volume: thus, 1 cubic foot of air at normal pressure and temperature of 32° F weighs 1.29 troy ounces (1 cu. cm. = 0.0013 gram). In meteorology it is more convenient to consider the weight of a column of air throughout its whole extent, from sea level upward. At sea level such a column of air presses upon the surface with an average force of 14.7 pounds, a pressure empirically termed 1 *atmosphere.*

The pressure of such a column varies, however, not only from day to day, but from hour to hour. If a mass or a wave of air accumulates over a given locality the pressure increases; conversely, if a depression, or a trough, occurs, the pressure decreases. As the observer goes from sea level to a higher altitude the pressure decreases also. At an altitude of 19,000 feet, a height occasionally reached by airmen, the pressure is about half of that at sea level.

The pressure of the air may be determined by weighing it; it is much more convenient to compare it with a column of mercury which balances it. A balance constructed for this purpose is a *barometer.* The theoretical construction of the barometer is simple; it consists of a glass tube about 33 inches long, closed at one end, filled with mercury, and inverted with the open end in a cup of mercury. The column of mercury within the tube exactly balances a column of air of equal section. If air accumulates, the increased pressure on the mercury in the cup forces the column higher in the tube; conversely, a decrease in pressure causes the mercury column to shorten;



The mercury barometer. Sectional view showing construction of cistern the decreased pressure cannot force so much mercury into the tube.

Construction of the Barometer.—A common form of the barometer is a siphon tube, the short arm of which is enlarged to a bulb, and this constitutes the mercury cistern. The barometric column is the distance between the upper and the lower surface of the mercury.

The Weather Bureau pattern is more complicated. The tube has a caliber usually about 0.25 inch. The cistern or tank containing the mercury consists of a short cylindrical glass tube. The cover is a piece of boxwood perforated to receive the barometer tube and flanged to fit the cylindrical glass section of the cistern. The lower part of the cistern is a broad ring, of boxwood, flanged and fitted to the lower edge of the glass cylinder. To the lower part of the boxwood ring a kidskin bag is attached. The mercury fills the bag and reaches nearly to the top of the glass cylinder. The cistern fits snugly into a cylindrical metal box. A plug within the cylindrical box, operated by a screw at the bottom, partly supports the bag of mercury. The construction may be likened to a glass tube projecting vertically from the mouth of a rubber bag filled with water. Pressure on the bag forces water up the tube; release of pressure causes it to lower in the tube.

The object of the leather bag and the plug is two-fold; it enables the observer to raise or to lower the mercury in the cistern so that the surface touches the ivory point which is the end of the scale, thereby giving a more accurate reading; it also enables the observer to close the cistern and tube, so that the barometer may be carried in any position without permitting the mercury to escape from the tube, or air to enter it.

The cistern of this pattern of barometer is commonly known as the Fortin cistern. It was improved by Henry J. Green. The improved pattern is used by the Weather Bureau. The Tuch cistern, also used by the Weather Bureau, has a piston bottom that can be raised and lowered by a thumb-screw. The Weather Bureau pattern of the barometer made by the Taylor Instrument Companies has a similar device. In each, a stopper pressed against the mouth of the tube secures the mercury so that the barometer may be transported with a minimum of risk.

Fixed-cistern barometers have not been favorably considered by meteorologists. The objection to them on the whole is not well founded. If the scale has been compensated a fixed-cistern barometer will meet all the requirements of accuracy demanded by ordinary meteorological measurements. It is more serviceable for use at sea than a cistern of the Fortin type. It is less likely to injury in transportation.

The necessity of a compensated scale may be understood from the following facts. The sectional area of the cistern is about fifty times the sectional area of the tube. If the atmospheric pressure increases, say, from 29.00 inches to 30.00 inches the rise of 1 inch in the tube is balanced by a fall of 0.02 inch in the cistern. The true height of the column therefore is 30.02 inches. When the sectional areas of both cistern and tube have been accurately determined, an empiric scale compensated for the instrument may be engraved to meet the requirements of accuracy. Should the tube be broken, however, a new scale will be required inasmuch as the caliber of tubes varies considerably.

A barometer with a fixed cistern, made by Schneider Brothers, is highly regarded among officials of the Weather Bureau. A feature of this barometer is the facility with which the mercury can be made secure within the cistern and tube, so that the instrument will not lose its adjustment.

Fixed-cistern barometers may not meet the requirements of precision measurements so well as instruments of the Fortin type of cistern; but for marine purposes or for field work, their simplicity of construction and stability commend instruments of this character. When securely adjusted, they may be transported over rough wagon roads and carried in any position without especial care.

The tube of the barometer is inclosed in a case with the necessary openings which permit the height of the mercury column to be read. Weather Bureau barometers are of the "gun-barrel" type, tube and cistern being inclosed in a cylindrical metal case. Openings, or "windows" are cut in the sides so that the top of the column of mercury is always in sight.

The scale of Weather Bureau barometers is on the left side of the window. It is a strip of white metal, with slotted screw holes so that it may be adjusted to compensate corrections which are constant, especially capillarity. The inch is divided into tenths and subdivided into twentieths. The scales of commercial barometers are usually without compensation adjustments.

The vernier enables the observer to read the height of the column to two one-thousandths of an inch, and to estimate it to a one-thousandth part. On commercial barometers the vernier enables the observer to read accurately to the one-hundredth part of an inch. A rack and pinion moved by a milled screw enable the observer to adjust the vernier to the height of the mercury.

The thermometer set into the metal case of the Weather Bureau barometer is always a standard instrument, whether carrying a certificate or not. The scale is etched on the tube to single degrees, but it may be read to half-degrees in accordance with the temperature corrections which are calculated to half-degrees.

The Installation of the Barometer.—When a barometer is sent from the manufacturer, or is issued from the Weather Bureau, it is pretty certain to be in good order and ready for installation. It is an almost universal custom to wrap the instrument first in tissue paper, then in cotton flannel, and finally in stout wrapping paper. The packing case should be so large that the elasticity of the packing material will compensate any jar that may occur from ordinary handling. Barometers sent out by the Weather Bureaus are usually packed in cases designed for the purpose. Ordinary precaution suggests that the cover of the packing case should be fastened with screws and not with nails.

When a barometer is sent by messenger it should be sent either in a leather case or a box designed for the purpose, with the handle so placed that it must be carried cistern uppermost. It should not be allowed to rest with the end on the floor of a moving vehicle.

Before the barometer is removed from the packing case, the position most advantageous for it should be determined. A wall or partition that is easily shaken should be avoided. A position on a window frame or near the corner of a room is often the best available. A position where the temperature is not subject to sudden change is very desirable.

Weather Bureau barometers are provided with a glass-paneled containing box, the front and right side of which swing open. Many observers prefer a plain board mounting. Marine barometers are usually contained in a box with an outrigger which permits them to be removed to a position convenient for reading.

The box or supporting board must be mounted so as to be vertical in all meridians. Metal eyelets, or hangers, accompany the supporting box or board. When in place, there should be no "wiggle" or dead motion. The hangers will be found in such a position that the barometer swings in the middle of the lower ring.

When the barometer is removed from the packing case it should be lifted, cistern uppermost, and laid on a table or bench to be unwrapped. Until it is finally in position it should be moved about cistern uppermost. When the wrappings are removed, it should be carried cistern uppermost to the support and turned carefully top end up. The cistern end should be put within its supporting ring before it is hung upon the hook of the support. If the box or the supporting board has been accurately leveled, the cistern will swing freely in the supporting ring. The centering screws in the ring may then be turned until each barely touches the cistern box. In case the screws are lost, pegs of soft wood, whittled to the right size, will answer temporarily. The case of the barometer should turn freely on the swivel, but there should be no dead motion.

The Care of the Barometer.—Except in unusual cases, a mercurial barometer should be kept indoors in a position where the temperature is as nearly uniform as possible. At temperatures materially below 10° F the readings of barometers side by side may vary enough to give concern to a conscientious observer. When the temperature is materially below zero, F, at an altitude of 5000 feet, more or less, the readings are often of uncertain value. The moral is obvious. Uniform and constant conditions are necessary for uniform results.

The compensation for capillarity is usually corrected by adjustment of the scale. Mercury does not "wet" glass; therefore the surface of the tube not only tends to retard the rise of the column, but prevents the mercury from assuming a level surface at the top. The rounded surface is the *meniscus*, the shape of which changes from time to time, as pressure varies.

With a rising column the convexity is visibly greater than with a falling column. The larger the bore of the tube the less the correction for capillarity. A tube with a bore of less than 0.25 inch should be avoided. Inasmuch as the meniscus of the larger tube has a narrower range, the readings during changes are a little more accurate with a tube of larger bore.

When a barometer is new, the surface of the mercury is very bright. In the course of two or three years—or less—the surface of the mercury in the cistern may become oxidized, turning gray. Although unsightly, this condition offers no material interference with accurate reading. In time, also, the vacuous part of a poorly constructed barometer may acquire a gray tint owing to the use of impure mercury in filling the tube and cistern.[1] Although this may not affect the reading appreciably, it is a mark of careless workmanship, and such an instrument should be sent to a reputable maker to be refilled with clean mercury.

After a few years of service the film on the surface of the mercury may require cleaning. Emptying, cleaning, and refilling a barometer tube is a delicate task even for trained experts; it should not be attempted by one without experience.

A clean room, free from dust, is desirable for barometers. Dust is not preventable, but it should not be permitted to accumulate on instruments. A soft, damp—not wet—cloth will remove and gather it without scattering; a camel's hair brush will remove it from corners and crevices which the cloth does not reach. If glass cylinder and tube are clean and bright there need be but little error in setting the mercury to the scale, or in cutting the top of the meniscus sharply by the sliding windows.

If a barometer is to be removed from its support the mercury in the cistern should first be raised until the mercury in the tube is flush with the opening near the top of the case. If it is to be

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[1] Pure mercury in a saucer made chemically clean leaves no stain or metallic film when shaken about. If it contains even a trace of other metal—lead, zinc, or tin—spots and streaks will adhere to the saucer. If the mercury is not freshly distilled it may contain moisture. Mercury may be freed of its own oxide by filtering through a *clean* paper funnel with a pin-hole perforation at the bottom. The mercury used in Weather Bureau barometers is chemically pure.

removed to a position materially lower, allowance should be made for the increase in pressure. Unless this precaution is observed, the pressure may be great enough to force mercury through the joints of the cistern.

The following instructions concerning the removal from position are issued by the Weather Bureau: "When moved about, the cistern end should be carried uppermost. To turn the barometer tube-end up, bring it gradually to a horizontal position, watching for a small bubble at the cistern. This should not be large, nor should it be absent, in which case there may be serious pressure from within, tending to force the mercury out of the cistern. If necessary the adjusting screw should be turned so that the bubble is not larger than the space within which a dime can be placed. If there is an air vent, as in the Tuch cistern, as soon as the mercury is raised to the top of the cistern, *close the air vent tight* and continue screwing up the cistern until the top of the column reaches the summit of the opening in the metal tube. Avoid raising the mercury in the cistern until the tube is entirely filled with mercury. Do not strain the screw if it turns hard; mercury may have leaked from the cistern and there may not be enough to fill the tube." If no air has entered the upper end of the tube, when the barometer is inclined about half way the mercury will rise to the top of the tube with a slight but distinct click; and when the instrument is nearly horizontal a bubble should appear at the cistern."

The foregoing cautions apply to Fortin type barometers chiefly, but will apply in some respects to other types. In the installation, removal, and care of other barometers, the directions of the makers should be followed. Marine barometers are provided with tubes a considerable portion of which is constricted to prevent the "pumping" of the mercury which the motion of the vessel would otherwise cause. The constriction prevents the vacuous part of the tube from filling quickly. The barometer must be inclined gradually, waiting until the flow ceases. By the time it is inclined about 40 degrees the mercury will have filled the tube. It can then be inverted and moved about in that position. Because the cistern is partly filled only, a marine barometer is easily put out of adjustment during transportation.

When a barometer is inclined so that the mercury is near the top of the tube, a slight lengthwise movement will cause it to flow to the top, striking it with an audible "click." There is a tradition that the character of the vacuum can be determined by the character of the sound; but inasmuch as trained experts are sometimes deceived, the value of the click as a test is uncertain; and inasmuch as such a practise is likely to break the tube, the negative value is pretty certain.

Barometer Scales and Standards.—For many years barometric pressure was expressed in the linear units of the country. The adoption of the metric system in several states of Europe changed the use of local units to metric units. The metric system has been authorized to be used in the United States, but the use has not been made compulsory. It is employed in laboratories and in certain scientific work, but not in the manufacture of precision machinery unless definitely ordered. It is not used for commercial purposes in English-speaking countries. In the latter, barometric pressure is expressed in inches. Metric scale barometers are furnished on order by the makers.

So far as choice between the two scales is concerned there is not much difference. Each is intelligible in the locality where it is used. So far as the keeping of records is concerned there is neither gain nor loss; each requires four figures and a decimal point.

Physicists who use the metric system of measurements find it convenient to use the dyne—a force that will impart to one gram an acceleration in velocity of one centimeter per second—as the unit of pressure. The pressure base proposed for barometric measurements is 1,000,000 dynes. This value is not sea level pressure, but the average pressure at a height of 106 meters (348 feet) above sea level. The unit is the *kilobar*, or 1000 millibars. The conventional atmosphere of 29.92 inches is 1013.2 millibars.

To the great majority of observers any barometer scale is more or less empiric. By long training and habit one gradually acquires a mental value of the figures which express pressure and these become visual proportions that can be compared in the mind. It is difficult to change the results of this education; it likewise requires time. So far as expression of barometric terms of pressure are concerned, there is not the slightest gain in the substitution of the metric for the inch scale or vice versa.[1] When records have covered considerable periods of time a change of either to the other results not only in confusion but in positive loss.

Barometer Observations and Records.—Weather Bureau barometer records are made at 8:00 A.M. and 8:00 P.M. Observers usually note any changes that may have occurred during the day. Making an observation for record that shall meet the demands for reasonable accuracy requires a certain amount of experience and familiarity with the barometer.

Inasmuch as temperature, pressure, humidity and wind observations are to be taken at clock time, and all these require about ten minutes in the aggregate, it is sometimes necessary to decide quickly as to preference of order. During heavy storms a variation in barometric pressure may change visibly; and in winter weather, temperature may rise more than 1 degree between 8:00 A.M. and 8:10 A.M. Judgment and experience must determine. As a rule, however, two minutes will be a generous allowance of time for temperature observation. To make such observations habitually out of the established time should be a good reason for looking with suspicion upon the records thus made; if for any reason an observation is made out of time, the fact and the time should be noted. Slipshod practise in the time of making observations may not impair the results, but they certainly impair the character of the observer.

Because body warmth may affect the attached thermometer, the temperature should first be noted. It is best to record the temperature to the nearest half-degree. In field work, especially, if the temperature is within a few degrees of the freezing point, reading the temperature to the nearest degree will be sufficient for ordinary determination. Below 29° F the temperature corrections are additive; above 28° F they are subtractive.

The milled screw at the bottom of the case raises or lowers the mercury to the scale. When the surface of the mercury

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[1] If a change from the English mercury-inch system should become desirable, the millibar scale would be considered preferable to any other so far proposed. At Greenwich, where the acceleration is 981.17 centimeters, the standard of pressure is 1,013,800 dynes; at Paris it is 1,013,600 dynes; in the United States (U. S. Coast Survey determination for Lat. 45°) the standard is 1,013,200 dynes, acceleration 980.62 centimeters or 32.16 feet.

in the cistern touches the ivory point it is at the zero of the scale and the distance to the top of the column is the *observed height.*

Adjusting the surface of the mercury to the ivory point is best accomplished in many instances by the use of artificial light. Where convenient an extension socket to the nearest light plug is the best method; a flashlight will answer all purposes. There are several ways to determine tangency of the ivory point and the mercury:

Contact between the point and its shadow on the surface of the mercury.

Making a visible dent in the mercury with the ivory point; then lowering the surface until the dent disappears.

With the eye in the horizontal plane of the end of the ivory point, noting the position when the light space between the point and the mercury ceases to appear.

Observers usually prefer the last method. In practise, the first method is associated with it. The second method is fairly safe when the surface of the mercury is bright, but it is not easy to discern the dent if the mercury is tarnished. Experience will usually determine the method by which the observer will obtain the most accurate results.

Setting the vernier scale exactly to the meniscus, or rounded top of the mercury in the tube, is not always easy. The first requisite is a clean tube. The film that gathers upon the cutside of the tube in damp weather catches dust and interferes with the transparency of the glass. The moral is obvious: the tube should be clean. The refraction of the glass has a tendency to produce a "drop," making it slightly difficult to adjust the two edges of the vernier shutter so that the line of sight is precisely tangent to the meniscus. The eye, of course, must be in a line with the edges of the windows.

A very great part of the value of barometer observations consists of the knowledge that may be obtained by comparisons. In order to compare observations they must be reduced to a common base; namely, a temperature of 32° F and sea level. The temperature correction, except as noted, is subtractive; the altitude correction is additive, except as the station may be below sea level. Death Valley and Imperial Valley, California, are stations in the United States to which this exception applies.

A correction for latitude is required at Weather Bureau stations. This correction in the United States, Alaska excepted, varies from nothing at Lat. 45° to 0.05 inch in the southern part of the country. It is additive in latitudes higher than 45° and subtractive in latitudes lower. Being a constant, it may be included in the sea level reduction.

Except for weather bureau records, or for comparison with sea level records, reduction to sea level is not necessary. In general, station-altitude readings and the oscillations in pressure are of greater value to the observer than reduced readings. This is notably the case in aviation. It is often necessary to know whether one is entering a region of increasing or of decreasing pressure. The difference involves not only questions of plane support; it is also the distinction between clearness and cloudiness.

Obtaining Station Altitudes.—The altitude of a permanent station should be determined as closely as is possible with ordinary facilities. Two points, a "plane of reference" and a station fixed point are required. The first should be, if possible, a bench mark of the United States Coast Survey, the Lake Survey, the Mississippi River Commission, the Engineer Corps, or the United States Geological Survey. Of less precision are railway levels and city bench marks, and other surveys made by engineers; they will be found useful for reference even when their precision is doubtful. Railway station levels are reasonably precise. The top of the rail at a designated point within yard limits may be taken as a plane of reference.

If a precisely determined elevation is required it can be obtained best by a survey from the most accessible established bench mark. The station fixed point should be made on some object that is both fixed and durable. A young and rapidly growing tree is not a desirable object for a station mark; but a mark made on a full-grown tree is not subject to material change. A stone post set firmly in the ground, or a piece of painted scantling attached firmly to the corner of a building will answer the purpose. The mark should be of such a character that it will resist ordinary weathering. The final point in the determination is the station barometer, that is, the chain of determinations which begin at an established plane of reference and end with the ivory point within the cistern of the barometer.

The term "sea level" is differently interpreted in different localities, "Mean tide," "mean low tide," "mean high tide," and "mean sea level" are used. If the local usage does not conform to that of established Federal usage, the nearest established *Plane of Reference*[1] practicable should be sought as a starting point. The Weather Bureau has established a specific elevation for each of its stations; the nearest station practicable therefore may be taken as an initial point.

Altitudes by Comparative Barometric Observations.—Reasonably correct altitudes may be established by synchronous observations, one series at an established altitude, the other at the place whose altitude is to be determined. For this purpose the position of known altitude should be a Weather Bureau station or an observatory having a standard barometer and an observer of experience. If a mercurial barometer is used at the location whose altitude is to be determined, it should be allowed to "rest"—that is, to adjust itself to the altitude—for a few days, if possible.

The readings may be made hourly at the same time at both stations, the height of the mercury, time and temperature correction being noted. This may be repeated for several days until the reduced readings are constant. If the stations are not far apart, a single series of observations may suffice; if they are more than 25 miles apart differences in pressure other than those due to altitude may interfere.

For instance, six consecutive observations between the stations show a constant difference, and the lower pressure at the upper station may be assumed as a difference in pressure due to altitude.

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[1] Planes of Reference established by the U. S. Geological Survey are established with reference to *mean sea level.*

CHAPTER XVII

THE MEASUREMENT OF PRESSURE: THE ANEROID BAROMETER

The aneroid[1] barometer has become an instrument of the greatest usefulness to the explorer, the meteorologist and the airman. To the last named it is indispensable; no other form of barometer to take its place has been devised. Its great virtue is its portability.

The Construction of the Aneroid Barometer.—The essential part of the aneroid barometer is the shallow metal box with thin corrugated top and bottom, usually of German silver, having a thickness of 0.004 inch. The corrugation gives a much greater degree of expansion and contraction than would be possessed by a plane surface.

The box is the *vacuum chamber* or *cell.* The top and bottom are so elastic that, when the air is exhausted, they collapse almost completely. To prevent permanent warping a stout steel spring attached to a stud in the top of the vacuum box pulls it into a normal position. This mechanism results in a surface that is very sensitive to atmospheric pressure.

A train of levers, a chain and a drum translate the movements of the vacuum chamber covers, caused by changing pressure, into a circular motion; an index pointer moves back and forth over an arc graduated to represent inches of mercury. A movable scale with a zero point that can be set at a desired position encircles the barometric pressure scale. This scale is graduated to express altitudes.

The steel service spring and the metal of the vacuum chamber are weakened by warmth, thereby impairing the accuracy of the readings. In some aneroid barometers this is offset to a considerable degree by the admission of a small portion of dry

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[1] The name is not connected with the Greek word meaning "air"; it is formed of two Greek words meaning "without a liquid."

air into the vacuum chamber; in others, the long lever extending from the steel service spring is made of two strips—brass and steel—brazed together. The altered length of the lever is made to offset the weakening of the service spring. An aneroid of this construction is thereby compensated for temperature. A barometer bearing the name of the maker, and not a fictitious name, is pretty apt to be as it is represented. Among commercial aneroid barometers one may find instruments thus marked in which the compensation is far from perfect.

When the aneroid is to be used wholly to indicate weather conditions, compensation, although desirable, is not essential. On the other hand, if it is to be used mainly for measuring altitudes, compensation must be regulated with extreme care. A compensated aneroid requires no temperature correction; the compensation is for the purpose of eliminating such corrections.

The Goldschmidt type of aneroid differs from the type commonly known by dispensing with the train of levers. A micrometer screw working in the cover of the box measures on its graduated rim the amount of the movement of the corrugated top of the vacuum chamber. When operated by an expert trained to the use of micrometry, this type of aneroid possesses many merits. It is not well adapted to general use.

At the best, the aneroid is a delicate instrument requiring great care, especially if it is a part of an engineer's equipment. The reading of an instrument having a large dial will change with any material change in its position. If the user watches its variations, however, such erratic changes—and they are small—will not result in erroneous readings.

Adjustment of Aneroid Barometers.—An aneroid barometer is sometimes blamed because it does not agree with the reading of a mercurial barometer at the same level. This may occur when rapid changes in pressure are taking place. An aneroid of the best type is very sensitive. It responds to changes in pressure far more quickly than does a mercurial barometer. Because of its complex mechanism it is easily put out of adjustment; moreover, it will get out of adjustment for causes that are not well known.

Adjustment to a correct reading should be made, if possible, when pressure is stationary. The adjustment is made by means of the small screw in the back of the case—usually the only screw-head in sight. The index hand moves in the same direction that the screw-driver turns. The adjusting should not be used to set the index more than three-tenths of an inch. If the error is materially greater than this, it is better to have the adjustment made by an expert. When this cannot be done without delay, the error may be temporarily reduced, for convenience in reading, to even tenths of an inch. If it is desirable to have the index read to sea level reduction, it may be lifted off the stud and replaced as nearly as possible in the correct position. Any slight difference may then be taken up by the adjusting screw.

In moving the adjustment screw, one must take into consideration the position in which the instrument habitually rests. If a barometer which has been adjusted to a hanging position is laid upon its back, the reading changes several hundredths of an inch, and *vice versa*. It therefore must be held in its habitual position when the adjustment is made.

If the error in reading is two- or three-tenths, the observer must watch the readings for several days to ascertain if the adjustment has changed. If the index has been set forward it is apt to "creep" forward still further; if backward, the creeping will be backward. The reason therefor is not known with certainty. An aneroid taken to a higher elevation is apt to respond quickly to the reduced pressure; taken to a level materially lower, it may not respond so quickly.[1]

If an aneroid is in a proper condition, tapping the case with the finger will cause an instantaneous vibratory movement of the index which will settle each time to the same position. If it fails to recover its normal position, bring the instrument rather sharply down upon a chair cushion or cane seat; if the index fails to recover its position, or does not vibrate, a binding at the lever joints exists, and the instrument should go to the repair shop. The best test as to whether or not it is in good

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[1] An aneroid taken by the author from sea level to stations in Colorado varying from 8000 to 13,000 feet, responded promptly to the decrease in pressure on the outward trip. After it had been brought back to sea level, it registered an altitude of about 2000 feet. At the end of three weeks it still varied by nearly 0.3 inch from normal pressure. It was therefore sent to the manufacturer to be put in order. This illustration will apply in many instances; it does not apply to aneroids of the better class made at the present time.

working condition is its sensitiveness to slight changes in elevation—for instance, the difference in elevation between the adjacent floors of a house. The response of the index should be instantaneous. An aneroid of the best type should show the difference of elevation between the top of a table and the floor.

Engineers' Aneroid Barometers.—Within the past few years material improvements in the construction of aneroids have removed the defects noted in the preceding paragraphs. On ordinary aneroids the divisions of the pressure scale are equal, while those of the altitude circle gradually diminish. It is evident therefore that a vernier could not be used on such a scale.

In the scale graduation of the engineer's type of aneroid, the arrangement is reversed; the pressure scale divisions diminish while those of the altitude circle are made equal. If the scale divisions represent 20 feet, the vernier subdivides them into 2-foot divisions. Many of the newer instruments have these values in scale construction; on others the scale divisions are 50 feet and 5 feet.

Although the engineer's aneroid is compensated for temperature a slight temperature correction is advisable where the difference in altitudes is considerable. P. R. Jameson has deduced the following rule: If the sum of the number of degrees at the two stations is greater than 100 degrees F (55 degrees C), increase the height by one one-thousandth part for each degree F in excess of 100 degrees F; if the sum of the number of degrees is less than 100 degrees F, diminish the altitude by one one-thousandth part for each degree F.

In using the engineer's aneroid for determining altitudes the zero point may be set at the station of known altitude. For reasons explained in a preceding paragraph, such a proceeding will not do with an aneroid whose scale divisions on the altitude circle are unequal. In using such an instrument the zero point should be set at a designated position and the correction made for the variation which the reading reduced to sea level shows to be necessary.

Pocket Aneroid Barometers.—This term is applied to small instruments about 2 inches in diameter. In quality they vary from good to poor. The chief virtue about them is convenience and portability. In spite of the name, the pocket is not a suitable receptacle in which to carry such an instrument. The moisture from the body sooner or later affects the metal mechanism; moreover, the knocking and banging which it is likely to receive if carried in an overcoat pocket are equally hurtful. In traveling, it is carried most safely in a grip sack.

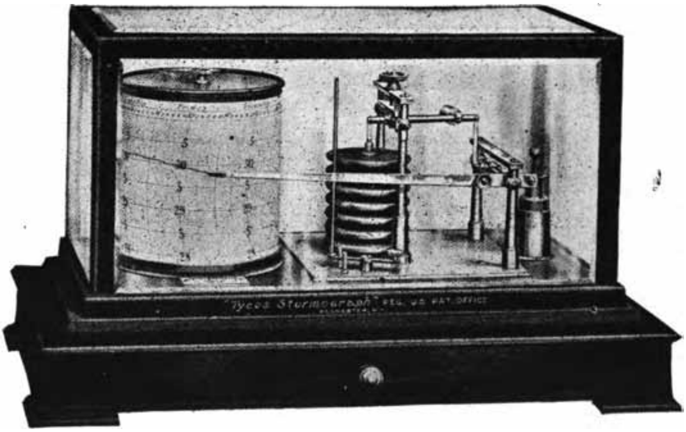
A very good place for the pocket aneroid is the observer's desk and it is advisable to set the zero mark of the altitude scale daily at the index position. Thereby is inculcated a habit of watching the barometric changes far more closely than is the custom when one must go across the room to set the mercurial barometer for a reading. The close observer gets a much better view-point of daily variations than does the casual observer.

Specific Uses of the Aneroid Barometer.—A custom that is wellnigh universal makes the mercurial barometer the standard instrument for the measurement of pressure at Weather Bureau stations. There is no doubt of the wisdom of this practise. For a substantial instrument not easily getting out of order, and susceptible of close reading, no other form of barometer approaches it. Such instruments as the Marvin normal barograph represent the highest skill in precision instruments.

The modern aneroid is quite as essential as the mercury barometer in the equipment of a Weather Bureau station, a maritime observatory, or a meteorological laboratory. For use on vessels it has many advantages over the mercurial barometer, Extras may be carried on various parts of the ship where convenience suggests. Not the least virtue of the ship's aneroid is the fact that it responds to pressure changes more quickly than does the mercurial barometer.

Aneroid Recording Barometers.—Recording aneroids are sold under various copyrighted names; in Weather Bureau cant such an instrument is known as a *barograph*. The essential feature is one or more vacuum chambers, a drum moved by a clock, and a ruled sheet of paper on which the record is made. The better type of barograph has a battery of eight vacuum chambers, one upon the top of another. This arrangement permits the movement due to pressure to be multiplied eightfold. A finer adjustment and a more accurate record is gained thereby. Temperature compensation is effected by the admission of a measured quantity of dry air into one of the chambers.

The long lever, the pen arm, carries a pen which presses lightly on the ruled paper wrapped around the drum. A milled screw adjusts the pressure of the pen on the paper, and a switch enables the observer to throw the pen off or on at pleasure. The drum makes one revolution per week. The record sheets are ruled with horizontal lines representing inches, halves, and twentieths. Arcs of circles, having radii equal to the length of the pen arm, divide the record sheet into midday and midnight periods, and two-hour intervals. Eight o'clock Monday morning is the normal time for changing the record sheets used by most observers. These contain day and month spaces for recording dates. In Weather Bureau practise the sheets are changed on the 1st, 8th, 15th, 22d and 29th days of the month.



Barograph.

The clocks used in most barographs are watch movements of the finest type. It is desirable to have the clock oiled and cleaned once a year. The clock is practically dust-proof, being within the drum, and protected also by the glass case which incloses the mechanism of the barograph.

In replacing the record sheet the observer must look carefully to two things; the lower edge of the record sheet must fit closely to the collar at the lower edge of the drum; the lines of equal pressure must match precisely. A failure to conform to these requirements leads to incorrect records.

The ink used consists usually of glycerine, water and color pigment. If a permanent record is required black ink is preferable; green or blue is fairly permanent; red and purple fade in the course of a few years. A red ink with a madder or a genuine carmine base will not fade. Aniline red inks are marketed as " carmine," however, and they are not at all permanent.

The pen of the barograph has a sleeve which slips over the end of the pen arm. It is not always easy to remove it when the pen requires cleaning. If it cannot be removed from the pen arm, lift the drum off the spindle; hold the pen firmly and clean with a small camel's hair brush and water. Before filling the pen, draw a narrow strip of paper or a very thin spatula blade through the prongs of the pen in order that the ink may flow freely. With reasonable care for its cleanliness the pen will make a sharply-cut line; a foul pen leaves its own record.

The milled screw in the bar directly over the vacuum chamber adjusts the pen so that it has the correct position on the record sheet. The pen may be adjusted to record sea level pressure; but, as a rule, it is better to keep local pressure. The record sheets are usually lithographed with figures ranging from 28 to 31 inches. They are lithographed for other altitudes and also without any altitude marks. A " long-range " barograph, registering from 25 to 31 inches, is also made. Metric charts may be obtained from dealers in meteorological supplies.

When a barograph is to be moved—if carried otherwise than by hand—the drum and the ink bottle should be removed and packed separately. The pen arm should be fastened loosely to the switch rod. A dozen thicknesses of tissue paper or of soft cloth should be wrapped around the glass case and stand; they should be fastened so firmly that the parts cannot jostle. With an additional protective wrapping of heavy paper the instrument will ride safely in the packing case. There should be no packing of any sort around the vacuum chambers and levers.

If the barograph is carried by hand, the drum need not be removed from the spindle, but the pen arm should be thrown from the drum. A handle should be fixed to the package so that it may be carried in its proper position.

Interpretation of Barograph Records.—The usual eight o'clock observations of pressure furnish nothing more than changes in pressure at twelve-hour intervals. For the purpose of scientific study the continuous barogram is the best object lesson. The West India hurricane, the ordinary storm, the heavy downpour, the thunder-storm and the cold wave—each leaves its individual earmarks on the record sheet. In no other way can the observer work out his position and time of diurnal inequality so well as by the use of the record sheet.

A discussion of the specific features made by the barograph pen, noted in the preceding paragraph, is not necessary. Each should be noted on the record sheets, at the time of its occurrence. At times the specific features in a record sheet enable an observer to make forecasts that would escape notice if the observations were made with an ordinary barometer. Thus, if the trace of the pen in the progress of a falling barometer is convex, an increasing violence of an approaching storm is indicated. In the same manner, a concave trace of the pen with a rising barometer indicates an increasing force of the wind—frequently the onset of a cold wave.

A close study of the trace of the barograph pen will enable an observer to discern conditions, leading to fairly certain predictions, which otherwise would pass unnoticed. Continuity of record constitutes, to a great degree, the value of pressure records, and while the records of hourly observations intelligently graphed, might lead to similar conclusions, few meteorological laboratories are so equipped as to make such observations possible. But the barograph catches and records minute pressure alterations that might escape the notice of the most careful observers even if hourly observations were recorded.

There is not much difficulty in comparing the graphs of metric charts with those of inch charts. A base line for either may be drawn on the other, and distances or ordinates are readily measured with dividers or with a graduated scale. A record sheet ruled on tracing cloth affords a convenient method of comparison. The best method of comparison is the one which best suits the observer.

CHAPTER XVIII

THE MEASUREMENT OF HUMIDITY: HYGROMETERS

The Water-vapor Content of the Air.—Water vapor exists in the troposphere, or lower shell of the air, at all times, the amount depending very largely on the temperature of the air. To the best of knowledge, little if any water vapor exists in the air of the stratosphere. The high cirrus clouds presumably mark the upper limit of the condensation of the water vapor of the air.

The maximum proportion of vapor—that is, the maximum quantity per unit of volume—depends on temperature; it is independent of the other constituents of the air. Were there no other constitutents, the atmosphere would be an atmosphere of water vapor, and the amount per unit of volume would be about the same as under existing conditions. It is best, therefore, to consider the water vapor content as an independent factor so far as measurements are concerned.

When the air—or rather, the water vapor itself—is near the point of saturation it is moist to the senses. Hygroscopic substances, such as sugar, salt and many other substances, absorb moisture; sized paper and starched fabrics swell and become limp. These conditions begin to be noticeable when the water vapor of the air passes 85 per cent of the amount that may exist.

When the vapor content is 30 per cent, or less, of the amount required for saturation, the dryness becomes apparent to the senses, especially to the lips and throat. The gummed surface of stamps, labels and adhesives shrinks, causing the paper to curl. Doors warp and thin panels of wood shrink and split.

The moisture sensation of the air is its *humidity*. Before saturation is reached, the moisture is in the form of vapor; at the point of saturation it may appear in the air as fog, or cloud; when the ground temperature reaches the point of saturation condensation takes place in the form of dew; or, if below 32° F (0° C) in the form of frost.

The table, p. 280, shows the amount of moisture at different temperatures which may be present mingled with the air. Thus, at 30° F a little less than 2 grains per cubic foot can be present before condensation begins; while at 70° F there may be nearly 8 grains. In other words, if 2 grains per cubic foot were present when the temperature was 30° F, condensation would be taking place; while, if the temperature were 70°, the air would be very dry, because only one-quarter of the moisture required for saturation is present. Sensible moisture, therefore, is relative, requiring measurement of temperature and absolute humidity at the same time.

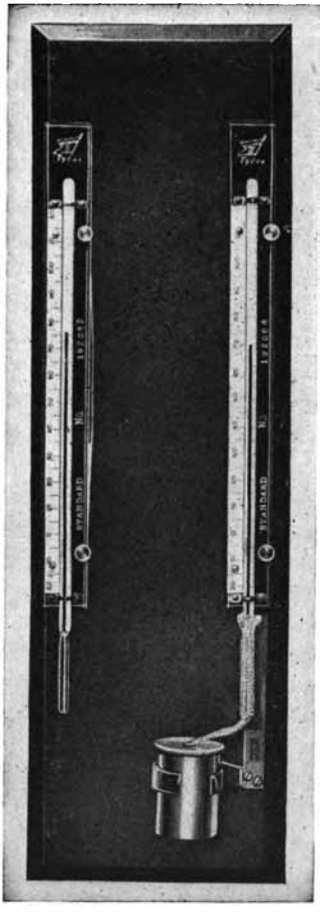
The measurement of absolute humidity by direct methods is not ordinarily required in weather observations. It may be determined by aspirating a measured quantity of air very slowly through a hygroscopic substance, weighing the substance before and after. It may be determined more easily, however, by ascertaining the relative humidity.

The Measurement of Humidity; Wet-Dry-Bulb Hygrometers.—Various methods of determining the humidity of the air have been devised. Some of them are merely hygroscopes. Thus, a slip of paper moistened with a solution containing gelatine and cobaltic chloride is pink in moist air and blue in dry air. A better hygroscope is the toy châlet from which a woman emerges in dry weather, while a man with an umbrella stands in the door during damp weather. The manikins are suspended by a short piece of catgut which, twisting in the one case and untwisting in the other, because of changing moisture content, indicates roughly the changes in the humidity of the air.

A curled piece of vegetable fiber, one end fastened to a base, the other carrying an index hand, has become popular as a hygroscope. It has practically no value for quantitative determinations, but is not without value in indicating conditions of moisture not at once apparent to the senses but at the same time necessary to bodily comfort.

For the quantitative measurement of humidity hygrometers are now practically reduced to two types, dry-wet-bulb thermometers, and hair hygrometers. The United States Weather Bureau provides several kinds of the first-named type.

The *Mason hygrometer*, nearly two hundred years old in principle, has been a standard in all countries for many years. It is made in various forms, but the essential features do not vary. The instrument consists of two thermometers mounted on the same base. One measures the temperature of the free air; the bulb of the other is covered with a single thickness of thin bolting silk or muslin, the lower end of which is in a small vessel of water attached to the base board. Capillary attraction keeps the fabric wet and evaporation is almost always taking place.



Mason Hygrometer. Weather Bureau pattern.

The evaporation of the water chills the bulb and the wet-bulb thermometer therefore registers a lower temperature. The more rapidly the evaporation takes place, the less is the moisture content of the air; and the percentage may be determined by the difference of the readings of the two thermometers. Tabulated determinations accompany the hygrometer, and the percentage of moisture already calculated is found from tables contained in the Weather Bureau Circular of Instruction.

The *hygro-autometer* is a very convenient form of the Mason hygrometer. The tables are carried on a roll attached to the hygrometer. Thumbscrews turn the rolls until the difference between air temperature and wet-bulb temperature appears in the space at the top; the per cent of humidity is opposite the air temperature reading. The hygro-autometer is a most excellent hygrometer for auditoriums and for household use.

The *hygrodeik* is a form of hygrometer in which the tabulated matter is shown on a card ruled with ordinates and co-ordinates for the convenience of reading. An index fastened by a hinge joint at the top carries also a sliding point. By the adjustment of these the relative humidity is read from the tabulated figures. The experience of nearly a century has shown the usefulness of this instrument for indoor purposes.

Unless " coaxed " by fanning, dry-wet-bulb calculations are subject to error, the nature of which is obvious. The use of an ordinary fan—or, better, an electric fan—on the bulbs will give much more accurate readings.

The *sling psychrometer* obviates this difficulty. The two thermometers of this instrument are made fast to a metal strip which whirls upon a pivoted handle. The covered bulb is dipped in water of the same temperature as the air and whirled on the pivot until the temperature of the wet bulb ceases to lower. Ordinarily, about twenty seconds are required to obtain a correct reading.

The *whirling table* is now generally employed where systematic observations are made. The geared mechanism used in whirling the thermometers does not give more accurate results than the sling psychrometer, but it affords an easier method of stimulating evaporation, and the thermometers are not so likely to be broken.

When the humidity of the air is near the point of saturation, determinations made at the same time may vary several points; and, unless a sling psychrometer or a whirling apparatus is used, the determinations are pretty certain to vary. The thermometer scales of the best psychrometers are graduated to half-degrees and may be read to quarter-degrees. This conduces materially to accuracy.

The chief source of inaccuracy, however, is the covering of the wet-bulb thermometer. No matter what the material of which it is constructed may be, sooner or later it becomes hard and loses its capillarity. It is no longer of use and should be thrown away. If it shows signs of discoloration it should be thrown away also, for its usefulness is gone. Tubular wicks are now much used and are kept by dealers in meteorological instruments. If any doubt as to the cleanliness of a wick exists, it should be boiled briskly in water and, when dry, soaked in pure alcohol in order to remove any traces of grease. Under no circumstances should gasoline be used. In adjusting it to the bulb, every trace of oil, grease, or other substance should be removed from the fingers. If the capillarity of the wick is sluggish it is better to try another. In an emergency, if the fabric about the bulb is dry it may be wet with a camel's hair brush dipped in water. Water containing any sort of impurity is apt to impair the capillarity of the wick or even destroy it. In " hard water " localities distilled water would better be used. In catching rain water it is well to bear in mind that the water falling during the first part of a shower may be very dirty.

When the moisture is close to saturation two or three successive determinations may be necessary for a satisfactory result. When the humidity is very low the difference between the dry- and the wet-bulb reading of several determinations may be considerable. In this case, too, the observer must use his judgment. A mean of several determinations is a fairly safe record.

When the water in the cup of the Mason hygrometer is frozen, care should be used in making the reading. If the upper end of the wick is dry—sometimes this is the case—the determination may be regarded with suspicion. It is better to wet the part around the bulb by means of a camel's hair brush and wait a few minutes until the thermometer has settled to a fixed temperature before reading. A sling psychrometer gives a more accurate result in freezing weather, and its use is more convenient. The wick, or covering, may be wet with water at ordinary temperature, but the whirling must be continued until no further reduction of the wet-bulb temperature occurs.

The Hair Hygrometer.—Human hair freed from its natural oil and from grease of every sort, is highly sensitive to moisture. It may be made chemically clean by a bath, first in water with a mild soap and, after drying, in ether. After the ether bath it should not come in contact with bare hands. If one end of a clean hair—or a strand of several hairs—be made fast to a binding post and the other wound around the axle of a dial needle and kept taut by a spring, the lengthening and shortening of the hair by changing moisture may be made to indicate humidity with a fair degree of accuracy.

Commercial hair hygroscopes and hair hygrometers of various forms are now made by several manufacturers. Those of the best quality retain the name of the manufacturer; others are stamped with the name of the retailer. When new and clean, those of the best quality are about equal in accuracy to the psychrometer. Hair hygrometers usually deteriorate with continued use. The chief trouble comes from dust, and from gumming or fouling of bearings. Like any other delicate mechanism, careful cleaning and oiling will prolong the life of a hair hygrometer and preserve the accuracy of its registration. In the case of a commercial hygrometer, when once it has gone wrong, it is usually less expensive to purchase a new instrument than to repair an old one.

In spite of its shortcomings, the convenience of the hair hygrometer outweighs its disadvantages. For use in dwellings, school-rooms, textile establishments, candy factories and tobacco factories it is far better than the ordinary Mason type of instrument. The humidity is read instantly; computation from reference tables is not required.

The *hygrograph* is a hygrometer with recording mechanism like that of the thermograph. Drum, clock and record sheets are much the same in both, except that the record sheets of the hygrograph show per cent values in their horizontal rulings. The instrument is delicate and very sensitive to changes. Its records are not always trustworthy, but its errors are readily checked and adjustments are easily made. It should be sheltered so that by no possibility can rain or snow be driven upon it.

A hygrograph is usually a part of the equipment of each Weather Bureau station. In spite of the difficulties of transportation it is a very useful instrument in field stations. It is useful not only in noting the changes in relative humidity; it also may be an indication of change in absolute humidity.

The normal movement of the thermograph pen is upward from sunrise until 3 o'clock, then downward to the minimum of the next morning; the normal curve of the hygrograph is opposite in movement—downward from sunrise to 3 o'clock and then upward. These movements usually are so regular that experience enables one to read temperature approximately from the hygrogram sheet, and humidity from the thermogram. But when the temperature line is normal and the humidity line is abnormal, a change in the absolute humidity has occurred.

Experience will teach the observer to look for the unusual in comparing the daily records, and also to interpret it.

The dew-point may be found without the use of the hygrometer by a very practical method. A thermometer, a polished tin cup—a "shaker" is better—and ice water are required, The cup must be absolutely free from grease. The cup is half-filled with water at about the temperature of the air. Ice water is added little by little and stirred with the thermometer until mist forms on the outside of the cup. The water is then at the temperature of the dew-point, and this is shown by the thermometer.

The Measurement of Evaporation; Evaporimeters.—The rate of evaporation depends on the amount of moisture in the air. If the humidity is low, evaporation is more rapid than when it is high. With the humidity above 95 per cent a piece of wet muslin in the open air may require more than an hour to dry; with the humidity at 100 per cent it does not dry at all. A high temperature also favors evaporation—chiefly from the fact that, with rising temperature, the relative humidity decreases without any change in absolute humidity. The rate of evaporation is therefore roughly an indication of the degree of humidity.

Evaporimeters vary in form but not in principle. In every case the evaporimeter is a device for measuring the depth of water lost by evaporation from an open surface. A very common form consists of a graduated glass tube filled with water, inverted in a vessel of water. A pin-hole aperture about half an inch from the lower end of the tube admits air to the top of the tube when evaporation lowers the water in the level of the pan. The level of the water in the pan is constant; the loss is in the tube. If the area of the surface of the container is 0.01 that of the section of the tube, a loss of 1 inch of water in the tube is equivalent to a loss of 0.01 inch by evaporation.

The *Piche evaporimeter* is a type of the best sort of instrument. A collar fastened around the tube at its mouth carries a disk which presses against and covers the mouth of the tube. A circular piece of filter paper, about twice the diameter of the tube, between the disk and the mouth of the tube allows a sufficient flow of water to keep the paper wet. By this device, loss of water by accident is avoided, and evaporation is recorded with a fair degree of accuracy. The Weather Bureau issues evaporimeters when they are deemed a necessary part of the equipment of a station. Field evaporimeters of different patterns, each for a specific use, are used at various Weather Bureau stations.

A bottle with straight sides may be inverted in a pan and used as an evaporimeter in an emergency. If the area of the section of the bottle be determined, an approximate rate of evaporation may be found. It is better to have the mouth of the bottle rest on circular pieces of blotting paper, several thicknesses being used. The flow of water through the blotting paper will be kept fairly steady by the admission of bubbles of air. It is hardly necessary to add that values obtained thus are only approximates.

CHAPTER XIX

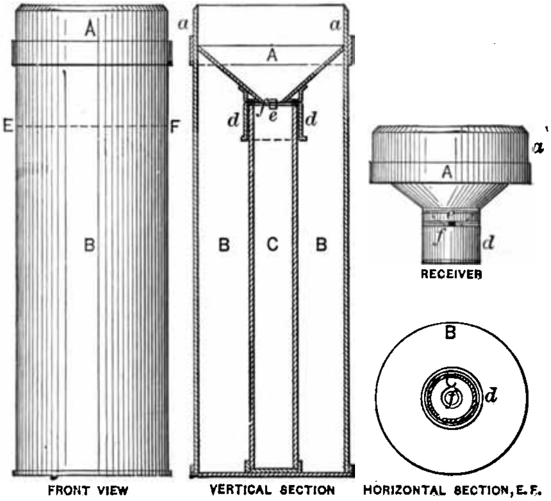
THE MEASUREMENT OF PRECIPITATION: RAIN GAUGES: SNOW MEASUREMENT

All moisture condensed from the air—rain, snow or hail—is classed as "precipitation" and is measured in terms of rain. It represents the depth of water which would accumulate on a level surface without loss by run-off, percolation or evaporation. For convenience in measurement the water of precipitation—rain, or melted snow—is caught in vessels of special construction called *rain gauges*. These are of various forms, but they have practically the same principle—the exhibition of a depth of rain expressed in inches and hundredths.

The standard Weather Bureau rain gauge is a cylindrical barrel of galvanized iron 26 inches in height over all. The receiver is a funnel with an upright collar of bronze 2 inches high. The edge of the collar is beveled so as to present a sharp cut-water to the rain. The receiver delivers the water to the measuring tube; a sleeve at the lower end of the funnel holds the mouth of the measuring tube in place and prevents the loss of water. The brass measuring tube, accurately calibrated, rests in a seat at the bottom of the barrel.

The receiver is exactly 8 inches in diameter; the section of the measuring tube is exactly one-tenth the area of the receiver. Its diameter is 2.53 inches and it is 20 inches high. An inch of rain therefore measures 10 inches in the tube, and the latter holds 2 inches of rain. Any excess beyond 2 inches overflows into the larger vessel; it is poured into the emptied measuring tube and added to the amount. The measuring stick is graduated to measure inches, tenths, and hundredths, and the depth of the rainfall is indicated by the length wetted when the stick is inserted in the measuring tube. Care must be used to keep the surface of the measuring stick free from grease. If it fails to show the wet-line clearly the surface may be cleaned with alcohol, or—better—rubbed clean with 00 sandpaper.

Recording and Registering Gauges.—The registering and recording gauges are mainly of two classes—float-gauges, in which the increasing depth of water, by lifting a float balanced by a weight translates motion to a pen arm; and the tipping-bucket gauges, in which each tip of a full bucket moves an index hand.



Standard Weather Bureau rain gauge: *A*, receiver; *B*, barrel; *C*, measuring tube.

The Marvin float gauge, used at many stations, is provided with a wind shield of the Nipher type, about 21 inches square. The drum carries a sheet ruled with lines nearly horizontal, but inclined so that they form a continuous spiral. These lines carry the record, one for each day of the week. Vertical lines divide the sheet into ten-minute spaces. The drum, driven by clockwork, makes one revolution in twenty-four hours. A screw thread of the required pitch causes the recording pen to follow the spaces between the spiral lines on the record sheet.

When rain begins to gather in the measuring-tube, the lifting of the float causes the rotation of the cam shaft and this imparts a lateral motion to the pen. The graph made by the pen consists of a sinuous line which curves back and forth across the day line. A complete revolution of the cam records half an inch of rain. The faster the precipitation, the sharper are the curves.

The Marvin gauge possesses several distinct advantages. Recording begins within a very few minutes after precipitation has commenced—a merit not possessed by tipping-bucket gauges; it likewise records the cessation of rainfall rather more promptly. A very desirable feature is the fact that it also records the rate of rainfall, a matter of great importance. In many instances the total of precipitation is of minor consequence, while the rate per unit of time must determine the discharging capacity of sewers and other run-off systems. The Marvin gauge is not fool-proof, but this detail applies also to other recording instruments.

The tipping-bucket gauge is chiefly used for recording rainfall. The drip from the funnel falls into one or the other of two scoop-shaped buckets placed back to back mounted on trunnion bearings. When 0.01 inch of rain has collected in a bucket the weight causes it to tip, spilling the water into a container and moving a pointer one division on a dial. The tipping of the full bucket swings the empty bucket into a position where it catches the drip.

Where a Friez triple recorder is used the pen which ordinarily records sunshine is also used to record rainfall. This it does with little or no confusion of records, because precipitation rarely occurs in appreciable amount while the sun is shining.

Tipping-bucket rain gauges are constructed so close to exactness of measurement that, when placed side by side with the standard gauges, the difference between the measurements of the two is not much greater than that of two gauges of the same type side by side.

Although the tipping-bucket rain gauges are simple in construction, various conditions may occur that result in erroneous recording. The bucket may rebound on emptying itself, in which case two registrations instead of one are made. With the Friez gauge this will appear as a mark of double length on the record. With the dial gauges, which register but do not record graphically, double registration cannot be discovered except by close watching. It may be suspected, when the catchment of the registering gauge runs uniformly greater than that of the standard Weather Bureau gauge. In the case of the Friez gauge a readjustment of the stop pins is necessary. With the Short and Mason gauge a pressure brake is provided; the tightening of this will prevent back-tipping.

Sometimes it happens that the stick measurement of the catch is considerably in excess of that registered on the dial or recorded on the paper; indeed, this is pretty apt to be the case in heavy summer showers. Usually this discrepancy is due to the fact that a measurable interval of time elapses while the bucket is discharging its load of water, after it has been filled. The water that flows into the bucket during the interval is therefore slightly in excess of the normal 0.01 inch. During a very heavy shower, aggregating 3 inches, the excess of the measured amount over the recorded amount may be as great as 0.15 inch. In such a case stick measurement rather than bucket measurement should be taken as the total precipitation.

The drip aperture of the Short and Mason registering gauge is very small; although protected against clogging by falling leaves, it may become clogged with dust. Under such circumstances the funnel may fill and overflow with no water running into the buckets. If the gauge receives even ordinary care such a condition is not likely to occur. Cleaning the receiver daily is not absolutely essential, but a conscientious observer will see that the gauge is always in order.

The inside of a gauge is a spot most dear to the heart of the spider, and in many a case the accumulation of spider web has tied up the registering mechanism so completely that registration ceased.

Another source of annoyance in registering and recording tipping-bucket gauges has to do with the condition of the buckets. In regions where the air is very dirty, sediment may cling to the surface of the bucket, and, adding to its weight unequally on opposite sides, prevent a true registration. A still greater source of error may result from handling the inner surface of the buckets with greasy fingers. The water will not cohere to, or " wet " a greasy surface; and this may cause a slight but persistent error in registration.

It is not wise to depend wholly upon a registering or a recording gauge; stick measurement is more certain. Nevertheless, a station of any sort should be provided with two gauges, and a registering gauge is a most excellent feature of equipment. H. J. Green makes an indoor dial that may be attached readily to any tilting-bucket gauge. Such a device is very convenient.

Intensity of Precipitation.—The intensity of rainfall may be of greater importance than the gross amount. The Marvin and the Friez gauges record intensity graphically. The observer with the ordinary gauge can find the intensity in one way only—by making measurements at regular intervals. During ordinary rainstorms measurements made at half-hour intervals will suffice, and these need be continued for not more than two hours. During heavy summer downpours, however, the measurements should be made at five-minute intervals.

To the farmer, 2 inches of rain distributed over the greater part of the day means a thorough soaking of the ground; but if concentrated within half an hour it means beaten-down grain and washed-out ditches. Such a rainfall, to the engineer, means washouts all along the track; to the city engineer it means flooded sewers and excavations. The engineer who takes care of drainage must know how to guard against phenomenal rainfalls by building so as to take care of them.

Observers will make their work more helpful by noting not only the fact of excessive rainfall but also its rate at five-minute intervals. In Weather Bureau practise, the term *excessive* has a technical application, and the tabulation of excessive amounts during such intervals is required. The following table shows the intensity of precipitation that technically is excessive. It is based on the experience of many years.

[1] Duration in minutes	Depth in inches	Duration in minutes	Depth in inches
5	0.25	35	0.55
10	0.30	40	0.60
15	0.35	45	0.65
20	0.40	50	0.70
25	0.45	60	0.80
30	0.50	..	....

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[1] At Porto Bello, Panama, 2.48 inches were reported during a period of five minutes, Nov. 29, 1911, at 2:07 A.M. At Curtea de Arges, Rumania, 8.07 inches fell in twenty minutes, July 7, 1889. These are the heaviest rainfalls of record, but they may have been exceeded by cloudbursts in which measurements were not made.

When excessive rainfall extends beyond a duration of two hours the measurements are recorded at fifty-minute intervals.

The amount of rainfall necessary to insure a specific crop varies with locality and with the character of the crop. More especially it depends on the distribution of the rainfall over the growing season. Roughly, rain must fall during a period which covers three-quarters or more of the growing season for the particular crop. The growing season for wheat is over, in most localities, by the middle of July—in some localities by the middle of June. The growing season for corn extends into September. A rainfall of 12 inches, fortunately distributed, may be all that is required for a specific crop. Unfortunately distributed, a fall two or three times as great may not suffice.

From the nature of the case, the knowledge which concerns crop safety must be gathered locally. Through its Climatological Service, the Weather Bureau is gathering knowledge of this sort, but additional information is very desirable. The observer, whether official or volunteer, can aid in gathering useful information along the following lines:

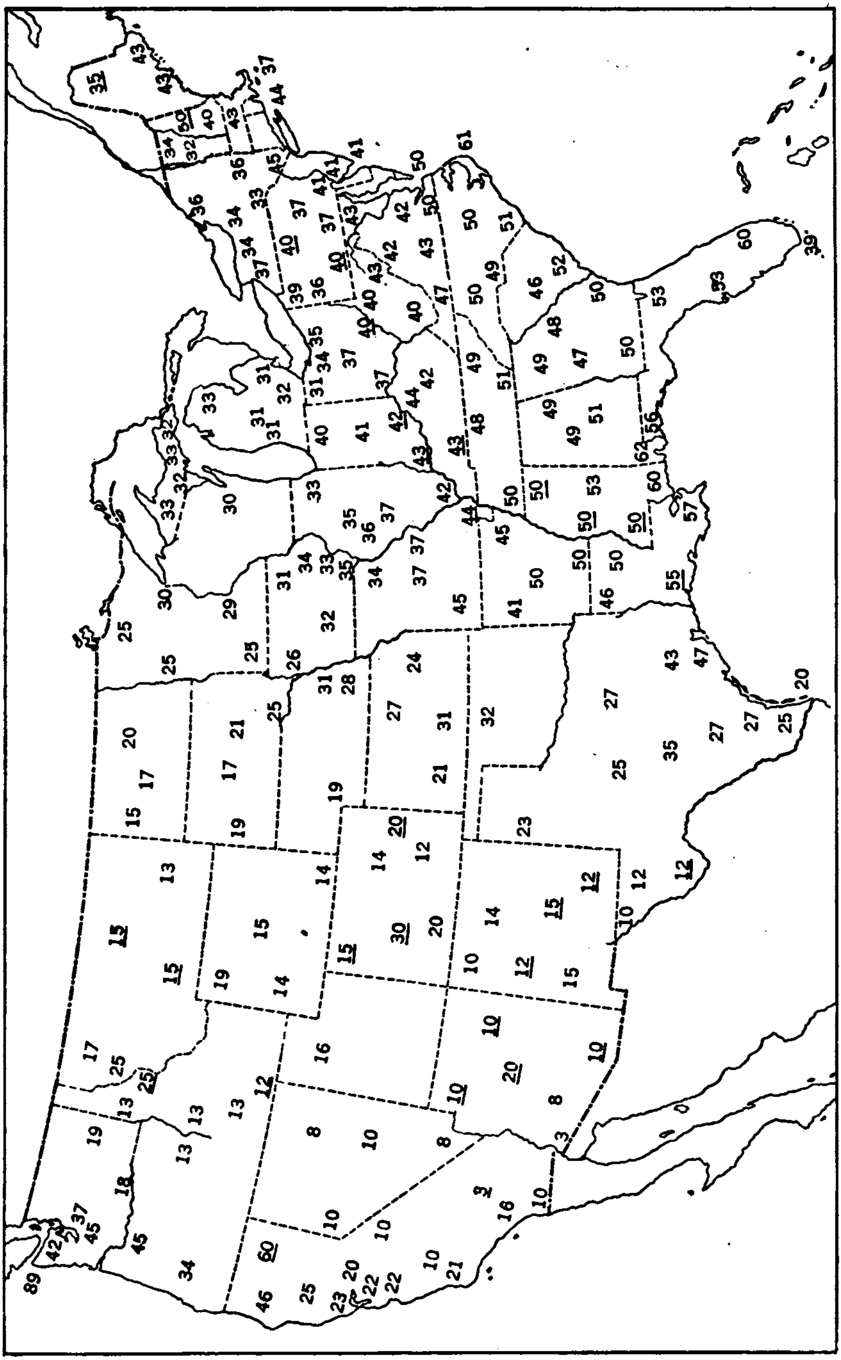
The length of the growing season—that is, the number of days between late spring frosts and early fall frosts.

The months during which rain is necessary for each specific crop.

The duration of droughts—that is, the number of days during which no rain or only a trace of rain falls—that are hurtful or destructive to specific crops.

The character of soil with respect to rainfall necessary to crop growth.

As a rule the precipitation records of the nearest Weather Bureau station—regular or cooperative—will furnish the necessary information concerning the amount of precipitation. The specific locality sometimes requires its own rain measurements. A rain gauge of the Weather Bureau pattern is useful, but a metal container with straight sides will answer fairly well, and an inch rule will answer the purpose of a measuring stick. The volunteer observer who studies the rainfall of a locality may thus gain the essential information required; namely, the minimum amount of rain, and also the optimum rainfall both as to amount and distribution, for a specific crop.



Mean annual rainfall of the United States: the figures express inches of precipitation.

The Location of the Rain Gauge.—In establishing any sort of a station where the measurement of rainfall is to be recorded, at least two rain gauges are desirable. One of these should be a standard Weather Bureau gauge or one of similar pattern; the second may be any vessel with an 8-inch circular opening in the cover.

In cities which are solidly built the flat roof of a building offers about the only suitable place for a rain gauge. If the edge of the roof is a parapet, so much the better, for the drive of the wind is less apt to blow aside the rain that should fall into the receiver. In a position of this sort the catchment of the two gauges is not likely to differ materially.

In suburban localities and in communities where buildings are 100 feet apart the gauges are better placed in such positions as have the full sweep of the rain-bearing winds. If two places 100 feet or more apart show no material difference in the catch, either location is probably suitable. With gentle rain and still air the two gauges should be in close agreement; if the wind blows in strong gusts there may be a material difference.

The wind is the chief obstacle to accuracy of rainfall measurement and shielding the gauge from the full strength of the wind is the best means to insure an accurate catch. The Nipher shield is a trumpet-shaped metal device about 20 inches across which surrounds the mouth of the gauge. It is surmounted by a rim of copper mesh which prevents insplashing. J. O. Alter, Observer at Salt Lake City, constructed a much simpler shield by fastening a strip of canvas about 9 inches wide, to a metal ring about 30 inches diameter. The screen thus constructed is suspended about the gauge by metal struts. The edge is about 2 inches higher than the mouth of the gauge. The Weather Bureau regards this shield with favor. The author has found a similar shield made of copper mesh, such as is used in window screens, a most excellent device. In the long run, a shielded gauge will catch from 6 per cent to 10 per cent more rain than one unshielded, according to the experience of the Weather Bureau. P. R. Jameson, with measurements covering many years, finds a gain of about 9 per cent in the case of shielded gauges.

The pit-gauge is favorably considered by C. F. Marvin, an authority on precipitation. The pit-gauge is merely a depression in which a standard Weather Bureau gauge is placed so that its mouth is 10 or 12 inches higher than ground surface. It is surrounded by a rim of earth in the form of a ring about 6 feet in diameter. A pit and ring of concrete with a movable cover of wire mesh, coarse enough to permit rain to enter without obstruction and fine enough to keep leaves out makes an ideal position for a rain gauge in an open and fairly level country.

The Ferguson gauge designed for isolated stations by S. P. Ferguson, of the United States Weather Bureau, totalizes a year's rainfall month by month, or in such measured proportions as may be desired. A film of oil in each of the thirteen receivers prevents loss by evaporation.

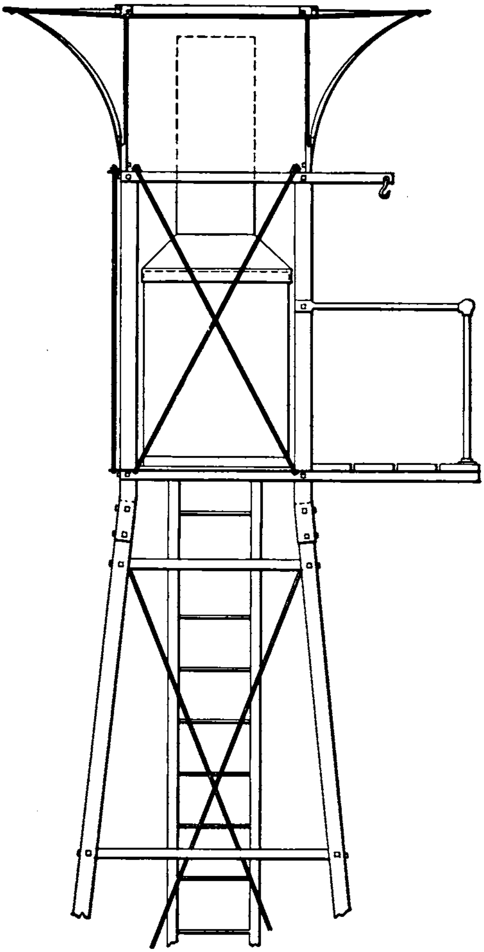
The Measurement of Snow.—A reasonably accurate measurement of snowfall is desirable in regions of plentiful rainfall; it is imperative in regions where the irrigation of crops or a knowledge of possible floods, or of droughts is a prerequisite.

In moderately level regions of gentle drainage the measurement of the precipitation derived from snow requires the care and judgment that comes only with experience. In mountainous regions it requires judgment, patience and a lot of hard work.

On the prairies of Indiana, for instance, the measurements made at the Weather Bureau stations give a pretty accurate total of precipitation. If the aggregate error amounted to 12 inches of snow, or even 2 inches of rain, however, the result would not be materially harmful. In California, however, the floods of the Sacramento and San Joaquin River valleys are largely predetermined by the snowfall in the mountain slopes to the eastward; and in many arid regions the crop production which depends on irrigation must be foretold mainly by the total of snowfall.

In level regions where the snow is not disturbed by the wind the measurement is not difficult. The observer uses his measuring stick in a dozen or more places within a radius of 300 feet. Usually the mean depth will become apparent without computation.

To find the equivalent in terms of rainfall requires "puttering and patience." A very convenient way is to cut a section in the snow with the inverted barrel of the standard rain gauge, thrusting a dust pan or a piece of sheet iron under the mouth in order to hold the section firmly. It is advisable to cut at least three sections. The melted snow may then be measured in the tube, taking one-third of the total. Melting the snow may be expedited by pouring into the barrel containing the snow a measuring tube exactly full of hot water, thereby reducing the snow to a condition sufficiently liquid to be measured. Two inches must be deducted for the water added; one-third of the remainder is the depth of equivalent rainfall.



The Marvin shielded seasonal snow-gauge.

In mountain regions where the depth of a single fall may be several feet, such a method of reduction is out of the question. Several convenient expedients are employed. A gauge 40 inches high with an interior diameter of 10 inches provided with a Nipher shield, is used at the station where not less than two observations a day are made. The accumulation of snow is weighed from time to time on a spring balance, the dial of which reads hundredths of an inch instead of ounces. A mechanical device lifts the receiver from its support so that it can be readily removed to the swinging arm that carries the balance. This is about the most expeditious method of measuring snowfall yet devised.

In the western slope of the Sierra Nevada Mountains "seasonal gauges," with collectors large enough to hold the accumulation of snow and rain for several weeks, are employed. The catch is weighed at convenient times.

When deep snowfalls occur the Marvin snow tube has been found a most convenient device. This tube, as improved by Church, is made of galvanized iron and is 2.75 inches in diameter. The upper end is left open; the lower end is reinforced by a piece of tubing forced inside the measuring tube. The lower edge of the tube is serrated with teeth like those of a cross-cut saw in order to facilitate boring through crusted snow and sheets of ice.

Tube and core are weighed by a spring balance that records inches and hundredths. The tube has also an engraved scale to show the depth of snow. Church, working in the Sierra Nevada ranges, used the tube in snow accumulations 30 feet thick.

The Marvin density bucket provides a quick and accurate method of obtaining the rain equivalent. The copper bucket is inverted and pressed lightly into the snow until the top of the snow touches the bottom of the bucket. The bucket, even full of snow, is then weighed on the accompanying scales, which are graduated to per cent of weight of an equal volume of water. Thus, if the net weight—the total weight minus that of the bucket—is 0.12 on the scales, it means that the snow is 12 per cent of an equal volume of water. Assuming that the depth of snow is 20 inches, 0.12×20, or 2.40 inches is the equivalent depth of rainfall.

In mountain regions the intensity of precipitation varies with altitude. On the western slopes of the high cordillera of the Pacific coast, McAdie found the greatest intensity of precipitation between 4000 and 5000 feet above the valley floor. On the eastern slope the intensity decreased irregularly with decreasing altitude. It may be incautious to assume this to be true elsewhere, but; as a general truth, the basis of assumption is not unreasonable. It is safe to assume that the measurement of precipitation of the montane part of a watershed must extend from its upper limit to the valley floor.

A multiplicity of snow gauges is not required, but with the combined results of gauges, snow tubes and fixed measuring posts, a fair approximate of the catchment of the basin may be obtained.

In practically all localities where snowfall requires measurement the following difficulties confront the observer: mixed or alternating snow and rain; rapid melting of snow while it is falling; a very light fall, say, less than half an inch; rapidly drifting snow. In the case of the first three, the observer may remove the receiver and tube from the gauge and catch the precipitation in the barrel. In the last case about the only way to overcome the difficulty is to make a considerable number of measurements where no drifting is apparent. One must use care to avoid measuring old snow with a fresh fall.

CHAPTER XX

THE MEASUREMENTS OF WIND VELOCITY: ANEMOMETERS

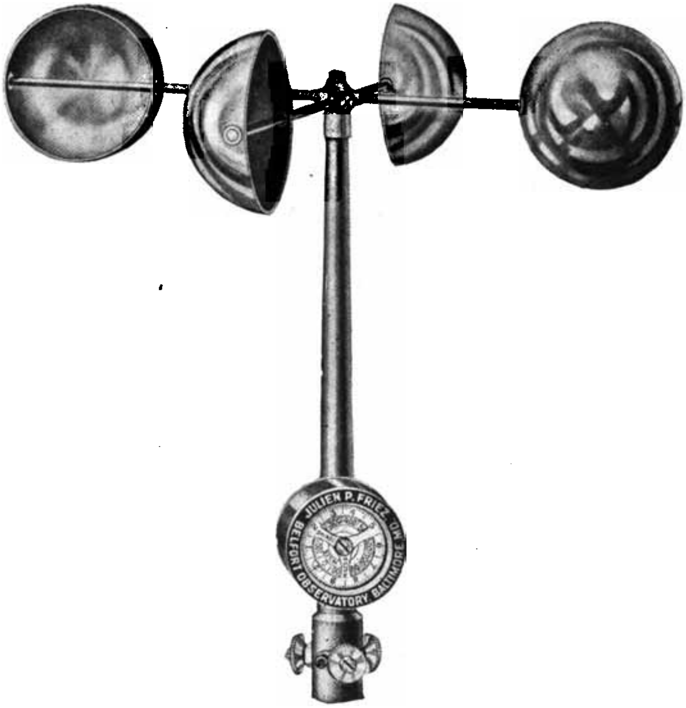
Wind direction, wind velocity and the duration of sunshine are usually recorded on the same sheet, each by a separate magneto apparatus. The revolving drum is driven by a powerful clock.

A record of wind direction is required at all observation stations controlled by the various departments of the government. At seaports wind observations are made the subject of public bulletins and shipping interests are furnished not only with information to date but also with forecasts of expected changes. Warnings of dangerous winds are sent broadcast by wireless for the benefit of all vessels that may encounter them.

The requirements of air navigation are even more exacting than those of marine navigation; for, while the marine pilot needs to know the conditions of wind and weather at sea level, the airman must know them from sea level to an altitude of 10,000 feet or more.

Until recently Weather Bureau stations have been equipped with instruments for the study of surface winds only. The research laboratories, however, have made great advances in the study of air conditions at considerable heights, using kites and pilot balloons carrying recording instruments. Ordinarily the observer must depend on wind vanes, smoke columns, flags, dust movements and clouds for the determination of wind conditions.

Wind Direction.—The prevailing directions of the planetary winds are discussed in another chapter. Observers are concerned chiefly with the direction of the wind at the surface. Ordinarily this does not vary materially from the direction of lower cloud movement; sometimes it does vary, however, and when it does the fact should be recorded as cross-winds, the direction of each being noted. If the barometer is steady and the sky is free from clouds, the direction shown by a wind vane may be taken as the direction of the wind to the height of ordinary flight altitudes. Neither the surface winds nor the cloud winds indicate definitely the presence of the updraughts and downdraughts which constitute bumps and air holes.



Robinson anemometer, electrically connected with recording apparatus, p. 239.

The Wind Vane.—The wind vane of the spread-tail pattern, used by the Weather Bureau, is probably the most practical form in use. It holds steadily to the wind; it is sensitive enough to respond to a breeze of 2 miles an hour. The regulation vane is 6 feet over all. The tail is made of very thin board strips, thoroughly weather-proofed; the metal work is rust-proof; the bearings are constructed so that friction is reduced to the minimum. This is the general service vane designed to show wind direction only. For obvious reasons it should be mounted as high above ground as possible, and it should not be in the lee of anything that may affect the wind flow.

The vane used in connection with recording apparatus is 4 feet in length. The axis carries four partly overlapping cam-collars arranged so that at least one collar is in contact with the electrical recording apparatus. The latter prints a dotted line on the record sheet. If two cam-collars are in contact at the same time the intermediate direction of the wind is denoted. Thus, with both north and west cams in contact, and the pen of each recording, the direction of the wind is northwest.

The adjustment of the box containing the contact apparatus should be made to the geographic meridian, and to solar and not standard time. Thus, if local time is 20 minutes faster than standard time and the date is May 27, the total correction will be 20 minutes plus 3 minutes. The sun will be on the geographic meridian at 23 minutes before 12:00 o'clock standard time, or 11:37 A.M. The shadow of the wind vane support *cast on a horizontal surface* will point due north when the sun is on the meridian.

Various devices are used to ascertain wind direction in times of very low velocity. A thread flown at the end of a stick fastened near the wind vane will often enable an observer to discover the direction of the wind when other evidence is absent. An ascending smoke column is swayed by a breeze too light to move a thread. The human face is exceedingly sensitive to the wind. The small boy who wets the ball of his forefinger and holds it against the air is using a method as old as the voyage of Jason in search of the Golden Fleece. Rather more uncertain is the movement of foliage. In many instances a wind vane whittled from a very thin strip of wood and perforated so as to whirl on a pin as an axis has been pretty nearly as serviceable as an expensive vane. Small vanes made of thin aluminium sheet metal, spread-tail in pattern, have answered every purpose required for ascertaining wind direction.

On the other hand, the commercial weather vane on a church steeple or a flagstaff may be an uncertain guide. Years of weathering may have rusted it fast to the spindle; and improper mounting may prevent its coming up to the wind by many degrees.

Obtaining wind direction from the movement of the clouds is frequently misleading as to results. Sometimes it happens that the surface wind blows from one direction, while clouds move toward another. If the clouds are low, the direction whence they come is most accurately obtained by facing them and then turning at a right angle to check the observation.

Cross-winds, that is wind currents of different directions, are more common than is generally known. Airmen have learned their meaning and watch sharply for them. They are apt to occur before and after a storm. At such times they practically mark the advancing or the retreating edge of a cyclonic movement. Billow clouds are the earmarks of cross-winds and such cross-winds are usually at a considerable height. Cross-winds are very common along the coasts of large bodies of water where the land and the sea breeze alternate. These alternating winds are shallow, however, and the airman usually finds the steady prevailing wind at an altitude of half a mile or more. The alternating mountain valley winds are cross-winds of similar character.

Cross-winds are not always discernible to the airman or to the marine pilot. They become visible as to position only when difference in temperature and humidity of the two layers produces cloudiness at the interface.

Wind Velocity.—The velocity of the wind at any locality varies greatly. The dead calm of tropical seas is frequently followed by hurricane winds having a velocity exceeding 100 miles an hour. The hurricane that wrecked Galveston blew with a velocity estimated at more than 125 miles an hour. At Cape Mendocino, California, a velocity of 144 miles was registered, and at Mount Washington a mean hourly velocity of 111 miles per hour was registered for a whole day.[1] At Battery Park, New York city, the anemometer has registered a velocity of 96 miles; and storm winds along the coast have reached a velocity of 100 miles a dozen times or more. Some of the strongest winds along the Atlantic Coast of the United States are storm winds of a recurved part of West Indian hurricanes.

For the greater part, the mean hourly velocity of the wind at the various stations provided with anemometers varies from

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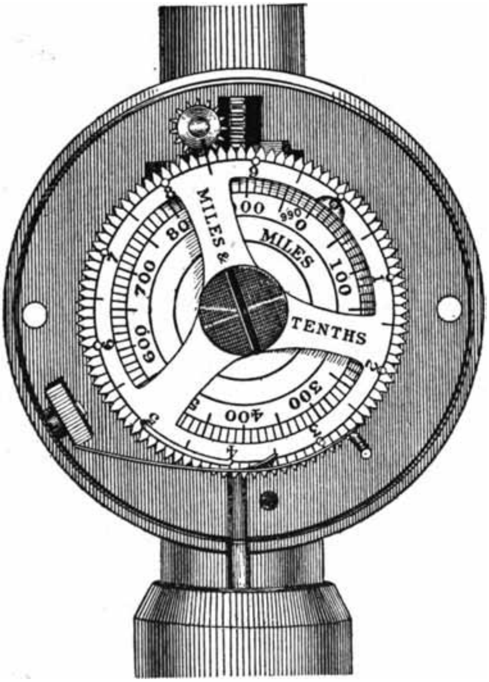
[1] February 27, 1886. In January, 1878, a velocity of 186 miles was recorded.

5 miles to 15 miles per hour. On sea and lake coasts it is materially higher; and in a few mountain valleys it is lower than 3 miles.

Throughout the prairie region and the great plains, the wind is apt to be steady, its velocity varying but little during the daylight period. In regions where land breezes alternate with those from the sea, a short period of calm precedes each change.



Dial of the Robinson anemometer.

Each Weather Bureau station is provided with the standard anemometer of the Robinson pattern; most stations are equipped with the Friez triple-magnet register, which records both direction and velocity of the wind. Recording instruments of this character are used at the principal military and naval stations.

The cooperative observation sub-stations, outnumbering the regular stations about twenty to one, are not equipped with recording instruments except as they are procured at private expense. For all observers—volunteer, regular and cooperative

—the Beaufort wind scale[1] affords a very good and practical method of approximate determination of wind velocity. The force numbers of the scale adopted by the Weather Bureau are the same as those of the British scale; the velocity in miles per hour corresponding to the force numbers differs considerably.

The table, p. 240, gives the Beaufort number, designation of wind and velocity as adopted by the Weather Bureau. The physical effects are those of the British scale.

Cooperative and volunteer observers report merely the prevailing direction of the surface winds, except as specifically directed. At the regular Weather Bureau stations the direction and velocity of upper winds are noted, a necessary step for the information of the rapidly growing air service. More information concerning the times of the daily maxima and minima of wind velocity is needed for the benefit of air service, and volunteer observers may be very helpful in obtaining this information.

The Anemometer.—For all ordinary purposes in the measurement of wind velocity the Robinson anemometer is almost universally used. For determining the mean velocity of the wind it is the best instrument in meteorological service. Inasmuch as it fails to record momentary gusts of wind perfectly, a Dines pressure anemometer is usually added to the equipment of regular stations. A wind meter of the Biram type is also useful in the measurement of wind gusts; it merely registers wind velocities without recording them.

The Robinson type of anemometer is simple in construction and does not easily get out of order. Four hemispherical cups fastened to arms 6.72 inches from axis to center, made fast to a spindle, communicate their motion to the measuring mechanism. The upper end of the spindle revolves in a sleeve; the lower end rests in an oil cup which also is a bearing. A worm screw thread near the lower end engages a train of wheels. Two of these are registering disks turning on the same axis.

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[1] The scale was devised by Admiral Beaufort in 1805, chiefly to advise sailing-masters of the kind and spread of sail which ships of the line might carry and their probable speed under such sail. Subsequently it was addressed to fishing smacks and trawlers. More recently it was revised for the benefit of weather observers. A few meteorologists have used it; many observers regard it as too complicated to be of practical use. Most observers express their estimate of wind velocity in very few terms: as, breeze, light wind, strong wind, and gale.

SCALE OF WIND FORCE—U. S. WEATHER BUREAU

Beaufort number	Designation	Physical effects (on land)	Pressure lbs. per sq. ft.	Meters per second (Br.)	Miles per hour	
					Br.	U. S.
0	Calm	Calm; smoke rises vertically............	0	Less than 0.3	Less than 1	0–3
1	Light air	Direction of wind shown by smoke drift, but not by wind vanes...............	.01	.03–1.5	1–3	3–8
2	Slight breeze	Wind felt on the face; leaves rustle; ordinary vane moved by wind............	.08	1.6–3.3	4–7	8–13
3	Gentle breeze	Leaves and small twigs in constant motion; wind extends light flag...............	.28	3.4–5.4	8–12	13–18
4	Moderate breeze	Raises dust; small branches are moved	.67	5.5–7.9	13–18	18–23
5	Fresh breeze	Small trees in leaf begin to sway; crested wavelets form on inland waters.........	1.31	8.0–10.7	19–24	23–28
6	Strong breeze	Large branches in motion; umbrellas used with difficulty......................	2.3	10.8–13.8	25–31	28–34
7	Moderate gale	Whole trees in motion; inconvenience felt when walking against the wind.........	3.6	13.9–17.1	32–38	34–40
8	Fresh gale	Breaks twigs off trees; impedes progress...	5.4	17.2–20.7	39–46	40–48
9	Strong gale	Slight structural damage occurs (chimney pots and slates removed).............	7.7	20.8–24.4	47–54	48–56
10	Whole gale	Seldom experienced inland; trees uprooted; considerable structural damage occurs...	10.5	24.5–28.4	55–63	56–65
11	Storm	Very rarely experienced; accompanied by widespread damage..................	14.0	28.5–33.5	64–75	65–75
12	Hurricane		Above 17.0	Above 33.6	Above 75	Over 75

Millibar pressures are approximately one-half as great as pound per square inch pressures.

One of these wheels contains 100 teeth and the other 99. By means of this differential motion the registration of the number of miles up to 990 may be read directly.

A type of Robinson anemometer in which registration is made with index hands is also made. Its mechanism does not differ otherwise from the ordinary type. One of the train of geared wheels in the ordinary form of anemometer is cut with 50 teeth. If replaced with one cut with 62 teeth the disks will record kilometers instead of miles. If an interchangeable gear of this sort is desirable, it is better to have the necessary adjustments made by the manufacturer.

Several types of magnet recorders are used with the Robinson anemometer. In the type most commonly used, an arm carrying the recording pen is attached to the armature of the magnet. The revolving disk carries the studs representing miles of wind movement against the spring which acts as a circuit closer; the recording pen thereupon makes an offset from the straight line on the record sheet. Each offset represents theoretically a mile of wind. As soon as the stud passes the contact spring—a matter of from five to ten seconds—the pen is drawn back to its normal position. The fourth and fifth studs are bridged and the closed circuit makes the offset which covers a theoretical mile of wind movement. This is a convenience which enables the number of miles to be counted in groups of ten. Should any intermediate mile-stud fail to record, the failure will not be lost; it is included in the count.

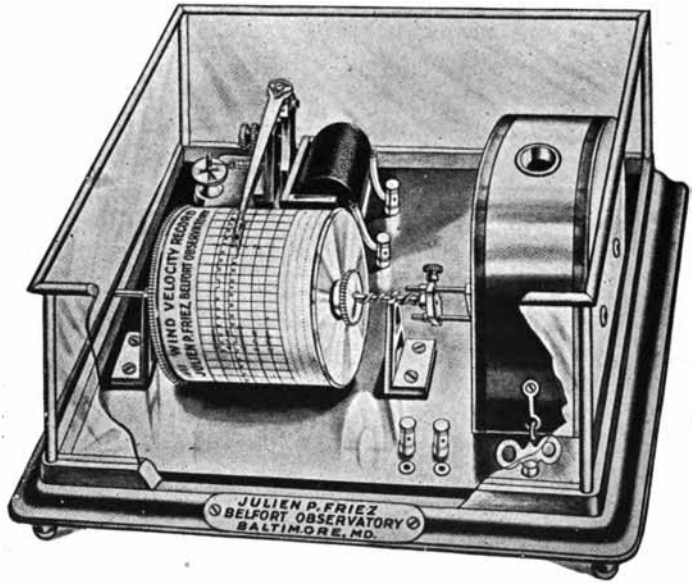
Caution is necessary at times in reading the closed circuit mile, especially when it represents a high velocity whose measure is to be determined closely. The observer must choose between closing and closing, or between opening and opening of the circuit. Because the opening—the "breaking"—of the circuit is quick and positive, this interval is considered preferable in determinations.

The record sheet is necessary in finding the time of maximum or of minimum velocity of the wind. From it one may also find the velocity for any hour of the day. And inasmuch as such information is frequently required in suits at court, accurate dating and time-checking of the record sheets are essential.

The totals for any specific time may be read from the record sheets. Daily and monthly totals may be read from the dial.

Indeed, many observers prefer to make dial readings, except in cases where hour totals are required.

The establishment of the time of the daily maxima and the daily minima is a most useful problem for cooperative and volunteer observers to undertake. This is very easily solved from the daily record sheets, but close observation will enable an observer to get pretty accurate results without the aid of instruments. Daily observations may be summarized in monthly averages, and from these the seasonal averages may be determined.



Wind velocity recording apparatus.

To obviate the inconvenience of changing record sheets at midnight, they are most commonly changed at noon. A day's record consists of the two lower lines of one sheet and the two upper lines of the sheet for the day following. The aggregates may be kept in half-day totals, but it is better to carry them over and enter them on the record sheet of the following day. The necessary thing is a definite plan followed with intelligence rather than slavish exactness.

Changing anemograph sheets precisely at noon is highly desirable. If the clock is either fast or slow, its rate is best established at that time. The pressure of the pen on the sheet is bound to vary slightly from day to day, and this in itself is likely to cause the rate of the clock to change. The pen should touch the paper positively but lightly.

The pen requires frequent cleaning; whenever the nib appears clogged it should be wiped with a bit of soft rag. Half a dozen times a year it should be removed and made thoroughly clean, scraping off the sediment that washing will not remove. A clean pen and good ink will leave a record as clear and clean as though the lines had been made with a drawing pen.

The wiring plan for the triple register is set forth in detail in Circular D, Instrument Division, and the details need not be rehearsed here. Wherever wires pass through woodwork, porcelain tube insulators are required by insurance regulations. If the wiring is situated where contact with electric light wires is possible, heavily insulated wires, such as are prescribed by local regulations, should be used. All permanent wire joints and splices should be snugly twisted a length of 2 inches—or, better, soldered—and wrapped with tape. All outside wires should be held by insulators.

Batteries.—In operating a triple register, 10 cells of battery are required; for the wind-direction register, 4 cells; for the anemometer, 3 cells; for the sunshine and rainfall recorder, 3 cells in common. For a 2-magnet register, recording wind-velocity and sunshine, 3 cells in common are sufficient. Unless the electromotive force is strong, however, the sunshine recorder may fail to register when the anemometer contact is on the bridge. This, however, need not lead to error; the bridge contact is always a long offset on the anemograph.

The requirement of battery cells for magnet registers is steadiness rather than strength. Dry cells run down in electromotive force so quickly that, if the wind is on the bridge for more than a few minutes, the sunshine recorder fails to register unless operated by a separate battery. The ordinary "wet cells" are not much better.

When storage batteries suitable for the work are not available, the cells of the Edison primary type are the best. Such a cell properly charged gives a feeble but steady current on a closed circuit for nearly 400 hours. It will operate a 2-magnet register for more than a year.

CHAPTER XXI

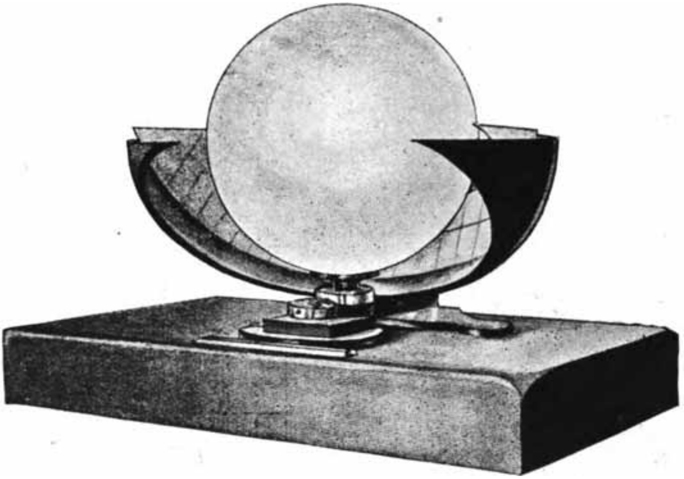
THE MEASUREMENT OF SUNSHINE: SUNSHINE RECORDERS

Recording the daily duration of sunshine is a part of the work of all Weather Bureau stations; it is carried on also at agricultural experiment stations, at university laboratories, and at many aviation fields. The objective information may be different in the various cases; the methods of measurement are usually the same.

Sunshine measurements are not required of cooperative observers; their reports, however, include an estimate of cloudiness; less than one-third of cloudiness, clear; one-third to two-thirds, partly cloudy; and two-thirds or more, cloudy. A day with a sky full of broken clouds is necessarily recorded as cloudy; nevertheless the registered sunshine may be almost continuous. At times the cloud film of a sky completely overcast may be so thin that a sunshine recorder of any sort will register a considerable part of the day. On the other hand, a light dust haze may interfere materially with registration, although to the sense of sight, the light seems normal. The amount of sunshine, therefore, cannot be reckoned from a record of cloudiness. Even with recording instruments having the best possible adjustments, the record of sunshine for a given period is an approximate only; there is no such refinement in sunshine measurements as exists in measurements of pressure or of temperature.

Sunshine Recording Instruments.—The various sunshine recording instruments may be reduced to three types: the burning-glass type, such as the Campbell-Stokes recorder; the photographic type, such as the Jordan recorder, for many years used in the United States Weather Bureau; and the thermo-electric type; of which the Marvin recorder is practically the only one.

The Campbell-Stokes recorder consists of a sphere of colorless or slightly yellow glass of a high degree of transparency. It is mounted in a frame in front of a concave surface set at focal distance from the glass sphere.[1] The central line of the recording chart must lie in the plane of the true meridian. The frame itself is adjustable to the sun's altitude. The recording chart is graduated to hour intervals. The focal rays, shifting with the position of the sun, char a line along the chart. The charred line represents the duration of the sunshine. When the sunshine has occurred at short and irregular intervals the aggregate duaration may be found most quickly by placing the edge of a sheet of paper along the record and marking thereon lengths equal to the lengths of the successive charrings. By sliding the paper along the trace, the lengths form a continuous line. Their aggregate then may be measured along the graduations of the paper.



Campbell-Stokes sunshine recorder.

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[1] A sphere of the sort has some of the characteristics of a prism; it refracts the various components of a ray of light unequally—red rays the least, violet rays the most. The registering paper gives the best record, on the whole, when set at the focus of greatest light intensity. The best focal distance cannot always be determined by rule of thumb, however; it varies slightly with the locality, and therefore the optimum focal distance must be determined by the observer.

The intensity of the charring varies according to the condition of the air as to cleanliness and freedom from moisture. If the air is clear and dry, the focal rays burn a long gap in the sheet. On the other hand, a moist or a polluted air may absorb so much heat that the surface of the recording chart is merely discolored. The record for the first half hour or more after sunrise is usually indistinct; this is usually true of the time just before sunset. If a cloud obscures the sun, even for a few minutes, the burning process is arrested.

Sunshine differential thermometer, electrically connected with the recording apparatus.

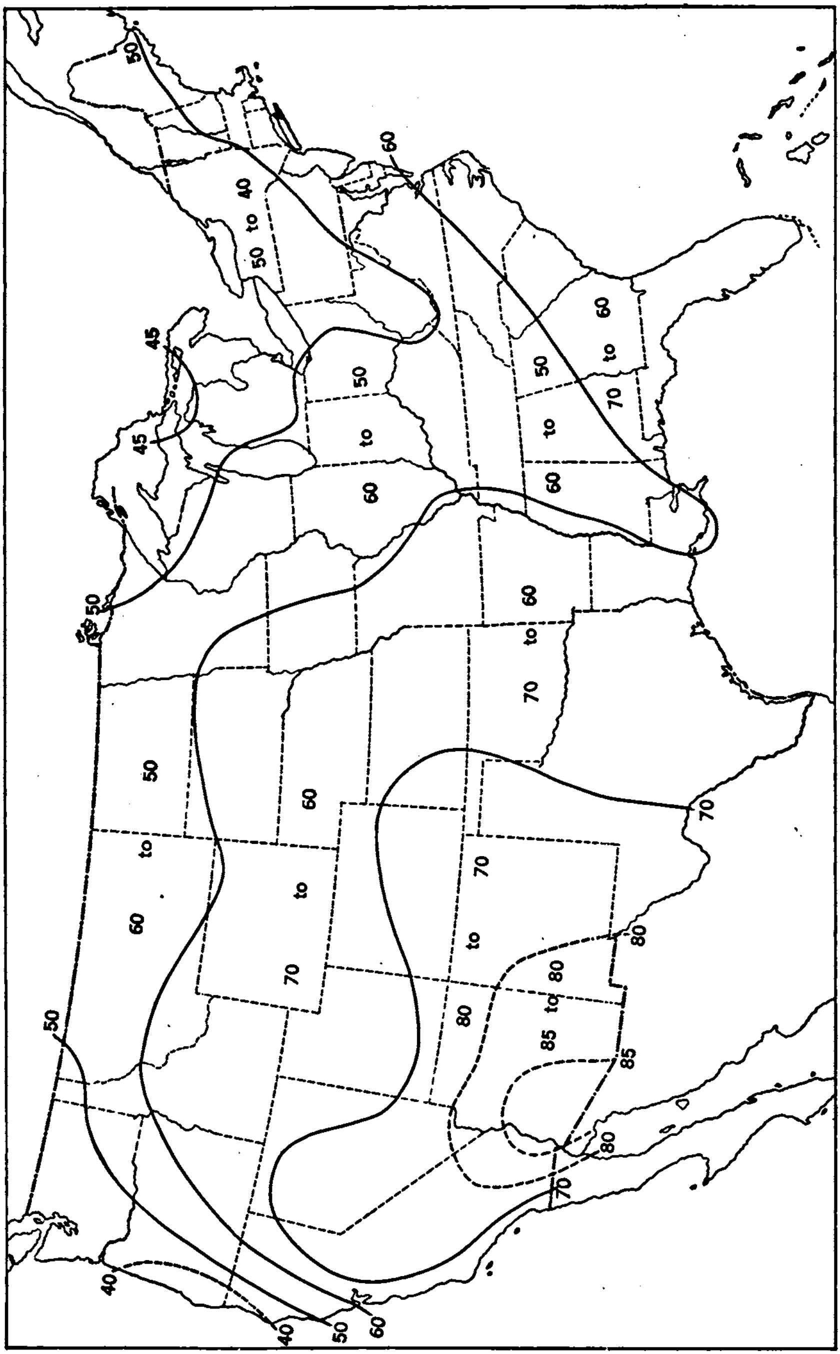
The charts used in this type of sunshine recorder may be changed at any time between sunset and sunrise of the following day. Each chart, therefore, carries the record of a full daily period of sunshine.

The Campbell-Stokes recorder is simple in construction and inexpensive. It requires neither clockwork nor electrical mechanism in its operation. The records are unsightly, but they are ineffaceable and permanent. As a piece of mechanism it is practically fool-proof. In the laboratories of Europe its use is general.

Photographic recorders depend on the action of sunlight on sensitive paper. The record sheet is placed within a camera of circular section. A minute aperture permits a spot of light to enter the camera and fall on the record sheet. In one form there are two apertures, one for the period from sunrise till noon, the other from noon to sunset. The changing position of the sun causes the spot of light to traverse the record sheet in an opposite direction. After exposure the sheets are developed and fixed by ordinary photographic processes. Silver paper gives the most legible charts; and when a bit of blue glass is used as a light filter, the line of record is more sharply drawn and clearer. Silver paper is expensive, however, and ordinary blue-print paper is more commonly used.

The time and effort required to prepare the sensitive paper, and to develop and fix the record sheets is the great objection to photographic recorders. In some respects they are more accurate in time measurement than any other form; and in this particular they have possibilities not possessed by any other recorders.

The *Marvin thermo-electric recorder* is used at United States Weather Bureau stations and in most meteorological laboratories. It consists of a differential thermometer in a vacuum tube and a recording apparatus. The expansion of a volume of air in a blackened tube pushes a column of mercury between two platinum points, the ends of which pierce the tube, thereby making an electric circuit possible in the recording apparatus. The air volume within the blackened tube is exceeding sensitive to heat. Even in the coldest weather, the heat of direct sunshine is sufficient to push the mercury to the circuit-making points; with the absence of sunshine the mercury drops below them. Inclining the tube takes some of the weight off the air chamber and causes the mercury to be more easily lifted. In



After Kiricer.

Sunshine in the United States. Figures show the per cent of possible sunshine.

order to overcome the friction of the mercury against the glass, it is lubricated with alcohol. The upper part of the tube, which is not blackened, also contains air. A dextrous shaking of the tube will transfer bubbles of air from one end to the other, thereby holding the column of mercury to any desired height, or to any desired distance from the circuit points.

The stand should be mounted in a locality that is not shaded. The tube should be in the plane of the true meridian, and face the south. The angle of inclination should be roughly about 45 degrees. In summer it should be a little nearer to the vertical; in winter a little more to the horizontal. The angle depends partly on the amount of air in the lower bulb and partly on the position that gives it the maximum of insolation. In general, the results are best when the top of the mercury is from half an inch to an inch above the circuit points during the warmest part of the day.

The recording device is attached to that of the anemometer, using the same sheet but a different recording pen. When the sun is shining, a contact of the clock completes the circuit. The movement of the armature operates a jigger, which moves the pen once every minute. The jigger and the progressive movement of the drum cause the pen to make steps in series of five, back and forth. Each series represents five minutes of time. These continue while the sun is shining. When the sun is not shining, the mercury in the thermometer drops away from the platinum circuit points. The pen then draws a straight line.

Even when carefully adjusted, the recorder will not begin to register for some time after sunrise; it ceases to register a short time before sunset. These periods must be measured from time to time by the observer, taking the time of sunrise and sunset from a reputable almanac for the approximate latitude of the station. These intervals are the *twilight corrections*.

The morning twilight correction is usually somewhat greater than that of evening. Both vary slightly between winter and summer. In localities where city smoke and floating dust do not contribute to instrumental sluggishness, the morning correction should not exceed one hour; the evening correction should not be more than half as much. The presence of smoke, dust and haze may extend this correction to more than one and one-half hours.

Measurement of Sunshine.—The adjustment for registration practised by the Weather Bureau is based on experience and is reasonable. The tube holding the thermometer should be inclined so that the recorder will register when the actual disk of the sun—not a shapeless blotch of light—can be discerned through the clouds of an overcast sky. It is better to make the adjustment when the sun is about two hours high, by inclining the tube. The observer must wait for such a day, and perhaps several trials may be necessary.

The computation of the total actual hours of sunshine may be made by any system which the observer finds convenient. If the total sunshine is not more than a few hours, it is perhaps most easily counted in the manner suggested in a previous paragraph—that is, measurement along the edge of a strip of paper. When the obscuration by cloudiness is slight, or is absent, the following method may be followed:

From the total possible hours for the day deduct:

(*a*) The excess, if any, of obscuration over the twilight corrections;
(*b*) The total of obscurations due to cloudiness; thus:

Total possible hours		13:36
Twilight corrections	1:30	
Excess over twilight corrections	0:54	
Cloud obscurations	2:22	4:46
Actual hours		8:50

The calculations may be made in detail on the back of the record sheet. On the face of the sheet these should be entered in the proper place:

Total hours carried forward	172:24
Saturday (or current day)	8:50
Total since first of month	181:14

By this, or by a similar method, the computation for the month is finished on the last day of the month. In Weather Bureau practise, minutes of time are reckoned in decimals of an hour, in the measurement of sunshine.

Sunshine records are approximate only; close calculation, however, will bring reasonably accurate results. At times the judgment of a careful observer may be more trustworthy than an imperfectly adjusted instrument. At times, too, there may be momentary periods of sunshine which are not registered at all. Even in the absence of all measuring instruments, an observer whose record consists merely of the total of overcast days is gathering information of great value.

Concrete Results of Sunshine Records.—It is well to bear in mind that the mere gathering and tabulating of monthly statistics of sunshine is not an end, but merely a means to an end. Knowledge of any sort possesses but little value unless it can be applied to the betterment of humanity. In agriculture the results may be applied so as to obtain more definite knowledge concerning the growth and maturity of plants—essentially the minimum amount of sunshine necessary to fructification. In almost every department of agriculture the total of sunshine has a direct bearing on the amount of evaporation.

In climatology, much more information concerning the relation of sunshine to public health is required. The healing value of sunlight is not overestimated; its value in therapy of the mind is underestimated. The mental depression following prolonged spells of overcast skies is marked.

In commerce and transportation, the effects of obscuration on visibility is becoming a matter of systematic study and investigation. The impairment of visibility costs more than money; its toll of human life is heavy.

In military and naval strategy, helio-signaling depends on sunshine; so also, sunshine is the key to many problems involving visibility.

The efforts of a single observer may not solve general problems, but they will go a long way in solving the specific cases of his own bailiwick. The observer may determine whether or not specific times of obscuration—daily or seasonal—prevail. In many parts of the country good beginnings have been made already by volunteer observers. Incidentally, there is no station, permanent or transient, from which additional information would not prove of value.

The area in which the per cent of sunshine is less than 40 is very small, and but little of it is crop-growing land. The region of greatest sunshine, for the greater part, is deficient in rainfall. Irrigated lands, however, produce crops that are extraordinary in quantity and unsurpassed in quality. The Lake region is below the average in sunshine, but the deficiency does not impair the quality of the fruit crop. The region of greatest cotton production receives from 60 to 70 per cent; and a comparison of this region with that of a lower per cent shows that the higher per cent is essential. Practically every part of the United States receives enough sunshine for a fair crop production, and a very great part receives enough for maximum production.

In the latitude of New Orleans, June days are about 14 hours long; in the latitude of Minneapolis they are nearly 16 hours. The aggregate warmth is about the same in each case. The oblique rays of the sun and their lower heating power are balanced by greater duration in time.

APPENDIX

REFERENCE TABLES

C. G. S. UNITS

The construction and evolution of the system of electrical units now in general use began in Europe where the metric system originated. Two of the basic units, the centimeter and the gram, are metric units; the second of time is universally employed in time measurements.

The meter, 3.2808 feet = 39.37 inches, is theoretically the one ten-millionth part of the earth's quadrant; actually it is the length of a metal rod differing from the theoretical value by about three-fourths of a millimeter. The prefixed multiples, deka-, hecto-, kilo- and mega- are in ten-fold ratio. They indicate respectively 10, 100, 1000 and 1,000,000. The prefixed decimal divisions, deci-, centi-, milli- and micro- indicate tenths, hundredths, thousandths and millionths.

The C. G. S. units are generally used in the United States in chemical and in abstract physical determinations. On account of their inconvenient magnitudes their use has not extended to mechanics; and for this reason the employment of them is strenuously resisted by manufacturers in every line.

Units of the C. G. S. System.—The *centimeter*, the one-hundredth part of the meter, is the unit of length. 1 cm = 0.0328 foot.

The *gram*, the unit of *mass*, is the weight of 1 cu cm of pure water under standard conditions. 1 g = 0.0022 pound = 15.432 grains. The weight of a cubic centimeter of a substance also represents its specific gravity.

The *square centimeter* is the unit of *area*. 1 sq cm or cm^2 = 0.001076 sq ft = 0.1550 sq in.

The *cubic centimeter* is the unit of *volume.* 1 cc = 0.0000353 cu ft = 0.061 cu in.

The unit of *density* is numerically the same as the specific gravity. It is the rate of 1 gram per cubic centimeter.

The unit of *velocity* is the velocity of 1 centimeter per second; 1 cm per second = 0.0328 foot per second = 0.0224 m. per hour.

The unit of *acceleration* is the rate of a unit of velocity per second or 1 centimeter per second, *per second.*

The unit of *force,* 1 *dyne,* is the force which imparts to 1 gram a velocity of 1 centimeter per second, *per second.* It is sometimes expressed in the term *poundals;* 1 dyne = 0.0000722 poundal. The acceleration of gravity of a falling body varies in different latitudes because the earth is spheroidal and not globular in form. In latitude 45°, the latitude to which results commonly are reduced, the acceleration is 980.621 centimeters per second, *per second.* If the relative value at latitude 45° be taken as a unit, the relative value at the equator will be 0.9974; at the pole 1.0027.

The unit of *pressure* is 1 *dyne* per square centimeter. The megadyne is a more convenient unit and generally is used. The megadyne is commonly called 1 *bar.* Barometric pressure is read in kilobars and its subdivisions in millibars. 1 bar = 1000 millibars = 0.001 kilobar. 1 kilobar = 0.03386 inch; 1 inch = 33.864 millibars; 1 millimeter = 1.333 millibars. The barometric pressure at 29.53 inches = 1000 millibars, which is equivalent to an altitude of 338 feet above mean sea level. The dyne may be conceived as the pressure upon the hand—that is, the weight—of a piece of very thin tissue paper 1 centimeter square.

The unit of *rainfall* is 1 *millimeter.* For all practical purposes, the reduction of hundredths of an inch in rainfall to millimeters of rainfall is effected by moving the decimal point two places to the right and dividing by 4. Thus, if the catchment of a storm is 2.40 inches; the division gives 60 millimeters. A more accurate result will be obtained by using 3.94 as the divisor. Multiplying by .04 reduces millimeters of rainfall to inches of rainfall.

The practical unit of *wind velocity* is 1 *meter per second*—that is, 100 times the C. G. S. unit.

The practical unit of *wind force* is 1 *kilodyne per unit of area.*

The practical unit of *wind pressure* is the *millibar.* Wind force is not always exactly proportional to the area.

The practical unit of *radiation* is the *gram calorie* (in distinction from the great calorie) or the *warmth required to raise* 1 *gram of water* 1° *C in temperature.*

The *erg*, the unit of *work*, is the amount of work done when a mass of 1 gram moves a distance of 1 centimeter, against a resistance of 1 dyne. A more practical unit is the *joule*, or 10,000,000 ergs.

The unit of *time* is the *second*, of which the mean solar day contains 86,400.

Units of Magnetism and Electricity.—Magnetism may be either positive or negative. Bodies charged with the same kind of magnetism repel each other; charged with opposite kinds, they attract. Commercial magnets are usually marked, the letter N or a dash being stamped upon the north-seeking pole. The convenient unit of magnetism is one which attracts or repels an equal quantity at a distance of 1 centimeter.

The absolute unit of current flowing through a centimeter of wire acts with a force of 1 dyne on a unit of magnetism 1 centimeter distant from every point of the wire.

An *ampere*, the practical unit of *current*, is the electromotive force of 1 volt against a resistance of 1 ohm. It is the tenth part of the absolute unit. An ordinary dry cell gives a current of about 2 amperes, a Daniels wet cell, 1 ampere. Dry cells differ somewhat in strength.

A *volt*, conversely, is the *electromotive force*, or "electric pressure," which, flowing in a conductor having a resistance of 1 ohm, will yield 1 ampere of current. The ordinary dry cell, when fresh, has an electromotive force of about 2 volts.

The *ohm* is the unit of *resistance*. For all practical purposes it is the resistance of 50 meters of copper wire 1 millimeter in diameter. Theoretically it was intended to be the resistance of a wire in which 1 ampere of current in 1 second would generate the amount of heat equivalent to 10,000,000 ergs.

The *watt* is the unit of power. At the rate of 10,000,000 ergs per second, a current of 1 ampere having the pressure of 1 volt has a value of 1 watt. A common candle has the heating equivalent of about 60 watts. One horse power, the power required to lift 33,000 pounds 1 foot high in a minute of time, is rated about 746 watts.

A *coulomb* is the unit of *quantity*. It is the quantity of electricity transferred by a current of 1 ampere in one second.

The *farad* is the unit of *capacity*. The capacity of a condenser is theoretically the electricity that can be stored in it by a cell of known electromotive force. For purposes of exact measurement the cell should have an electromotive force equal to 1 unit absolute measure. It is practically a condenser which, charged with 1 coulomb of current, has a difference of potential of 1 volt.

CHEMICAL FORMULAS

Freezing Mixtures.—Salt, 1 part; snow at 32°, 2 parts, produce a zero mixture.

Calcium chloride, 2 parts; snow at 32°, 1 part, produce a temperature of −40° F.

Potassium hydrate (concentrated) at 32° and snow at 32°, equal parts, produce a temperature of −30° F.

Ammonium chloride, potassium nitrate and water at 32°, equal parts, produce a temperature of −10° F.

The temperature produced by these mixtures is approximate only. The first mentioned may vary not more than 3 degrees; usually the variation is not more than 1 degree; a variation of as much as 10 degrees may occur in the second. As a rule, the larger the volume of the mixture the better the result.

Chemical Hygroscopes.—Various chemical salts are sensitive to the moisture of the air; some of them change color with the absorption or the discharge of moisture. Cobaltic chloride is the basis of most of the commercial hygroscopes of this character. A solution consisting of 5 grains of cobaltic chloride, 50 grains of gelatine and 1 fluid ounce of water is a good porportion. There must be a complete emulsification of the gelatine. A strip of unsized paper wet with the emulsion is normally pink in moist air, violet in moderately moist air, and blue in dry air. When the winter fires are on in dwellings, the strip of paper is persistently blue. Ordinarily it does not begin to turn until the moisture of the air is about 75 per cent.

Ozone Test Papers.—Qualitative tests for ozone are often desirable. The following solution is highly regarded. Distilled water, 1 oz; starch, 25 grains; potassium iodide, 4 grains. Dissolve the potassium iodide in a small part of the water; boil the starch in the remaining part; mix and shake thoroughly. Moisten strips of unsized white paper and suspend them in the thermometer shelter or in shaded open air. Usually an exposure of from 3 hours to 10 hours is required. The ozone decomposes the potassium iodide, thereby turning the paper blue in color. This is probably the best test.

A slip of paper moistened with a solution of manganous sulphate is turned brown by ozone. The reaction oxidizes the manganous to manganic sulphate.

A paper strip smeared thinly with lead sulphide is more or less bleached by ozone, the sulphide being oxidized to a sulphate, which is white. This test is characteristic if the sulphide is smeared upon black paper.

Storm Glasses.—The so-called " storm-glass " which is sold under several fanciful names, consists of a solution just beyond the point of precipitation inclosed in a thin glass tube about 7 inches long and half an inch in diameter. The solution consists of camphor, 10 parts; potassium nitrate (saltpeter) 5 parts; ammonium chloride (sal ammoniac) 5 parts; 95 per cent alcohol 105 parts; and distilled water 45 parts. The virtue of the solution depends on the fact that neither the solution nor the precipitation is complete; the proportion of alcohol must be regulated to prevent more than a small part of the chemical salts from precipitation. The glass must be thin enough and elastic enough to yield slightly to changes in atmospheric pressure. About 1 inch of air space in the tube adds to the sensitiveness of precipitation. An increase in pressure causes the precipitation to extend nearly to the top of the solution; a decrease causes increased solution and a settling to the bottom of the tube. With a very low barometer the precipitated matter sinks to the bottom and becomes gelatinous. Increase of pressure is followed by the formation of minute crystals that grow in size. The only weather changes indicated are those foretold by a rising or by a falling barometer.

Table 1—Miscellaneous Equivalents

Linear Equivalents

1 mile = 320 rods
= 1760 yards
= 5280 ft
= 63360 in
= 1.60935 kilometers

1 rod = 0.003125 mi
= 16.5 ft.
= 198.0 in
= 5.0292 meters

1 yard = 0.000568 mi
= 0.9144 meter

1 foot = 0.3333 yd
= 0.000189 mi
= 0.3048 meter

1 inch = 1000 mils
= 0.08333 ft
= 0.02777 yd
= 2.54 centimeters

1 mil = 0.001 in
= 0.0254 millimeter

1 fathom = 6 ft
= 1.8288 meter

1 nautical mile = 6080.27 ft US
= 1.1516 stat mi US
= 6080 ft Br Ad
= 1.1515 stat mi
1 statute mile = 0.8684 naut mi US
1 geographical mile = 0°1′ at equator
= 6087.15 ft
= 1.1528 stat mi

1 nautical mi Br Ad
= 1853.248 meters
1 geographical mi (U S)
= 1855.345 meters

1 chain (engineers)
= 100 ft
= 6.0606 rods
= 1.5157 Gunter's chain
= 30.48 meters

1 Gunter's chain = 66 ft
= 4 rods
= 0.66 chain
= 0.0125 mi
= 20.1168 meters
1 link = 7.92 in

1 kilometer = 0.62137 mi
= 198.8384 rods
= 1093.61 yds
= 3280.83 ft

1 meter = 39.37 in
= 3.28083 ft
= 1.09361 yds

1 centimeter = 0.3937 in
= 0.032808 ft

1 millimeter = 0.03937 in
= 39.37 mils
= 1000 mikrons
1 mikron = 0.001 mm

Square Equivalents

1 square mile = 640 acres
= 102400 sq rd
= 3,097,600 sq yd
= 27,878,400 sq ft
= 2.59 sq kilo

1 acre = 160 sq rd
= 4840 sq yd
= 43560 sq ft
= 4046.87 sq meters
= 0.0404687 hectare

1 square yd=0.83613 sq meter
1 square foot=0.1111 sq yd
=144 sq in
=0.0929 sq meter
=929.03 sq cm

1 square inch=0.006944 sq ft
=6.4516 sq cm

1 square mil=0.00001 sq in
=0.00064516 sq mm

1 square kilometer
=0.3861 sq mi
=247.105 acres
=1,000,000 sq meters

1 square meter=1.196 sq yd
=10.7639 sq ft
=1550 sq in

1 square centimeter
=0.155 sq in
=0.0001 sq meter

1 square millimeter=1550 sq mils
=0.00155 sq in

1 hectare=2.471 acres
=107,639 sq ft

Cubic Equivalents

1 cubic yard=27 cu ft=46,656 cu in=0.76456 cu meter

1 cubic foot=0.037 cu yd
=1728 cu in
=7.4805 U S gals
=6.2321 Imp gal
=0.0283 cu meter
=28317 cu cm

1 cubic inch=16.3872 cu cm

1 cubic meter=1.30794 cu yd
=35.3145 cu ft
=61,023.4 cu in

1 cubic decimeter (1 liter)
=0.03531 cu ft
=61.0234 cu in
=1000 cu cm
=0.26417 U S gal
=0.22 Imp gal

Capacity

1 bushel U S=1.24445 cu ft
=2150.4 cu in

1 bushel Br=1.28368

1 gallon U S=0.133681 cu ft
=231 cu in
=3.78543 liters
=3785 cu cm
=4 qts
=8 pts

A cylinder 7 in diameter and 6 in high has a capacity of 230.9 cu in—practically 1 gal.

1 gallon, Imperial=277.274 cu in
=4.5437 liters
1 quart=57.75 cu in
=946.25 cu cm

1 fluid ounce=1.8047 cu in
=29.574 cu cm

Weight

1 ton, long=2240 lbs (av)
=1.016 met tons
=1016.05 kg

1 ton, short=2000 lbs
=0.907 met ton
=907 kilo

1 pound avoirdupois=16 oz
=7000 grains
=0.4536 kg
=453.59 gram

1 pound troy = 12 oz
= 5760 grains
= 372.631 grams
= 0.37323 kg

1 ounce avoirdupois = 437.5 grains
= 0.0625 lb
= 28.35 grams

1 ounce troy = 480 grains
= 0.0833 lb
= 31.1 grams

1 metric ton = 0.9842 long tons
= 1.1023 short tons
= 2204.62 lbs
= 1000 kg

1 kilogram = 2.20462 lb av
= 2.6792 lb troy
= 35.274 oz av
= 33.140 oz troy

1 gram = 15.432 grains
= 1000 mg
= 1 cu cm water
1 grain = 0.0648 gram

Work Equivalents

1 horse power
= 33,000 ft lb per min
= 1,980,000 ft lb per sec
= 273,746 kg meters
= 2,685,443 joules
= 2544.99 lb
= 641.326 kilo

1 Br.therm.unit = 1 lb 1° F
= 778 ft lb
= 0.252 kg C°
= 107.56 kg meters

1 joule = 0.7373 ft lb
= 0.102 kg meter

1 kilogrammeter
= 7.89 h p min
= 0.1315 h p sec
= 7.233 ft lb
= 0.8 met h p min
= 0.0133 met h p sec
= 9.81 joules
1 kilogram degree C°
= 3087.35 ft lb
= 3.968 deg lb F°
= 426.84 kg meters

1 metric horse power
= 1,952,910 ft lb (hour)
= 2,648,700 joules

Precipitation

1 acre foot = 43,560 cu ft
= 325,850.58 U S gal
= 0.6234 U S gal per sq ft
= 1233.46 cu meters
= 1344.2 tons

1 acre inch = 3630 cu ft
= 27154.21 U S gal
= 102.8 cu meters
= 112.01 tons

1 acre centimeter
= 0.24542 U S gal per sq ft

Atmospheric Equivalents

t = 32° P = 29.92 in or 760 mm

1 cubic yard of air = 2.17888 lb av
= 988.615 grams

1 cubic foot of air = 0.807 lb av
= 565.061 grains
= 36.615 grams
= 1.291 oz av

1 atmosphere = 29.921 in of mercury
= 760 mm of mercury
= 33.9 ft of water
= 14.7 lb per sq in
= 1.0333 kg per sq cm

1 metric atmosphere
=0.9678 atmosphere
1 cubic meter of air (32° F)
=2.85 lb
=1.293 kg

VELOCITY

1 inch per second=300 ft per hour
=152.4 cm per min

1 foot per second
=60 ft per min
=3600 ft per hour
=0.682 mi per hour
=1.097 kilo per hour

1 mile per hour
=1.466 ft per sec
=88 ft per min
=0.447 meter per sec
=26.822 meters per min

1 mile per min
=5280 ft per min
=96.5608 kilo per hour
=16.035 kilo per min

1 kilometer per min
=2.2369 mi per hour
=96.5608 ft per min

MISCELLANEOUS

1 knot
=rate of 1 nautical mile per hour
1′ of longitude at equator
=1855.345 meters
=6087.15 ft

1′ of latitude at equator
=1842.787 meters
=6045.95 ft
=1.14507 st mi
1′ longitude at equator
=1.15287 st mi
Equatorial radius of earth
=3962.571 mi
Polar radius of earth
=3949.67 mi

1 cu ft of ice at 32°=57.5 lbs
1 lb of ice at 32°=0.0174 cu ft
1 inch of mercury in the barometer tube=13.5956 in of water

Table 2—Inches to Centimeters

Inches	0	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in
	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm
0		2.54	5.08	7.62	10.16	12.70	15.24	17.78	20.32	22.86
10	25.40	27.94	30.48	33.02	35.56	38.10	40.64	43.18	45.72	48.26
20	50.80	53.34	55.88	58.42	60.96	63.50	66.04	68.58	71.12	73.66
30	76.20	78.74	81.28	83.82	86.36	88.90	91.44	93.98	96.52	99.06
40	101.60	104.14	106.68	109.22	111.76	114.30	116.84	119.38	121.92	124.46
50	127.00	129.54	132.08	134.62	137.16	139.70	142.24	144.78	147.32	149.86
60	152.40	154.94	157.48	160.02	162.56	165.10	167.64	170.18	172.72	175.26
70	177.80	180.34	182.88	185.42	187.96	190.50	193.04	195.58	198.12	200.66
80	203.20	205.74	208.28	210.82	213.36	215.90	218.44	220.98	223.52	226.06
90	228.60	231.14	233.68	236.22	238.76	241.30	243.84	246.38	248.92	251.46
100	254.00	256.54	259.08	261.62	264.16	266.70	269.24	271.78	274.32	276.86

Table 3—Centimeters to Inches

Centi-meters	0	1 cm	2 cm	3 cm	4 cm	5 cm	6 cm	7 cm	8 cm	9 cm
		in	in	in	in	in	in	in	in	in
0		0.394	0.787	1.181	1.575	1.969	2.362	2.756	3.150	3.543
10	3.937	4.331	4.724	5.118	5.512	5.906	6.299	6.643	7.087	7.480
20	7.874	8.268	8.662	9.055	9.449	9.843	10.236	10.630	11.024	11.418
30	11.811	12.205	12.599	12.922	13.386	13.780	14.173	14.567	14.961	15.355
40	15.748	16.142	16.536	16.929	17.323	17.717	18.111	18.504	18.898	19.292
50	19.685	20.079	20.473	20.867	21.260	21.650	22.048	22.441	22.835	23.229
60	23.622	24.016	24.410	24.804	25.197	25.591	25.985	26.378	26.772	27.166
70	27.560	27.950	28.347	28.741	29.134	29.528	29.922	30.316	30.709	31.103
80	31.497	31.890	32.284	32.678	33.071	33.465	33.859	34.253	34.646	35.040
90	35.434	35.827	36.221	36.615	37.009	37.402	37.796	38.190	38.583	38.977
100	39.370	39.764	40.158	40.552	40.945	41.339	41.733	42.126	42.520	42.914

1 inch = 2.540005 centimeters; 1 centimeter = 0.397 inch.

TABLE 4—CUBIC INCHES TO CUBIC CENTIMETERS

	0	1	2	3	4	5	6	7	8	9
0		16.38	32.77	49.16	65.55	81.93	98.32	114.71	131.09	147.48
10	163.87	180.26	196.65	213.04	229.43	245.81	262.19	278.58	294.88	311.35
20	327.73	344.12	360.50	376.89	393.27	409.66	426.05	442.44	458.74	475.21
30	491.59	507.99	524.37	540.76	557.14	573.53	569.92	606.31	622.61	639.08
40	655.46	671.85	688.23	704.52	721.00	737.39	753.78	770.17	786.47	802.94
50	819.33	835.72	851.10	868.49	884.87	901.26	917.65	934.04	950.34	966.81
60	983.20	999.59	1016.0	1032.4	1048.7	1065.1	1081.5	1097.9	1114.2	1130.7
70	1147.1	1163.5	1179.9	1196.3	1212.6	1229.0	1245.4	1261.8	1278.1	1294.6
80	1310.9	1327.3	1343.7	1360.1	1374.6	1392.8	1409.2	1425.6	1441.9	1458.4
90	1474.8	1491.2	1507.6	1524.0	1540.3	1556.7	1573.1	1589.5	1605.8	1622.3
100	1638.7	1655.1	1671.5	1687.9	1704.2	1720.6	1737.0	1753.4	1769.7	1786.2

TABLE 5—CUBIC CENTIMETERS TO CUBIC INCHES

	0	1	2	3	4	5	6	7	8	9
0		0.0610	0.1221	0.1831	0.2441	0.3051	0.3661	0.4272	0.4882	0.5492
10	0.6102	0.6712	0.7323	0.7933	0.8543	0.9153	0.9763	1.0374	1.0984	1.1594
20	1.2205	1.2815	1.3426	1.4036	1.4646	1.5256	1.5866	1.6477	1.7087	1.7697
30	1.8308	1.8918	1.9529	2.0139	2.0749	2.1359	2.1964	2.2580	2.3190	2.3800
40	2.4410	2.5020	2.5631	2.6241	2.6851	2.7461	2.8071	2.8682	2.9292	2.9902
50	3.0513	3.1123	3.1734	3.2344	3.2954	3.3564	3.4174	3.4785	3.5395	3.6005
60	3.6615	3.7225	3.7836	3.8446	4.9056	3.9066	4.0276	4.0887	4.1497	4.2107
70	4.2718	4.3328	4.3939	4.4549	5.5159	4.5769	4.6379	4.6990	4.7600	4.8210
80	4.8820	4.9430	5.0041	5.0651	5.1261	5.1871	5.2481	5.3092	5.3702	5.4312
90	5.4923	5.5533	5.6144	5.6754	5.7364	5.7974	5.8584	5.9195	5.9805	6.0415
100	6.1025	6.1635	6.2246	6.2856	6.3466	6.4076	6.4686	6.5297	6.5907	6.6517

1 cubic inch = 16.3872 cubic centimeters; 1 cubic centimeter 0.061023 cubic inch.

TABLE 6—MILES TO KILOMETERS

Miles	0	1	2	3	4	5	6	9	8	9
	kilom	kilom	kilom	kilom	kilom	kilom	kilom	kilom	kilom	kilom
0		1.6093	3.2186	4.8279	6.4372	8.0465	79.6558	11.265	12.874	14.485
10	16.093	17.702	19.312	20.921	22.530	24.139	25.749	27.358	28.967	30.577
20	32.186	33.795	35.406	37.104	38.623	40.392	41.842	43.451	45.060	46.670
30	48.279	49.888	51.498	53.107	54.716	56.325	57.935	59.544	61.153	62.763
40	64.372	65.981	67.591	69.200	70.809	72.418	74.028	75.637	77.246	78.856
50	80.465	82.074	83.684	85.293	86.902	88.511	90.121	91.370	93.339	94.949
60	96.558	98.167	99.777	101.39	102.99	104.60	106.21	107.82	109.43	111.04
70	112.65	114.26	115.87	117.48	119.08	120.69	122.30	123.91	125.52	127.13
80	128.74	130.35	131.96	133.57	135.17	136.78	138.39	140.00	141.61	143.22
90	144.85	146.44	148.05	149.66	151.26	152.87	154.48	156.09	157.70	159.31
100	160.93	162.53	164.14	165.75	167.35	168.96	170.57	172.18	173.79	175.40

TABLE 7—KILOMETERS TO MILES

Kilom	0	1	2	3	4	5	6	7	8	9
	mi	mi	mi	mi	mi	mi	mi	mi	mi	mi
0		0.6214	1.2427	1.8641	2.4855	3.1069	3.7282	4.3497	4.9711	5.5924
10	6.2138	6.8352	7.4565	8.0780	8.6994	9.3208	9.9421	10.562	11.185	11.805
20	12.427	13.049	13.670	14.292	14.913	15.534	16.156	16.776	17.399	18.019
30	18.641	19.263	19.884	20.506	21.127	21.748	22.370	22.990	23.613	24.233
40	24.855	25.477	26.098	26.720	27.341	27.962	28.584	29.204	29.827	30.447
50	31.069	31.690	32.311	32.933	33.554	34.175	34.797	35.417	36.040	36.660
60	37.282	37.904	38.525	39.147	39.768	40.389	40.011	41.631	42.254	42.874
70	43.497	44.118	44.739	45.361	45.982	46.603	47.225	47.845	48.468	49.088
80	49.711	50.332	50.953	51.575	52.196	52.817	53.439	54.059	54.682	55.303
90	55.924	56.545	57.166	57.788	58.409	59.030	59.652	60.272	60.895	61.515.
100	62.138	62.759	63.380	64.002	64.623	65.244	65.866	66.486	67.109	67.729

1 mi. = 1.609347 kilometers; 1 kilometer = 0.62137 mile.

TABLE 8—FEET TO METERS

	0	1	2	3	4	5	6	7	8	9
0		0.305	0.610	0.914	1.219	1.524	1.829	2.133	2.438	2.743
10	3.048	3.353	3.658	3.962	4.267	4.572	4.877	5.181	5.486	5.791
20	6.096	6.401	6.706	7.010	7.315	7.620	7.925	8.229	8.534	8.839
30	9.144	9.449	9.753	10.058	10.363	10.668	10.972	11.277	11.582	11.887
40	12.192	12.496	12.801	13.106	13.411	13.716	14.020	14.325	14.630	14.935
50	15.239	15.544	15.849	16.154	16.459	16.763	17.068	17.373	17.678	17.983
60	18.287	18.592	18.897	19.202	19.507	19.811	20.116	20.421	20.726	21.031
70	21.335	21.640	21.945	22.250	22.555	22.859	23.164	23.469	23.774	24.079
80	24.383	24.688	24.993	25.298	25.603	25.907	26.212	26.517	26.822	27.126
90	27.431	27.736	28.041	28.346	28.651	28.955	29.260	29.565	29.870	30.174
100	30.479									

TABLE 9—METERS TO FEET

	0	1	2	3	4	5	6	7	8	9
0		3.281	6.562	9.843	13.123	16.404	19.685	22.966	26.247	29.528
10	32.808	36.089	39.370	42.651	45.932	42.213	52.494	55.775	59.056	62.337
20	65.617	68.897	72.178	75.459	78.741	82.022	85.303	88.584	91.865	95.146
30	98.425	101.71	104.99	108.27	111.55	114.83	118.11	121.39	124.67	127.96
40	131.23	134.51	137.79	141.08	144.36	147.64	150.92	154.20	157.48	160.76
50	164.04	167.32	170.60	173.88	177.17	180.45	183.73	187.01	190.29	193.57
60	196.85	200.13	203.41	206.69	209.98	213.26	216.54	219.82	223.10	226.38
70	229.66	232.94	236.22	239.50	242.79	246.07	249.35	252.63	255.91	259.19
80	262.47	265.75	269.03	272.31	275.60	278.88	282.16	285.44	288.72	292.00
90	295.27	298.56	301.84	305.12	308.40	311.69	314.97	318.25	321.53	324.81
100	328.08									

1 foot = 0.3048006 meter; 1 meter = 3.280833 feet.

TABLE 10—BAROMETER INCHES TO MILLIMETERS

Inches	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
0.0	0.00	0.25	0.51	0.76	1.02	1.27	1.52	1.78	2.03	2.29
0.1	2.54	2.79	3.05	3.30	3.56	3.81	4.06	4.32	4.57	4.83
0.2	5.08	5.33	5.59	5.84	6.10	6.35	6.60	6.86	7.11	7.37
0.3	7.62	7.87	8.13	8.38	8.64	8.89	9.14	9.40	9.65	9.91
0.4	10.16	10.41	10.67	10.92	11.18	11.43	11.68	11.94	12.19	12.45
0.5	12.70	12.95	13.21	13.46	13.72	13.97	14.22	14.48	14.73	14.99
0.6	15.24	15.49	15.75	16.00	16.26	16.51	16.76	17.02	17.27	17.53
0.7	17.78	18.03	18.29	18.54	18.80	19.05	19.30	19.56	19.81	20.07
0.8	20.32	20.57	20.83	21.08	21.34	21.59	21.84	22.10	22.35	22.61
0.9	22.86	23.11	23.37	23.62	23.88	24.13	24.38	24.64	24.89	25.15

Proportionate Parts

in 1.00	in 2.00	in 3.00	in 4.00	in 5.00	in 6.00	in 7.00	in 8.00	in 9.00	in 10.00	in 20.00	in 30.00
mm 25.40	mm 50.80	mm 76.20	mm 101.60	mm 127.00	mm 152.40	mm 177.50	mm 203.20	mm 228.60	mm 254.00	mm 508.00	mm 762.00

in 0.001	in 0.002	in 0.003	in 0.004	in 0.005	in 0.006	in 0.007	in 0.008	in 0.009	in 0.01
mm 0.025	mm 0.051	mm 0.076	mm 0.102	mm 0.127	mm 0.152	mm 0.178	mm 0.203	mm 0.229	mm 0.254

TABLE 11—BAROMETER MILLIMETERS TO INCHES

Milli-meters	0	1	2	3	4	5	6	7	8	9
	in	in	in	in	in	in	in	in	in	in
0	0.0000	0.0394	0.0787	0.1181	0.1575	0.1968	0.2362	0.2756	0.3150	0.3543
10	0.3937	0.4331	0.4724	0.5118	0.5512	0.5906	0.6299	0.6693	0.7087	0.7480
20	0.7874	0.8268	0.8661	0.9055	0.9449	0.9842	1.0236	1.0630	1.1024	1.1417
30	1.1811	1.2205	1.2598	1.2992	1.3386	1.3780	1.4173	1.4567	1.4961	1.5354
40	1.5748	1.6142	1.6535	1.6929	1.7323	1.7716	1.8110	1.8504	1.8898	1.9291
50	1.9685	2.0079	2.0472	2.0866	2.1260	2.1654	2.2047	2.2441	2.2835	2.3228
60	2.3622	2.4016	2.4409	2.4803	2.5197	2.5590	2.5984	2.6378	2.6772	2.7165
70	2.7559	2.7953	2.8346	2.8740	2.9134	2.9528	2.9921	3.0315	3.0709	3.1102
80	3.1496	3.1890	3.2283	3.2677	3.3071	3.3464	3.3858	3.4252	3.4646	3.5039
90	3.5433	3.5828	3.6220	3.6614	3.7008	3.7402	3.7795	3.8189	3.8583	3.8976

Proportionate Parts	mm 100	mm 200	mm 300	mm 400	mm 500	mm 600	mm 700	mm 800		
	in 3.937	in 7.874	in 11.811	in 15.748	in 19.685	in 23.622	in 27.559	in 31.496		
	mm 0.1	mm 0.2	mm 0.3	mm 0.4	mm 0.5	mm 0.6	mm 0.7	mm 0.8	mm 0.9	mm 1.0
	in 0.0039	in 0.0079	in 0.0118	in 0.0157	in 0.0197	in 0.0236	in 0.0276	in 0.0315	in 0.0354	in 0.0394
	mm 0.01	mm 0.02	mm 0.03	mm 0.04	mm 0.05	mm 0.06	mm 0.07	mm 0.08	mm 0.09	mm 0.1
	in 0.0004	in 0.0008	in 0.0012	in 0.0016	in 0.0020	in 0.0024	in 0.0028	in 0.0031	in 0.0035	in 0.0039

TABLE 12—BAROMETER INCHES TO KILOBARS

31.00	1049.8	30.80	1043.0	30.60	1036.2	30.40	1029.5	30.20	1022.7	30.00	1015.9	29.80	1009.1
30.99	1049.5	30.79	1042.7	30.59	1035.9	30.39	1029.1	30.19	1022.4	29.99	1015.6	29.79	1008.8
30.98	1049.1	30.78	1042.3	30.58	1035.6	30.38	1028.8	30.18	1022.0	29.98	1015.2	29.78	1008.5
30.97	1049.8	30.77	1042.0	30.57	1035.2	30.37	1028.4	30.17	1021.7	29.97	1014.9	29.77	1008.1
30.96	1048.4	30.76	1041.7	30.56	1034.9	30.36	1028.1	30.16	1021.3	29.96	1014.0	29.76	1007.8
30.95	1048.1	30.75	1041.3	30.55	1034.5	30.35	1027.8	30.15	1021.0	29.95	1014.2	29.75	1007.5
30.94	1047.8	30.74	1041.0	30.54	1034.2	30.34	1027.4	30.14	1020.7	29.94	1013.9	29.74	1007.1
30.93	1047.4	30.73	1040.6	30.53	1033.9	30.33	1027.1	30.13	1020.3	29.93	1013.5	29.73	1006.8
30.92	1047.1	30.72	1040.3	30.52	1033.5	30.32	1026.8	30.12	1020.0	29.92	1013.2	29.72	1006.4
30.91	1046.7	30.71	1040.0	30.51	1033.2	30.31	1026.4	30.11	1019.6	29.91	1012.9	29.71	1006.1
30.90	1046.4	30.70	1039.6	30.50	1032.9	30.30	1026.1	30.10	1019.3	29.90	1012.5	29.70	1005.8
30.89	1046.1	30.69	1039.3	30.49	1032.5	30.29	1025.7	30.09	1019.0	29.89	1012.2	29.69	1005.4
30.88	1045.7	30.68	1038.9	30.48	1032.2	30.28	1025.4	30.08	1018.6	29.88	1011.9	29.68	1005.1
30.87	1045.4	30.67	1038.6	30.47	1031.8	30.27	1025.1	30.07	1018.3	29.87	1011.5	29.67	1004.7
30.86	1045.0	30.66	1038.3	30.46	1031.5	30.26	1024.7	30.06	1018.0	29.86	1011.2	29.66	1004.4
30.85	1044.7	30.65	1037.9	30.45	1031.2	30.25	1024.4	30.05	1017.6	29.85	1010.8	29.65	1004.1
30.84	1044.4	30.64	1037.6	30.44	1030.8	30.24	1024.0	30.04	1017.3	29.84	1010.5	29.64	1003.7
30.83	1044.0	30.63	1037.3	30.43	1030.5	30.23	1023.7	30.03	1016.9	29.83	1010.2	29.63	1003.4
30.82	1043.7	30.62	1036.9	30.42	1030.1	30.22	1023.4	30.02	1016.6	29.82	1009.8	29.62	1003.1
30.81	1043.3	30.61	1036.6	30.41	1029.8	30.21	1023.0	30.01	1016.3	29.81	1009.5	29.61	1002.7

TABLE 12—BAROMETER INCHES TO KILOBARS—*Continued*

29.60	1002.4	29.40	995.6	29.20	988.8	29.00	982.1	28.80	975.3	28.60	968.5
29.59	1002.0	29.39	995.3	29.19	988.5	28.99	981.7	28.79	974.9	28.59	968.2
29.58	1001.7	29.38	994.9	29.18	988.2	28.98	981.4	28.78	974.6	28.58	967.8
29.57	1001.4	29.37	994.6	29.17	987.8	28.97	981.0	28.77	974.3	28.57	967.5
29.56	1001.0	29.36	994.2	29.16	987.5	28.96	980.7	28.76	973.9	28.56	957.2
29.55	1000.7	29.35	993.9	29.15	987.1	28.95	980.4	28.75	973.6	28.55	966.8
29.54	1000.4	29.34	993.6	29.14	986.8	28.94	980.0	28.74	973.2	28.54	966.5
29.53	1000.0	29.33	993.2	29.13	986.5	28.93	979.7	28.73	972.9	28.53	966.1
29.52	999.7	29.32	992.9	29.12	986.1	28.92	979.3	28.72	972.6	28.52	965.8
29.51	999.3	29.31	992.6	29.11	985.8	28.91	979.1	28.71	972.2	28.51	965.5
29.50	999.0	29.30	992.2	29.10	985.4	28.90	978.6	28.70	971.9	28.50	965.1
29.49	998.6	29.29	991.9	29.09	985.1	28.89	978.3	28.69	971.6	28.49	964.8
29.48	998.3	29.28	991.5	29.08	984.8	28.88	978.0	28.68	971.2	28.48	964.4
29.47	998.0	29.27	991.2	29.07	984.4	28.87	977.7	28.67	970.9	28.47	964.1
29.46	997.6	29.26	990.9	29.06	984.1	28.86	977.3	28.66	970.5	28.46	963.8
29.45	997.0	29.25	990.5	29.05	983.7	28.85	977.0	28.65	970.2	28.45	963.4
29.44	996.9	29.24	990.2	29.04	984.4	28.84	976.6	28.64	969.9	28.44	963.1
29.43	996.6	29.23	989.8	29.03	983.1	28.83	976.3	28.63	969.5	28.43	962.8
29.42	996.3	29.22	989.5	29.02	982.7	28.82	976.0	28.62	969.2	28.42	962.4
29.41	995.9	29.21	989.2	29.01	982.4	28.81	975.6	28.61	968.8	28.41	962.1

TABLE 12—BAROMETER INCHES TO KILOBARS—*Continued*

28.40	961.7	28.20	955.0	28.00	948.2	27.80	941.4	27.60	934.6	27.40	927.9
28.39	961.4	28.19	954.6	27.99	947.8	27.79	941.1	27.59	934.3	27.39	927.5
28.38	961.1	28.18	954.3	27.98	947.5	27.78	940.7	27.58	934.0	27.38	927.2
28.37	960.7	28.17	953.9	27.97	947.2	27.77	940.4	27.57	933.6	27.37	926.9
28.36	960.4	28.16	953.6	27.96	946.8	27.76	940.1	27.56	933.3	27.36	926.5
28.35	960.0	28.15	953.3	27.95	946.5	27.75	939.7	29.55	933.0	27.35	926.2
28.34	959.7	28.14	952.9	27.94	946.1	27.74	939.4	27.54	932.6	27.34	925.8
28.33	959.4	28.13	952.6	27.93	945.8	27.73	939.0	27.53	932.3	27.33	925.5
28.32	959.1	28.12	952.3	27.92	945.5	27.72	938.7	27.52	931.9	27.32	925.2
28.31	958.7	28.11	951.9	27.91	945.1	27.71	938.4	27.51	931.6	27.31	924.8
28.30	958.3	28.10	951.6	27.90	944.8	27.70	938.0	27.50	931.3	27.30	924.5
28.29	958.0	28.09	951.2	27.89	944.4	27.69	937.7	27.49	930.9	27.29	924.1
28.28	957.7	28.08	950.9	27.88	944.1	27.68	937.4	27.48	930.6	27.28	923.8
28.27	957.3	28.07	950.6	27.87	943.8	27.67	937.0	27.47	930.2	27.27	923.5
28.26	957.0	28.06	950.2	27.86	943.4	27.66	936.7	27.46	929.9	27.26	923.1
28.25	956.7	28.05	949.9	27.85	943.1	27.65	936.3	27.45	929.6	27.25	922.8
28.24	956.3	28.04	949.5	27.84	942.8	27.64	936.0	27.44	929.2	27.24	922.5
28.23	956.0	28.03	949.2	27.83	942.4	27.63	935.7	27.43	928.9	27.23	922.1
28.22	955.6	28.02	948.9	27.82	942.1	27.62	935.3	27.42	928.5	27.22	921.8
28.21	955.3	28.01	948.5	27.81	941.7	27.61	935.0	27.41	928.2	27.21	921.4

TABLE 12—BAROMETER INCHES TO KILOBARS—*Continued*

27.20	921.1	27.00	914.3	26.80	907.6	26.60	900.8	26.40	894.0	26.20	887.2
27.19	920.8	26.99	914.0	26.79	907.2	26.59	900.4	26.39	893.7	26.19	886.9
27.18	920.4	26.98	913.6	26.78	906.9	26.58	900.1	26.38	893.3	26.18	886.6
27.17	920.1	26.97	913.3	26.77	906.5	26.57	899.8	26.37	893.0	26.17	886.2
27.16	919.7	26.96	913.0	26.76	906.2	26.56	899.4	26.36	892.7	26.16	885.9
27.15	919.4	26.95	912.6	26.75	905.9	26.55	899.1	26.35	892.3	26.15	885.5
27.14	919.1	26.94	912.3	26.74	905.5	26.54	898.7	26.34	892.0	26.14	885.2
27.13	918.7	26.93	912.0	26.73	905.2	26.53	898.4	26.33	891.6	26.13	884.9
27.12	918.4	26.92	911.6	26.72	904.8	26.52	898.1	26.32	891.3	26.12	884.5
27.11	918.1	26.91	911.3	26.71	904.5	26.51	897.7	26.31	891.0	26.11	884.2
27.10	917.7	26.90	910.9	26.70	904.2	26.50	897.4	26.30	890.6	26.10	883.8
27.09	917.4	26.89	910.6	26.69	903.8	26.49	897.1	26.29	890.3	26.09	883.5
27.08	917.0	26.88	910.3	26.68	903.5	26.48	896.7	26.28	889.9	26.08	883.2
27.07	916.7	26.87	909.9	26.67	903.2	26.47	896.4	26.27	889.6	26.07	882.8
27.06	916.4	26.86	909.6	26.66	902.8	26.46	896.0	26.26	889.3	26.06	882.5
27.05	916.0	26.85	909.2	26.65	902.5	26.45	895.7	26.25	888.9	26.05	882.2
27.04	915.7	26.84	908.9	26.64	902.1	26.44	895.4	26.24	888.6	26.04	881.8
27.03	915.3	26.83	908.6	26.63	901.8	26.43	895.0	26.23	888.3	26.03	881.5
27.02	915.0	26.82	908.2	26.62	901.5	26.42	894.7	26.22	887.9	26.02	881.1
27.01	914.7	26.81	907.9	26.61	901.1	26.41	894.3	26.21	887.6	26.01	880.8

For the extension of this table multiply the number of inches and hundredths by 33.866, the value of 1 inch in kilobars.

1 millimeter = 1.3332 kilobars. 1000 kilobars = 29.5306 barometer inches, or 750.076 millimeters.

TABLE 13—MILES PER HOUR TO METERS PER SECOND

Miles per hour	0	1	2	3	4	5	6	7	8	9
	meters per sec	meters per sec	meters per sec	meters per sec	meters per sec	meters per sec	meters per sec	meters per sec	meters per sec	meters per sec
0	0.00	0.45	0.89	1.34	1.79	2.24	2.68	3.13	3.58	4.02
10	4.47	4.92	5.36	5.81	6.26	6.71	7.15	7.60	8.05	8.49
20	8.94	9.39	9.83	10.28	10.73	11.18	11.62	12.07	12.52	12.96
30	13.41	13.86	14.31	14.75	15.20	15.65	16.09	16.54	16.99	17.43
40	17.88	18.33	18.78	19.22	19.67	20.12	20.56	21.01	21.46	21.90
50	22.35	22.80	23.25	23.69	24.14	24.59	25.03	25.48	25.93	26.37
60	26.82	27.27	27.72	28.16	28.61	29.06	29.50	29.95	30.40	30.85
70	31.29	31.74	32.19	32.63	33.08	33.53	33.98	34.42	34.87	35.32
80	35.76	36.21	36.66	37.10	37.55	38.00	38.44	38.89	39.34	39.79
90	40.23	40.68	41.13	41.57	42.02	42.47	42.92	43.36	43.81	44.26
100	44.70	45.15	45.60	46.04	46.49	46.94	47.39	47.83	48.28	48.73
110	49.17	49.62	50.07	50.51	50.96	51.41	51.86	52.30	52.75	53.20
120	53.64	54.09	54.54	54.98	55.43	55.88	56.33	56.77	57.22	57.67
130	58.12	58.56	59.01	59.46	59.90	60.35	60.80	61.24	61.69	62.14
140	62.59	63.03	63.48	63.93	64.37	64.82	65.27	65.72	66.16	66.61
150	67.06	67.50	67.95	68.40	68.84	69.39	69.84	70.29	70.73	71.18

1 mile per hour = 0.4470409 meter per second; 1 meter per second = 3.6 kilometers per hour; 1 kilometer per hour = $\frac{10}{36}$ meter per second.

1 mile per hour = $\frac{44}{30}$ foot per second; 1 foot per second = $\frac{30}{44}$ mile per hour.

TABLE 14—METERS PER SECOND TO MILES PER HOUR

Meters per sec	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	miles per hour	miles per hour	miles per hour	miles per hour	miles per hour	miles per hour	miles per hour	miles per hour	miles per hour	miles per hour
0	0.0	0.2	0.4	0.7	0.9	1.1	1.3	1.6	1.8	2.0
1	2.2	2.5	2.7	2.9	3.1	3.4	3.6	3.8	4.0	4.3
2	4.5	4.7	4.9	5.1	5.4	5.6	5.8	6.0	6.3	6.5
3	6.7	6.9	7.2	7.4	7.6	7.8	8.1	8.3	8.5	8.7
4	8.9	9.2	9.4	9.6	9.8	10.1	10.3	10.5	10.7	11.0
5	11.2	11.4	11.6	11.9	12.1	12.3	12.5	12.8	13.0	13.2
6	13.4	13.6	13.9	14.1	14.3	14.5	14.8	15.0	15.2	15.4
7	15.7	15.9	16.1	16.3	16.6	16.8	17.0	17.2	17.4	17.7
8	17.9	18.1	18.3	18.6	18.8	19.0	19.2	19.5	19.7	19.9
9	20.1	20.4	20.6	20.8	21.0	21.3	21.5	21.7	21.9	22.1
10	22.4	22.6	22.8	23.0	23.3	23.5	23.7	23.9	24.2	24.4
20	44.7	45.0	45.2	45.4	45.6	45.9	46.1	46.3	46.5	46.8
30	67.1	67.3	67.6	67.8	68.0	68.2	68.5	68.7	68.9	69.1
40	89.5	89.7	89.9	90.2	90.4	90.6	90.8	91.0	91.3	91.5
50	111.8	112.1	112.3	112.5	112.7	113.0	113.2	113.4	113.6	113.9
60	134.2	134.4	134.7	134.9	135.1	135.3	135.6	135.8	136.0	136.2

1 meter per second = 2.236932 miles per hour.

TABLE 15—COMPARISON OF APPROXIMATE ABSOLUTE, CENTIGRADE AND FAHRENHEIT THERMOMETER SCALES

Abs°	C°	F°	Abs°	C°	F°	Abs°	C°	F°	Abs°	C°	F°	Abs°	C°	F°
373	100	212.0	348	75	167.0	323	50	122.0	298	25	77.0	273	± 0	32.0
372	99	210.2	347	74	165.2	322	49	120.2	297	24	75.2	272	− 1	30.2
371	98	208.4	346	73	163.4	321	48	118.4	296	23	73.4	271	− 2	28.4
370	97	206.6	345	72	161.6	320	47	116.6	295	22	71.6	270	− 3	26.6
369	96	204.8	344	71	159.8	319	46	114.8	294	21	69.8	269	− 4	24.8
368	95	203.0	343	70	158.0	318	45	113.0	293	20	68.0	268	− 5	23.0
367	94	201.2	342	69	156.2	317	44	111.2	292	19	66.2	267	− 6	21.2
366	93	199.4	341	68	154.4	316	43	109.4	291	18	64.4	266	− 7	19.4
365	92	197.6	340	67	152.6	315	42	107.6	290	17	62.6	265	− 8	17.6
364	91	195.8	339	66	150.8	314	41	105.8	289	16	60.8	264	− 9	15.8
363	90	194.0	338	65	149.0	313	40	104.0	288	15	59.0	263	−10	14.0
362	89	192.2	337	64	147.2	312	39	102.2	287	14	57.2	262	−11	12.2
361	88	190.4	336	63	145.4	311	38	100.4	286	13	55.4	261	−12	10.4
360	87	188.6	335	62	143.6	310	37	98.6	285	12	53.6	260	−13	8.6
359	86	186.8	334	61	141.8	309	36	96.8	284	11	51.8	259	−14	6.8
358	85	185.0	333	60	140.0	308	35	95.0	283	10	50.0	258	−15	5.0
357	84	183.2	332	59	138.2	307	34	93.2	282	9	48.2	257	−16	3.2
356	83	181.4	331	58	136.4	306	33	91.4	281	8	46.4	256	−17	1.4
355	82	179.6	330	57	134.6	305	32	89.6	280	7	44.6	255	−18	− 0.4
354	81	177.8	329	56	132.8	304	31	87.8	279	6	42.8	254	−19	− 2.2
353	80	176.0	328	55	131.0	303	30	86.0	278	5	41.0	253	−20	− 4.0
352	79	174.2	327	54	129.2	302	29	84.2	277	4	39.2	252	−21	− 5.8
351	78	172.4	326	53	127.4	301	28	82.4	276	3	37.4	251	−22	− 7.6
350	77	170.6	325	52	125.6	300	27	80.6	275	2	35.6	250	−23	− 9.4
349	76	168.8	324	51	123.8	299	26	78.8	274	+1	33.8	249	−24	−11.2

TABLE 15—COMPARISON OF APPROXIMATE ABSOLUTE, CENTIGRADE AND FAHRENHEIT THERMOMETER SCALES—*Continued*

Abs°	C°	F°	Abs°	C°	F°	Abs°	C°	F°	Abs°	C°	F°	Abs°	C°	F°
248	−25	−13.0	223	−50	−58.0	198	−75	−103.0	173	−100	−148.0	148	−125	−193.0
247	−26	−14.8	222	−51	−59.8	197	−76	−104.8	172	−101	−149.8	147	−126	−194.8
246	−27	−16.6	221	−52	−61.6	196	−77	−106.6	171	−102	−151.6	146	−127	−196.6
245	−28	−18.4	220	−53	−63.4	195	−78	−108.4	170	−103	−153.4	145	−128	−198.4
244	−29	−20.2	219	−54	−65.2	194	−79	−110.2	169	−104	−155.2	144	−129	−200.2
243	−30	−22.0	218	−55	−67.0	193	−80	−112.0	168	−105	−157.0	143	−130	−202.0
242	−31	−23.8	217	−56	−68.8	192	−81	−113.8	167	−106	−158.8	142	−131	−203.8
241	−32	−25.6	216	−57	−70.6	191	−82	−115.6	166	−107	−160.6	141	−132	−205.6
240	−33	−27.8	215	−58	−72.4	190	−83	−117.4	165	−108	−162.4	140	−133	−207.4
239	−34	−29.2	214	−59	−74.2	189	−84	−119.2	164	−109	−164.2	139	−134	−209.2
238	−35	−31.0	213	−60	−76.0	188	−85	−121.0	163	−110	−166.0	138	−135	−211.0
237	−36	−32.8	212	−61	−77.8	187	−86	−122.8	162	−111	−167.8	137	−136	−212.8
236	−37	−34.6	211	−62	−79.6	186	−87	−124.6	161	−112	−169.6	136	−137	−214.6
235	−38	−36.4	210	−63	−81.4	185	−88	−126.4	160	−113	−171.4	135	−138	−216.4
234	−39	−38.2	209	−64	−83.2	184	−89	−128.2	159	−114	−173.2	134	−139	−218.2
233	−40	−40.0	208	−65	−85.0	183	−90	−130.0	158	−115	−175.0	133	−140	−220.0
232	−41	−41.6	207	−66	−86.8	182	−91	−131.8	157	−116	−176.8	132	−141	−221.8
231	−42	−43.6	206	−67	−88.6	181	−92	−133.6	156	−117	−178.6	131	−142	−223.6
230	−43	−45.4	205	−68	−90.4	180	−93	−135.4	155	−118	−184.0	130	−143	−225.4
229	−44	−47.2	204	−69	−92.2	179	−94	−137.2	154	−119	−182.0	129	−144	−227.2
228	−45	−49.0	203	−70	−94.0	178	−95	−139.0	153	−120	−184.0	128	−145	−229.0
227	−46	−50.8	202	−71	−95.8	177	−96	−140.8	152	−121	−185.8	127	−146	−230.8
226	−47	−52.6	201	−72	−97.6	176	−97	−142.6	151	−122	−187.6	126	−147	−232.6
225	−48	−54.4	200	−73	−99.4	175	−98	−144.4	150	−123	−189.4	125	−148	−234.4
224	−49	−56.2	199	−74	−101.2	174	−99	−146.2	149	−124	−191.2	124	−149	−236.2

TABLE 15—COMPARISON OF APPROXIMATE ABSOLUTE, CENTIGRADE AND FAHRENHEIT THERMOMETER SCALES—*Continued*

Abs°	C°	F°	Abs°	C°	F°	Abs°	C°	F°	Abs°	C°	F°	Abs°	C°	F°
123	−150	−238.0	98	−175	−283.0	73	−200	−328.0	48	−225	−373.0	23	−250	−418.0
122	−151	−239.8	97	−176	−284.8	72	−201	−329.8	47	−226	−374.8	22	−251	−419.8
121	−152	−241.6	96	−177	−286.6	71	−202	−331.6	46	−227	−376.6	21	−252	−421.6
120	−153	−243.4	95	−178	−288.4	70	−203	−333.4	45	−228	−378.4	20	−253	−423.4
119	−154	−245.2	94	−179	−290.2	69	−204	−335.2	44	−229	−380.2	19	−254	−425.2
118	−155	−247.0	93	−180	−292.0	68	−205	−337.0	43	−230	−382.0	18	−255	−427.0
117	−156	−248.8	92	−181	−293.8	67	−206	−338.8	42	−231	−383.8	17	−256	−428.8
116	−157	−250.6	91	−182	−295.6	66	−207	−340.6	41	−232	−385.6	16	−257	−430.6
115	−158	−252.4	90	−183	−297.4	65	−208	−342.4	40	−233	−387.4	15	−258	−432.4
114	−159	−254.2	89	−184	−299.2	64	−209	−344.2	39	−234	−389.2	14	−259	−434.2
113	−160	−256.0	88	−185	−301.0	63	−210	−346.0	38	−235	−391.0	13	−260	−436.0
112	−161	−257.8	87	−186	−302.8	62	−211	−347.8	37	−236	−392.8	12	−261	−437.8
111	−162	−259.6	86	−187	−304.6	61	−212	−349.6	36	−237	−394.6	11	−262	−439.6
110	−163	−261.4	85	−188	−306.4	60	−213	−351.4	35	−238	−396.4	10	−263	−441.4
109	−164	−263.2	84	−189	−308.2	59	−214	−353.2	34	−239	−398.2	9	−264	−443.2
108	−165	−265.0	83	−190	−310.0	58	−215	−355.0	33	−240	−400.0	8	−265	−445.0
107	−166	−266.8	82	−191	−311.8	57	−216	−356.8	32	−241	−401.8	7	−266	−446.8
106	−167	−268.6	81	−192	−313.6	56	−217	−358.6	31	−242	−403.6	6	−267	−448.6
105	−168	−270.4	80	−193	−315.4	55	−218	−360.4	30	−243	−405.4	5	−268	−450.4
104	−169	−272.2	79	−194	−317.2	54	−219	−362.2	29	−244	−407.2	4	−269	−452.2
103	−170	−274.0	78	−195	−319.0	53	−220	−364.0	28	−245	−409.0	3	−270	−454.0
102	−171	−275.8	77	−196	−320.8	52	−221	−365.8	27	−246	−410.8	2	−271	−455.8
101	−172	−277.6	76	−197	−322.6	51	−222	−367.6	26	−247	−412.6	1	−272	−457.6
100	−173	−279.4	75	−198	−324.4	50	−223	−369.4	25	−248	−414.4	0	−273	−459.4
99	−174	−281.2	74	−199	−326.2	49	−224	−371.2	24	−249	−416.2			

TABLE 16—FAHRENHEIT DEGREES TO CENTIGRADE DEGREES

F°	C°	F°	C°	F°	C°	F°	C°	F°	C°
−40	−40.0	12	−11.1	63	17.2	114	45.6	165	73.9
−39	−39.4	13	−10.6	64	17.8	115	46.1	166	74.4
−38	−38.9	14	−10.0	65	18.3	116	46.7	167	75.0
−37	−38.3	15	− 9.4	66	18.9	117	47.2	168	75.6
−36	−37.8	16	− 8.9	67	19.4	118	47.8	169	76.1
−35	−37.2	17	− 8.3	68	20.0	119	48.3	170	76.7
−34	−36.7	18	− 7.8	69	20.6	120	48.9	171	77.2
−33	−36.1	19	− 7.2	70	21.1	121	49.4	172	77.8
−32	−35.6	20	− 6.7	71	21.7	122	50.0	173	78.3
−31	−35.0	21	− 6.1	72	22.2	123	50.6	174	78.9
−30	−34.4	22	− 5.6	73	22.8	124	51.1	175	79.4
−29	−33.9	23	− 5.0	74	23.3	125	51.4	176	80.0
−28	−33.3	24	− 4.4	75	23.9	126	52.2	177	80.6
−27	−32.8	25	− 3.9	76	24.4	127	52.8	178	81.1
−26	−32.2	26	− 3.3	77	25.0	128	53.3	179	81.7
−25	−31.7	27	− 2.8	78	25.6	129	53.9	180	82.2
−24	−31.1	28	− 2.2	79	26.1	130	54.4	181	82.8
−23	−30.6	29	− 1.7	80	26.7	131	55.0	182	83.3
−22	−30.0	30	− 1.1	81	27.2	132	55.6	183	83.9
−20	−29.4	31	− 0.6	82	27.8	133	56.1	184	84.4
−19	−28.3	32	0.0	83	28.3	134	56.4	185	85.0
−18	−27.8	33	0.6	84	28.9	135	57.2	186	85.6
−17	−27.2	34	1.1	85	29.4	136	57.8	187	86.1
−16	−26.7	35	1.7	86	30.0	137	58.3	188	86.7
−15	−26.1	36	2.2	87	30.6	138	58.9	189	87.2
−14	−25.6	37	2.8	88	31.1	139	59.4	190	87.8
−13	−25.0	38	3.3	89	31.7	140	60.0	191	88.3
−12	−24.4	39	3.9	90	32.2	141	60.6	192	88.9
−11	−23.9	40	4.4	91	32.8	142	61.1	193	89.4
−10	−23.3	41	5.0	92	33.3	143	61.7	194	90.0
− 9	−22.8	42	5.6	93	33.9	144	62.2	195	90.6
− 8	−22.2	43	6.1	94	34.4	145	62.8	196	91.1
− 7	−21.7	44	6.7	95	35.0	146	63.3	197	91.7
− 6	−21.6	45	7.2	96	35.6	147	63.9	198	92.2
− 5	−20.6	46	7.8	97	36.1	148	64.4	199	92.8
− 4	−20.0	47	8.3	98	36.7	149	65.0	200	93.3
− 3	−19.4	48	8.9	99	37.2	150	65.6	201	93.9
− 2	−18.9	49	9.4	100	37.8	151	66.1	202	94.4
− 1	−18.3	50	10.0	101	38.3	152	66.7	203	95.0
0	−17.8	51	10.6	102	38.9	153	67.2	204	95.6
1	−17.2	52	11.1	103	39.4	154	67.8	205	96.1
2	−16.7	53	11.7	104	40.0	155	68.3	206	96.7
3	−16.1	54	12.2	105	40.6	156	68.9	207	97.2
4	−15.6	55	12.8	106	41.1	157	69.4	208	97.8
5	−15.0	56	13.3	107	41.7	158	70.0	209	98.3
6	−14.4	57	13.9	108	42.2	159	70.6	210	98.9
7	−13.9	58	14.4	109	42.8	160	71.1	211	99.4
8	−13.3	59	15.0	110	43.3	161	71.7	212	100.0
9	−12.8	60	15.6	111	43.9	162	72.2		
10	−12.2	61	16.1	112	44.4	163	72.8		
11	−11.7	62	16.7	113	45.0	164	73.3		

TABLE 17—BOILING POINT OF WATER (F) AS AFFECTED BY PRESSURE

P inches	t°	P inches	t°	P inches	t°	P inches	t°
16.79	184.0	19.96	192.0	23.59	200.0	27.73	208.0
16.97	184.5	20.18	192.5	23.84	200.5	28.00	208.5
17.16	185.0	20.39	193.0	24.08	201.0	28.69	209.0
17.35	185.5	20.61	193.5	24.33	201.5	28.56	209.5
17.54	186.0	20.82	194.0	24.58	202.0	28.85	210.0
17.74	186.5	21.05	194.5	24.83	202.5	29.15	210.5
17.93	187.0	20.26	195.0	25.08	203.0	29.42	211.0
18.12	187.5	20.49	195.5	25.33	203.5	29.71	211.5
18.32	188.0	21.71	196.0	25.59	204.0	30.00	212.0
18.52	188.5	21.95	196.5	25.86	204.5	30.30	212.5
18.72	189.0	22.17	197.0	26.11	205.0	30.59	213.0
18.92	189.5	22.41	197.5	26.38	205.5	30.89	213.5
19.13	190.0	22.64	198.0	26.64	206.0	31.10	214.0
19.33	190.5	22.89	198.5	26.91	206.5		
19.54	191.0	23.11	199.0	27.18	207.0		
19.74	191.5	23.36	199.5	27.45	207.5		

TABLE 18—BOILING POINT OF WATER (C) AS AFFECTED BY PRESSURE

P mm	t°	P mm	t°	P mm	t°	P mm	t°
680	96.92	710	98.11	740	99.26	770	100.37
682	97.00	712	98.18	742	99.33	772	100.44
684	97.08	714	98.26	744	99.41	774	100.51
685	97.12	715	98.30	745	99.44	775	100.55
686	97.16	716	98.34	746	99.48	776	100.58
688	97.24	718	98.42	748	99.56	778	100.66
690	97.32	720	98.49	750	99.63	780	100.73
692	97.40	722	98.57	752	99.70	782	100.80
694	97.48	724	98.65	754	99.78	784	100.87
695	97.52	725	98.69	755	99.82	785	100.91
696	97.56	726	98.72	756	99.85	786	100.94
698	97.63	728	98.80	758	99.93	788	101.02
700	97.71	730	98.88	760	100.00	790	101.09
702	97.79	732	98.95	762	100.04	792	101.16
704	97.87	734	99.03	764	100.11	794	101.23
705	97.91	735	99.07	765	100.18	795	101.26
706	97.95	736	99.10	766	100.22	796	101.30
708	98.03	738	99.18	768	100.29	798	101.37

Table 19—Quantity of Rainfall in Cu Ft and U S Gallons per Acre

Inches of rainfall	Cu ft per acre	Gallons per acre	Inches of rainfall	Cu ft per acre	Gallons per acre
0.01	36.3	271.5	0.10	363	2715.4
0.02	72.6	543	0.20	726	5430
0.03	108.9	815	0.30	1089	8146
0.04	145.2	1086	0.40	1452	10862
0.05	181.5	1358	0.50	1815	13577
0.06	217.8	1629	0.60	2718	16293
0.07	254.1	1900	0.70	2541	19007
0.08	290.4	2171	0.80	2904	21722
0.09	326.7	2442	0.90	3267	24438
0.10	363.0	2715	1.00	3630	27153

The U S or Queen Anne gallon used in the foregoing table contains 231 cu in or 0.1368 cu ft. The Imperial, or British gallon contains 277.3 cu in. To reduce U S to Imperial gallons multiply by 0.83⅓.

To find the quantity of rainfall per square mile, multiply the quantity per acre by 640.

One inch of rain per acre is at the rate of 113 tons per acre or 7320 tons per sq mi.

Table 20—Depth of Water in a Standard 8-inch Gauge Corresponding to the Weight of Snow or of Rain.

Weight Pounds	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	in	in	in	in	in	in	in	in	in	in
0.0	.00	.01	.01	.02	.02	.03	.03	.04	.04	.05
0.1	.06	.06	.07	.07	.08	.08	.09	.09	.10	.10
0.2	.11	.12	.12	.13	.13	.14	.14	.15	.15	.16
0.3	.17	.17	.18	.18	.19	.19	.20	.20	.21	.22
0.4	.22	.23	.23	.24	.24	.25	.25	.26	.26	.27
0.5	.28	.28	.29	.29	.30	.30	.31	.31	.32	.32
0.6	.33	.34	.34	.35	.35	.36	.36	.37	.38	.38
0.7	.39	.39	.40	.40	.41	.41	.42	.43	.43	.44
0.8	.44	.45	.45	.46	.46	.47	.47	.48	.49	.49
0.9	.50	.50	.51	.51	.52	.52	.53	.54	.54	.55

One pound equals 0.5507 in.

TABLE 21—WEIGHT OF A CUBIC FOOT OF SATURATED WATER VAPOR

Temp F	Grains Troy	Temp F	Grains Troy	Temp F	Grains Troy	Temp F	Grains Troy	Temp F	Grains Troy	Temp F	Grains Troy
−30	0.095	−5	0.377	20	1.244	45	3.436	70	8.066	95	17.305
−29	0.100	−4	0.391	21	1.301	46	3.563	71	8.329	96	17.812
−28	0.106	−3	0.411	22	1.362	47	3.693	72	8.600	97	18.330
−27	0.112	−2	0.433	23	1.425	48	3.828	73	8.879	98	18.863
−26	0.119	−1	0.455	24	1.490	49	3.965	74	9.165	99	19.407
−25	0.126	±0°	0.479	25	1.558	50	4.108	75	9.460	100	19.966
−24	0.134	+1	0.503	26	1.629	51	4.225	76	9.761	101	20.538
−23	0.141	2	0.529	27	1.703	52	4.407	77	10.072	102	21.123
−22	0.150	3	0.056	28	1.779	53	4.564	78	10.392	103	21.723
−21	0.158	4	0.584	29	1.859	54	4.725	79	10.720	104	22.337
−20	0.167	5	0.613	30	1.942	55	4.891	80	11.056	105	22.966
−19	0.176	6	0.644	31	2.028	56	5.062	81	11.401	106	23.611
−18	0.187	7	0.676	32	2.118	57	5.238	82	11.756	107	14.721
−17	0.197	8	0.709	33	2.200	58	5.420	83	12.121	108	24.946
−16	0.208	9	0.744	34	2.286	59	5.567	84	12.494	109	25.663
−15	0.220	10	0.780	35	2.375	60	5.800	85	12.878	110	26.343
−14	0.232	11	0.818	36	2.466	61	5.999	86	13.272	111	27.066
−13	0.244	12	0.858	37	2.560	62	6.203	87	13.676	112	27.807
−12	0.258	13	0.900	38	2.658	63	6.413	88	14.090	113	28.563
−11	0.272	14	0.943	39	2.759	64	6.630	89	14.515	114	29.338
−10	0.286	15	0.988	40	2.863	65	6.852	90	15.951	115	30.130
− 9	0.302	16	1.035	41	2.970	66	7.082	91	15.400	116	30.940
− 8	0.318	17	1.084	42	3.082	67	7.317	92	15.858	117	31.768
− 7	0.335	18	1.135	43	3.196	68	7.560	93	16.328	118	32.616
− 6	0.353	19	1.189	44	3.315	69	7.809	94	16.810	119	33.842

The foregoing values accord with the determinations of Marks and Davis, 1909. The specific gravity of saturated vapor at 32° F (0° C) is 0.6238; at 50° F (10° C) 0.6241; at 100° F (38° C) 0.6256.

TABLE 22—EXPANSION OF AIR FROM THE FREEZING TO THE BOILING POINT OF WATER

t°	V	t°	V	t°	V	t°	V	t°	V	t°	V
32	1000.000	52	1040.700	72	1081.400	92	1122.100	112	1162.800	132	1203.500
33	1002.035	53	1042.735	73	1083.435	93	1124.135	113	1164.835	133	1205.535
34	1004.070	54	1044.770	74	1085.470	94	1126.170	114	1166.870	134	1207.570
35	1006.105	55	1046.805	75	1087.505	95	1128.205	115	1168.905	135	1209.610
36	1008.140	56	1048.840	76	1089.540	96	1130.240	116	1170.940	140	1219.780
37	1010.175	57	1050.875	77	1091.575	97	1132.275	117	1172.975	145	1229.955
38	1012.210	58	1052.910	78	1093.610	98	1134.310	118	1175.010	150	1240.130
39	1014.245	59	1054.945	79	1095.645	99	1136.345	119	1177.045	155	1250.305
40	1016.280	60	1056.980	80	1097.680	100	1138.380	120	1179.080	160	1260.480
41	1018.315	61	1059.015	81	1099.715	101	1140.415	121	1181.115	165	1270.655
42	1020.350	62	1061.050	82	1101.750	102	1142.450	122	1183.150	170	1280.830
43	1022.385	63	1063.085	83	1103.785	103	1144.485	123	1185.185	175	1291.005
44	1024.420	64	1065.120	84	1105.820	104	1146.520	124	1187.220	180	1301.180
45	1026.455	65	1067.155	85	1107.855	105	1148.555	125	1189.255	185	1311.355
46	1028.490	66	1069.190	86	1109.890	106	1150.590	126	1191.290	190	1321.530
47	1030.525	67	1071.225	87	1111.925	107	1152.625	127	1193.325	195	1331.705
48	1032.560	68	1073.260	88	1113.960	108	1154.660	128	1195.360	200	1341.880
49	1034.595	64	1075.295	89	1115.995	109	1156.695	129	1199.395	205	1352.055
50	1036.630	70	1077.330	90	1118.030	110	1158.730	130	1199.430	210	1362.230
51	1038.665	71	1079.365	91	1120.065	111	1160.765	131	1201.465	212	1364.255

Approximate difference for each degree F = 2.035

TABLE 21—WEIGHT OF A CUBIC FOOT OF SATURATED WATER VAPOR

Temp F	Grains Troy	Temp F	Grains Troy	Temp F	Grains Troy	Temp F	Grains Troy	Temp F	Grains Troy	Temp F	Grains Troy
−30	0.095	−5	0.377	20	1.244	45	3.436	70	8.066	95	17.305
−29	0.100	−4	0.391	21	1.301	46	3.563	71	8.329	96	17.812
−28	0.106	−3	0.411	22	1.362	47	3.693	72	8.600	97	18.330
−27	0.112	−2	0.433	23	1.425	48	3.828	73	8.879	98	18.863
−26	0.119	−1	0.455	24	1.490	49	3.965	74	9.165	99	19.407
−25	0.126	±0°	0.479	25	1.558	50	4.108	75	9.460	100	19.966
−24	0.134	+1	0.503	26	1.629	51	4.225	76	9.761	101	20.538
−23	0.141	2	0.529	27	1.703	52	4.407	77	10.072	102	21.123
−22	0.150	3	0.056	28	1.779	53	4.564	78	10.392	103	21.723
−21	0.158	4	0.584	29	1.859	54	4.725	79	10.720	104	22.337
−20	0.167	5	0.613	30	1.942	55	4.891	80	11.056	105	22.966
−19	0.176	6	0.644	31	2.028	56	5.062	81	11.401	106	23.611
−18	0.187	7	0.676	32	2.118	57	5.238	82	11.756	107	14.721
−17	0.197	8	0.709	33	2.200	58	5.420	83	12.121	108	24.946
−16	0.208	9	0.744	34	2.286	59	5.567	84	12.494	109	25.663
−15	0.220	10	0.780	35	2.375	60	5.800	85	12.878	110	26.343
−14	0.232	11	0.818	36	2.466	61	5.999	86	13.272	111	27.066
−13	0.244	12	0.858	37	2.560	62	6.203	87	13 676	112	27.807
−12	0.258	13	0.900	38	2.658	63	6.413	88	14 090	113	28.563
−11	0.272	14	0.943	39	2.759	64	6.630	89	14.515	114	29.338
−10	0.286	15	0.988	40	2.863	65	6.852	90	15.951	115	30.130
− 9	0.302	16	1.035	41	2.970	66	7.082	91	15.400	116	30.940
− 8	0.318	17	1.084	42	3.082	67	7.317	92	15.858	117	31.768
− 7	0.335	18	1.135	43	3.196	68	7.560	93	16.328	118	32.616
− 6	0.353	19	1.189	44	3.315	69	7.809	94	16.810	119	33.842

The foregoing values accord with the determinations of Marks and Davis, 1909. The specific gravity of saturated vapor at 32° F (0° C) is 0.6238; at 50° F (10° C) 0.6241; at 100° F (38° C) 0.6256.

TABLE 22—EXPANSION OF AIR FROM THE FREEZING TO THE BOILING POINT OF WATER

t°	V	t°	V	t°	V	t°	V	t°	V	t°	V
32	1000.000	52	1040.700	72	1081.400	92	1122.100	112	1162.800	132	1203.500
33	1002.035	53	1042.735	73	1083.435	93	1124.135	113	1164.835	133	1205.535
34	1004.070	54	1044.770	74	1085.470	94	1126.170	114	1166.870	134	1207.570
35	1006.105	55	1046.805	75	1087.505	95	1128.205	115	1168.905	135	1209.610
36	1008.140	56	1048.840	76	1089.540	96	1130.240	116	1170.940	140	1219.780
37	1010.175	57	1050.875	77	1091.575	97	1132.275	117	1172.975	145	1229.955
38	1012.210	58	1052.910	78	1093.610	98	1134.310	118	1175.010	150	1240.130
39	1014.245	59	1054.945	79	1095.645	99	1136.345	119	1177.045	155	1250.305
40	1016.280	60	1056.980	80	1097.680	100	1138.380	120	1179.080	160	1260.480
41	1018.315	61	1059.015	81	1099.715	101	1140.415	121	1181.115	165	1270.655
42	1020.350	62	1061.050	82	1101.750	102	1142.450	122	1183.150	170	1280.830
43	1022.385	63	1063.085	83	1103.785	103	1144.485	123	1185.185	175	1291.005
44	1024.420	64	1065.120	84	1105.820	104	1146.520	124	1187.220	180	1301.180
45	1026.455	65	1067.155	85	1107.855	105	1148.555	125	1189.255	185	1311.355
46	1028.490	66	1069.190	86	1109.890	106	1150.590	126	1191.290	190	1321.530
47	1030.525	67	1071.225	87	1111.925	107	1152.625	127	1193.325	195	1331.705
48	1032.560	68	1073.260	88	1113.960	108	1154.660	128	1195.360	200	1341.880
49	1034.595	64	1075.295	89	1115.995	109	1156.695	129	1199.395	205	1352.055
50	1036.630	70	1077.330	90	1118.030	110	1158.730	130	1199.430	210	1362.230
51	1038.665	71	1079.365	91	1120.065	111	1160.765	131	1201.465	212	1364.255

Approximate difference for each degree F = 2.035

TABLE 23—WIND PRESSURE—POUNDS PER SQUARE FOOT

Ind Vel	0	1	2	3	4	5	6	7	8	9
0	......	......	......	......	......	0.104	0.144	0.190	0.243	0.303
10	0.369	0.433	0.511	0.586	0.666	0.762	0.853	0.949	1.05	1.16
20	1.27	1.38	1.50	1.63	1.76	1.90	2.04	2.19	2.34	2.48
30	2.64	2.81	2.98	3.14	3.32	3.50	3.67	3.87	4.04	4.24
40	4.44	4.64	4.84	5.07	5.27	5.51	5.72	5.93	6.18	6.40
50	6.66	6.89	7.12	7.40	7.64	7.88	8.14	8.43	8.69	8.95
60	9.22	9.49	9.76	10.1	10.4	10.6	10.9	11.2	11.6	11.9
70	12.2	12.5	12.8	13.1	13.5	13.8	14.1	14.4	14.8	15.1
80	15.5	15.8	16.2	16.5	16.9	17.3	17.6	18.0	18.4	18.8
90	19.2	......	......	......	......	......	......	......	......	......

The foregoing are calculated for wind pressure on plane surfaces at right angles to the direction of the wind by the formula $P=.004\frac{B}{30}SV^2$. $P=$ pressure in pounds avoirdupois; $S=$surface in square feet; $V=$true (or corrected) velocity in mi per hour; $B=$height of barometer in inches.

Corrected velocities indicated for Robinson anemometer for above table.

Ind Vel	0	1	2	3	4	5	6	7	8	9
0	......	......	......	......	......	5.1	6.0	6.9	7.8	8.7
10	9.6	10.4	11.3	12.1	12.9	13.8	14.6	15.4	16.2	17.0
20	17.8	18.6	19.4	20.2	21.0	21.8	22.6	23.4	24.2	24.9
30	25.7	26.5	27.3	28.0	28.8	29.6	30.3	31.1	31.8	32.6
40	33.3	34.1	34.8	35.6	36.3	37.1	37.8	38.5	39.3	40.0
50	40.8	41.5	42.2	43.0	43.7	44.4	45.1	45.9	46.6	47.3
60	48.0	48.7	49.4	50.2	50.9	51.6	42.3	53.0	43.8	54.5
70	55.2	55.9	56.6	57.3	48.0	58.7	59.4	60.1	60.8	61.5
80	62.2	62.9	63.6	64.3	65.0	65.8	66.4	67.1	67.8	68.5
90	69.2	......	......	......	......	......	......	......	......	......

TABLE 24

Weight of a cubic foot of water in pounds, av., between the freezing and the boiling point. F

$t°$	Wt	$t°$	Wt
32	62.42	130	61.56
40	62.42	140	61.37
50	62.41	150	61.18
60	62.37	160	60.98
70	62.31	170	60.77
80	62.23	180	60.55
90	62.13	190	60.32
100	62.02	200	60.12
110	61.89	210	59.88
120	61.74	212	59.83

Volume of a cubic foot of water from temperature of maximum density to that of boiling point. F

$t°$	Vol	$t°$	Vol
39.1	1.00000	131	1.01423
50	1.00025	140	1.01678
59	1.00083	149	1.01951
68	1.00171	158	1.02241
77	1.00286	167	1.02548
86	1.00425	176	1.02872
95	1.00586	185	1.03213
104	1.00767	194	1.03570
113	1.00967	203	1.03943
122	1.01186	212	1.04332

TABLE 25—LONGEST SUMMER DAY AND WINTER NIGHT IN DIFFERENT LATITUDES

Read down

Lat	Mar 20	Apr 5	Apr 20	May 5	May 20	June 5	June 20	Lat
0°	12:00	12:00	12:00	12:00	12:00	12:00	12:00	0°
10	12:00	12:11	12:23	12:34	12:44	12:47	12:49	10
20	12:00	12:21	12:47	13:08	13:27	13:34	13:38	20
30	12:00	12:32	13:10	13:42	14:10	14:21	14:27	30
40	12:00	12:43	13:33	14:16	14:53	15:08	15:16	40
45	12:00	12:48	13:43	14:33	15:35	15:31	15:40	45
50	12:00	12:54	13:57	14:49	15:36	15:55	16:05	50
55	12:00	13:07	14:26	15:32	16:28	16:58	17:17	55
60	12:00	13:20	14:55	16:14	17:20	18:00	18:30	60
65	12:00	13:45	15:40	17:25	19:10	20:55	22:40	65
66.5	12:00	14:00	16:00	18:00	20:00	22:00	24:00	66.5
	Sept 20	Sept 5	Aug 20	Aug 5	July 20	July 5	June 20	

Read up

TABLE 26—MEAN BAROMETER AT DIFFERENT LATITUDES

Lat	January [1]		July [1]		Year [2]	
	mm	in	mm	in	mm	in
75°	758.3	29.86	758.0	29.85	760.0	29.92
70	760.1	29.93	757.6	29.82	758.6	29.86
65	762.0	30.00	757.5	29.82	758.2	29.85
60	760.8	29.96	757.7	29.83	758.7	29.86
55	761.1	29.97	758.1	29.84	759.7	29.91
50	762.3	30.03	758.9	29.92	760.7	29.95
45	763.0	30.04	759.6	29.90	761.5	29.98
40	763.9	30.08	760.0	29.92	762.0	30.00
35	764.8	30.11	759.8	29.91	762.4	30.02
30	765.0	30.11	759.3	29.89	761.7	29.99
25	764.0	30.08	758.5	29.86	760.4	29.94
20	762.3	30.03	758.0	29.84	759.2	29.89
15	760.5	29.94	757.5	29.82	758.3	29.85
10	759.1	29.88	757.7	29.80	757.9	29.84
5	758.2	29.85	758.5	29.86	758.0	29.84
0	758.0	29.84	759.1	29.88	758.0	29.84

[1] Spitaler [2] Ferrel

The difference in results shown in the foregoing tables are much too great to be attributed merely to observational error. Spitaler's means were computed mainly from observations made in Europe; Ferrel's from American data. Means obtained in latitudes lower than Lat 25° are from unknown sources. The following means were obtained at the Key West Weather Bureau Station, Lat 24° 33′.

	mm	in		mm	in		mm	in
Jan.	764.40	30.09	May	761.58	29.98	Sept.	760.90	29.96
Feb.	764.08	30.08	June	761.80	29.99	Oct.	760.38	29.94
March	763.55	30.06	July	763.10	30.04	Nov.	763.05	30.07
April	762.90	30.03	Aug.	762.20	30.01	Dec.	764.34	30.09

Mean for the years 1891–1904, 762.69 mm, 30.03 in.

Table 27—Determination of Speed per Hour According to Distance, in Seconds per Mile

Time in		Miles per hour	Time		Miles per hour	Time		Miles per hour
min	sec		min	sec		min	sec	
0	20	180.0	0	44	81.8	1	08	52.9
0	21	171.4	0	45	80.0	1	09	52.1
0	22	163.6	0	46	78.2	1	10	51.5
0	23	156.5	0	47	76.6	1	11	50.7
0	24	150.0	0	48	75.0	1	12	50.0
0	25	144.0	0	49	73.4	1	13	49.3
0	26	138.5	0	50	72.0	1	14	48.6
0	27	133.3	0	51	70.5	1	15	48.0
0	28	128.6	0	52	69.2	1	16	47.3
0	29	124.1	0	53	67.9	1	17	46.7
0	30	120.0	0	54	66.6	1	18	46.1
0	31	116.1	0	55	65.4	1	19	45.5
0	32	112.5	0	56	64.3	1	20	45.0
0	33	109.0	0	57	62.0	1	21	44.4
0	34	105.8	0	58	61.0	1	22	43.9
0	35	102.8	0	59	60.0	1	23	43.3
0	36	100.0	1	00	60.0	1	24	42.8
0	37	97.3	1	01	59.0	1	25	42.3
0	38	94.7	1	02	58.0	1	26	41.8
0	39	92.3	1	03	57.1	1	27	41.3
0	40	90.0	1	04	56.2	1	28	40.9
0	41	87.8	1	05	55.3	1	29	40.4
0	42	85.7	1	06	54.5	1	30	40.0
0	43	83.7	1	07	53.7	1	31	39.5

To find the rate of speed in miles per hour divide 3600, the number of seconds in an hour by the number of seconds required to traverse 1 mile. That is, if 1 mile is traversed in 25 seconds, the rate per hour in miles = 3600 ÷ 25 = 144 miles per hour.

TABLE 28—MEAN ALTITUDE, IN FEET, OF CLOUDS AT DIFFERENT LATITUDES

Summer

Station	Ci	Ci-St	Ci-Cu	A-St	A-Cu	St-Cu	Nb	Cu top	Cu base	Cu-Nb top	St
Bossekop, 70° N....	27,000	22,000	17,500	15,000	11,500	4,500	3,200	7,100	4,300	13,000	2,200
Pavlovsk, 60° N.....	28,900	26,600	15,000	......	10,000	6,100	......	7.900	5,400	15,400	2,760
Upsala, 60° N.......	27,000	20,000	21,000	9,100	13,000	5,800	3,900	6,600	4,700	13,000	......
Potsdam, 52° N.....	29,000	26,000	19,000	10,800	12,000	7,100	5,900	6,900	4,700	13,100	2,230
Trappe, 49° N......	29,200	25,600	19,000	12,500	12,000	5,970	3,500	7,100	......	18,000	3,100
Toronto, 44° N.....	35,800	29,200	29,100	13,900	11,500	6,760	......	......	......	......	......
Blue Hill, 42° N.....	31,200	33,100	22,000	20,400	12,300	3,800	3,900	9,500	5,800	29,500	1,670
Washington, 39° N..	33,800	34,800	28,900	19,000	16,400	9,400	6,300	8,000	3,900	16,300	2,760
Allahabad, 25° N....	35,100	......	37,000	......	14,700	......	2,700	......	......	......	......
Manila, 15° N......	36,100	42,500	22,300	14,000	18,700	6,200	4,500	......	......	21,000	3,500
Batavia...........	37,800	34,500	20,700	......	17,800	......	......	......	......	......	2,300

Winter

Station	Ci	Ci-St	Ci-Cu	A-St	A-Cu	St-Cu	Nb	Cu top	Cu base	Cu-Nb top	St
Pavlovsk..........	25,300	23,300	19,600	......	10,400	4,900	......	5,200	3,700	......	3,300
Upsala............	22,900	17,700	20,000	13,400	13,600	6,400	3,200	5,000	2,300	17,000	1,600
Potsdam..........	26,500	25,000	17,700	9,800	11,000	4,700	4,200	5,700	3,200	3,200	2,000
Trappe............	27,900	19,100	18,400	12,500	14,000	5,300	3,400	7,800	......	12,600	......
Toronto...........	32,800	27,900	26,900	13,700	8,200	5,000	......	......	......	......	......
Blue Hill..........	28,200	29,200	20,200	15,000	12,000	5,200	2,200	5,300	5,000	......	2,000
Washington........	31,200	31,300	24,300	15,700	12,500	7,800	5,900	7,500	3,900	12,200	3,700
Manila............	34,800	38,300	21,000	12,500	15,200	7.600	4,900	......	......	10,300	......

Table 29—Constants

Circular Measure

Radius of a circle in seconds of arc = 206,264.8062
Radius of a circle in minutes of arc = 3437.74677
Radius of a circle in degrees of arc = 57.2957795
Circumference of a circle (360°) in seconds = 1,296,000
Circumference of a circle in minutes = 21,600
Ratio of circumference to diameter (2π R) = 3.1415926536

Astronomical

Calendar year = 365 d, 5 h, 48 min, 46 sec.
Sidereal year = 365.2563578 days
Sidereal day = 23 h, 56 min, 41 sec
Mean solar day in sidereal time = 24 h, 03 min, 56.5 sec
Mean distance of the earth from the sun = 92,800,000 miles

Physical

Velocity of light per second = 186,337 miles
Velocity of light per second = 299,878 kilometers
Velocity of sound per second in dry air at 0° C = $1090\sqrt{1+0.00367\,t^{\circ}}$ C feet
Velocity of sound per second in dry air at 32° F = $1090\sqrt{1+0.00204\,t^{\circ}}$ F feet

The formula $1090\sqrt{1+\frac{t^{\circ}}{273}}$ for Centigrade, and $1909\sqrt{1+\frac{t^{\circ}}{459}}$ for Fahrenheit scales is practically the same. For all ordinary purposes the value 1110 ft per sec when the temperature of the air is 50° F (10° C) or 1148 ft per sec when the temperature is 86° F (30° C) will meet all requirements.

INDEX

Reference Tables

TABLES

D