AIR MINISTRY
METEOROLOGICAL OFFICE

THE
METEOROLOGICAL GLOSSARY

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METEOROLOGICAL GLOSSARY

SECOND EDITION

Entirely rewritten

In continuation of The Weather Map

Published by the Authority of the Meteorological Commiteee

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METEOROLOGICAL GLOSSARY

CONTAINING INFORMATION IN EXPLANATION OF TECHNICAL METEOROLOGICAL TERMS.

The first edition of the Meteorological Glossary was issued in 1916, and was reprinted with additions in 1917 and again in 1918. Since 1918 there have been many advances in meteorology, for example in connexion with the study of weather maps, and the present edition has been almost completely re-written, the task being apportioned among the Professional Staff of the Office. The opportunity has been taken, by increasing the size of the page, to bring the Glossary into conformity with the other handbooks published by the Meteorological Office.

In accordance with the practice of the Oxford Dictionary the initial word of each article is in black type. Words in small capitals in the body of the text are the subjects of articles in another part of the Glossary. International definitions of cloud forms are distinguished by the use of italic type.

The International Meteorological Committee at the meeting in London in 1921 passed a resolution requesting the inclusion, in a future edition of the Meteorological Glossary, of the equivalents in various languages of the words defined. In this edition it has been possible to give effect to this resolution by the inclusion at the end of the work of equivalents in Danish, Dutch, French, German, Italian, Norwegian, Portuguese, Spanish and Swedish. Thanks are due to the Directors of the Meteorological Services of the countries concerned for their assistance in providing these translations.

Meteorological Office, Air Ministry,

June, 1930.

METEOROLOGICAL GLOSSARY

Absolute Extremes.—See EXTREMES.

Absolute Humidity is the mass of aqueous vapour, expressed in grammes per cubic metre of air. The term is sometimes incorrectly applied to the pressure of the aqueous vapour in the air. In accordance with Dalton's Law the water vapour in the atmosphere exerts the same pressure as it would if the air were not present. Knowing the vapour pressure e, we therefore obtain δ, the mass of vapour in a cubic metre of moist air, from the formula—

$$\delta = \delta_0 \frac{e}{P_0} \times \frac{T_0}{T}$$

where δ_0 is the density of aqueous vapour under standard pressure and temperature P_0 and T_0

whence $\delta = 216{\cdot}7 \frac{e}{T}$ grams per cubic metre.

Absolute Temperature.—The temperature of the centigrade thermometer, increased by 273, more properly called the temperature on the absolute, or thermodynamic scale. The absolute scale is formulated by reasoning about the production of mechanical work at the expense of heat (which is the special province of the science of thermodynamics, see ENTROPY), but for practical purposes the scale may be taken as identical with that based on the change of volume and pressure of one of the permanent gases with heat. For thermometric purposes aiming at the highest degree of refinement the hydrogen scale is used, but for the purposes of meteorological reckoning the differences of behaviour of the permanent gases, hydrogen, oxygen, nitrogen are unimportant. In physical calculations for meteorological purposes the absolute is the natural scale; the densities of air at any two temperatures on the absolute scale are inversely proportional to the temperatures. Thus the common formula for a gas,

$$\frac{p}{\rho\,(273 + t)} = \frac{p_0}{\rho_0\,(273 + t_0)}$$

where p is the pressure, ρ the density and t the temperature centigrade of the gas at one time, p_0, ρ_0, t_0 the corresponding values at another, becomes

$$\frac{p}{\rho T} = \frac{p_0}{\rho_0 T_0},$$

where T and T_0 are the temperatures on the absolute centigrade scale. Its most important feature for practical meteorology is that from its definition there can be no negative temperatures. The zero of the absolute scale is the temperature at which all that we call heat would have been spent. In the centigrade scale all temperatures below the freezing point of water have to be prefixed by the negative sign —. This is very inconvenient, especially for recording observations in the upper air, which never gives temperatures above the freezing point in our latitudes at much above 4 kilometres (13,000 ft.), and often gives temperatures below the freezing point nearer the surface.

The absolute temperature comes into meteorology in other ways; for example, the rate at which heat goes out into space from the earth depends, according to Stefan's Law, upon the fourth power of the absolute temperature of the radiant substance. See RADIATION.

On the absolute scale defined by Lord Kelvin, the freezing point is at 273·1, and the boiling point at 373·1. The name *tercentesimal* has been given to the scale of temperatures obtained by adding 273 to the centigrade temperature. This scale is a sufficiently close approximation to the absolute thermodynamical scale for all practical purposes in meteorology. Temperatures on this scale are frequently represented by the sign °A.; thus 10°C. = 283°A. This convention has been adopted throughout the present edition of the "Glossary."

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Temperatures can also be expressed in an absolute scale of Fahrenheit degrees (A.F.) of which the zero is approximately 459° below the Fahrenheit zero.

Some common temperatures on the absolute scales and their equivalents in Centigrade and Fahrenheit are :—

——	Centigrade.		Fahrenheit.	
	°A.	°C.	°F.	AF.
The boiling point of helium ..	4	−269	−452·2	7·2
The boiling point of nitrogen..	77	−196	−320·8	138·6
The freezing point of mercury	234·2	− 38·8	− 37·8	421·6
The freezing point of water ..	273	0	32	491·4
The mean temperature of London.	282·7	9·7	49·5	508·9
" Temperate " as shown on an ordinary thermometer.	285·8	12·8	55	514·4
The best temperature for a living room.	290	17	62·6	522·0
A hot summer day	300	27	80·6	540·0
The temperature of the human body.	310	37	98·6	558·0
The temperature of the sun ..	6,000	—	—	10,000

Absorption (Atmospheric).—See RADIATION (*radiation and the atmosphere*).

Accumulated Temperature.—A term used to describe the excess or defect of temperature in relation to a selected base level, prevailing over a more or less extended period of time, e.g. a day, week, month or year. The aggregate areas above and below the selected base line bounded by (1) a curve showing the variation of temperature with time, (2) the base line, and (3) the two ordinates from the base to the curve at the beginning and end of the period of time considered, are measures of the accumulated temperature above or below that base line. Values of accumulated temperature are intended to afford a better means of tracing the influence of temperature on crops during critical periods of their growth than mean temperature, the variations of which from year to year are not so marked. Accumulated temperature is expressed in day-degrees, a day-degree Fahrenheit signifying 1°F. of excess or defect of temperature above or below the selected base line continued over a period of 24 hours, or any other number of day-degrees for an inversely proportional number of hours. The base temperature adopted by the Meteorological Office is 42°F., as being nearly equivalent to 6°C., the temperature considered by several Continental investigators* to be the critical value above which the growth of vegetation in an European climate commences and is maintained. It follows from the definitions that to compute the accumulated temperature accurately it would be necessary to integrate the excess or defect of temperature above or below the critical limit by utilising thermograph records. As few observing stations are equipped with thermographs an approximation is made. Formulae for computing approximate values of accumulated temperature from daily values of maximum and minimum temperature were devised by the late Lieutenant-General Sir Richard Strachey (*Quarterly Weather Report*, 1878, Appendix II) and modified by him so as to be applicable to weekly means of maximum and minimum temperature, in which form they have been used in computing the totals of accumulated temperature published in the *Weekly Weather Report* for individual stations from 1878 to 1914 and for districts from 1878 to 1927.

While Strachey's formulae as applied to weekly means give reasonably accurate results when the daily extremes are both on the same side of the

* A. Angot : " Etude sur la marche des phénomènes de la végétation en France pendant les années 1880 et 1881." *Paris, Ann. Bureau Central Météorologique*, 1882. Part I, p. B. 17.

base line, recent investigation has shown that no formulae applicable to weekly means can give results comparable in accuracy with formulae designed to apply to daily values of maximum and minimum temperature, in those weeks in which the temperature fluctuates about the base line; e.g. the mean of the seven readings of minimum temperature during a given week may be above 42°F. even though some of the readings pass below that limit. In such cases Strachey's formulae as applied to weekly means give zero accumulated temperature below 42°F., which is obviously incorrect. Accordingly in the *Weekly Weather Report* (for 1928–9) daily values of maximum and minimum temperature have been utilised in the computation of accumulated temperature, in accordance with formulae designed to apply to daily values of maximum and minimum temperature. In practice tables are employed which give the accumulated temperature above and below 42°F. in day-degrees Fahrenheit corresponding with given daily values of maximum and minimum temperature. Particulars of the formulae used in the computation of the tables, and instruction for their use, are given with the tables in the "Computer's Handbook," Section VII.

As examples of the application of statistics of accumulated temperature may be mentioned "Correlation of the Weather and Crops," by R. H. Hooker (*J.R. Stat. Soc.*, **70**, part 1, 1907) and "Seasons in the British Isles from 1878," by Sir Napier Shaw (*J.R. Stat. Soc.*, **68**, part 2, 1905).

Accuracy.—Strictly defined, the term accuracy signifies exactitude. No physical quantity, however, can be measured with exact precision. If a number of measurements are made of the quantity, every care being taken to eliminate all known sources of error, the final results will still differ amongst themselves. The deviation of these values from the true value is due to the accumulated sum of numerous small errors of unknown origin which cannot be allowed for. Hence in physical work the word accuracy is used in a comparative rather than in an absolute sense. It indicates the closeness with which an observation of a quantity is considered to approach the unknown true value of that quantity. A considerable body of mathematical doctrine has been built up dealing with this subject: it is usually called the Theory of Errors.

See also ERROR.

Actinic Rays.—Radiation which is effective in bringing about chemical changes, as in photography.

Actinometer.—An early name for an instrument measuring the rate at which radiation is received from the sun (see PYRHELIOMETER). More recently the same name has been given to instruments for measuring the intensity of actinic rays.

Action Centre.—See CENTRE OF ACTION.

Adiabatic.—The word which is applied in the science of thermodynamics to the corresponding changes which may take place in the pressure and density of a substance when no heat can be communicated to it or withdrawn from it.

In ordinary life we are accustomed to consider that when the temperature of a body rises it is because it takes in *heat* from a fire, from the sun or from some other source, but in the science of thermodynamics it is found to be best to consider the changes which occur when a substance is compressed or expanded without any possibility of heat getting to it or away from it. In the atmosphere such a state of things is practically realised in the interior of a mass of air which is rising to a position of lower pressure, or sinking to one of higher pressure. There is, in consequence, a change of temperature which is called mechanical or dynamical, and which must be regarded as one of the most vital of meteorological phenomena because it accounts largely for the formation and disappearance of cloud, and probably for the whole of our rainfall.

Tyndall illustrated the change of temperature due to sudden compression by pushing in the piston of a closed glass syringe and thus igniting a piece of tinder in the syringe. The heating of a bicycle pump is a common experience due to the same cause.* On the other hand the refrigeration of air is often obtained simply by expansion, particularly in the free atmosphere.

To plan out the changes of temperature of a substance under compression and rarefaction alone, we have to suppose the substance enclosed in a case impermeable to heat—the word adiabatic has been coined to denote impermeable to heat in that sense. The changes of temperature thereby produced are very great, for example :—

For adiabatic change of pressure decreasing from 1000 mb. by			The fall of temperature from 290°A., 62·6° F., is		
mb.		in.	°C.		°F.
10	or	0·30	0·9	or	1·6
100	,,	2·95	8·7	,,	15·7
200	,,	5·91	18·2	,,	32·8
300	,,	8·86	28·4	,,	51·1
400	,,	11·81	39·9	,,	71·8
500	,,	14·77	52·8	,,	95·0
600	,,	17·72	67·6	,,	121·7
700	,,	20·67	85·5	,,	153·9
800	,,	23·62	108·1	,,	194·6
900	,,	26·58	141·3	,,	254·3

Near the surface of the earth the adiabatic LAPSE rate of dry air is at the rate of approximately 1°C. per 100 metres.

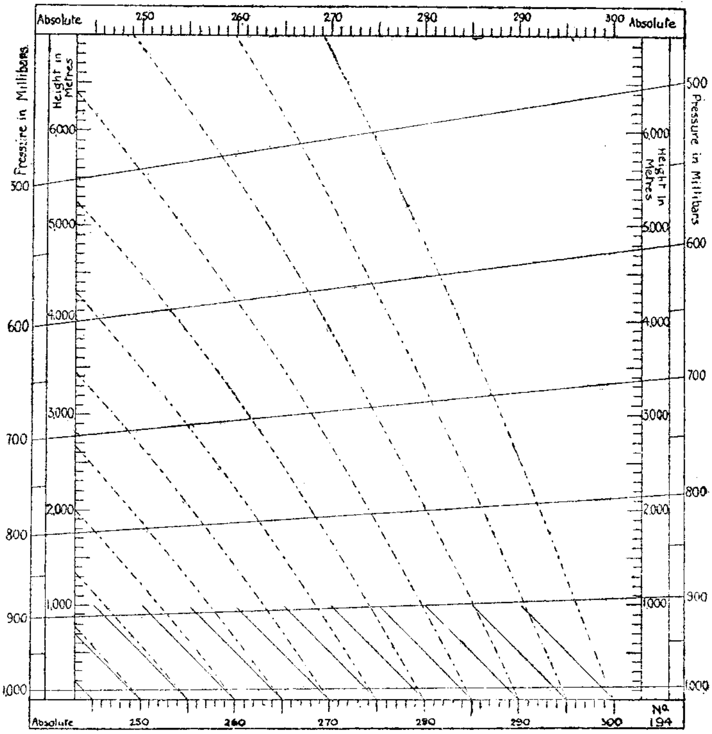


Fig. 1.—Diagram showing the pressure in the upper air corresponding with the standard pressure (1013·2 mb.) at the surface and adiabatic lines for saturated air referred to height and temperature. (From Neuhoff Smithsonian Miscellaneous Collections, Vol. 51, No. 4, 1910.)

The pressure is shown by full lines crossing the diagram, and the adiabatic lines for saturated air by dotted lines. Temperatures are given in the absolute scale.

The short full lines between the ground and the level of 1,000 metres show the direction of the adiabatic lines for dry air.

* Dangerous heating may result on firing a gun from the sudden compression of gas within the bursting charge of the shell if there are cavities in the explosive therein.

Advection.—The process of transfer by horizontal motion. The term is more particularly applied to the transfer of heat by horizontal motion of the air. The transfer of heat from low to high latitudes is the most obvious example of advection.

Aerodynamics.—The study of the forces and reactions arising from the motion of bodies, more particularly the parts of an aeroplane, through the air. It is from such forces or reactions that the upward pressure beneath the wings of an aeroplane, which provides the lifting power, is obtained.

Aerology.—A word denoting the modern study of the atmosphere, and including the upper air as well as the more general studies understood by the word METEOROLOGY. It is frequently used as limiting the study to the upper air.

After glow.—See ALPINE GLOW.

Air.—The mixture of gases which form the atmosphere. Air from which the dust and water vapour have been removed shows no measurable changes in composition from place to place, within the limits of height accessible to direct observation. The dust is regarded as an impurity and the water, whether in the form of vapour or cloud, as an addition to the air. For meteorological purposes we may therefore treat dry air as a uniform mixture. Its composition is shown in the following table :—

	Specific gravity (O=16).	Proportional composition.	
		By volume.	By weight.
		%	%
Dry air	14·48	100	100
Nitrogen	14·01	78·03	75·48
Oxygen	16·00	20·99	23·18
Argon	19·94	·94	1·29
Carbon dioxide	22·15	·03	·045
Hydrogen	1·008	·01?	·0007?
Neon	10·1	·0012	·0008
Helium	1·99	·0004	3×10^{-5}
Krypton	41·5	$\frac{1}{2} \times 10^{-5}$	$1{\cdot}5 \times 10^{-5}$
Xenon	65	$\frac{1}{2} \times 10^{-6}$	2×10^{-6}

Dry atmospheric air at 0°C. and 1,000 mb. has a density of $1{\cdot}27617 \times 10^{-3}$ grams per cubic centimetre. The ratio of the density of water vapour to that of dry air at the same pressure is 0·6221, or very nearly $\frac{5}{8}$. If v is the volume in cubic centimetres of one gram of air, p the pressure in millibars, and T the temperature on the absolute scale ; these quantities are related by the equation $pv = RT$, where $R = 2{\cdot}8703 \times 10^3$. The number of molecules in one c.c. of dry air at 0°C. and 760 mm., or 1013·2 mb. is $2{\cdot}75 \times 10^{19}$. The specific heat of dry air at constant volume (c_v) is 0·1715, and the specific heat at constant pressure (c_p) is 0·2417. The ratio of the specific heats is 1·40. The thermal conductivity of air is very low, being $5{\cdot}6 \times 10^{-5}$ in c.g.s. units.

Air is slightly viscous, the coefficient of viscosity, ν, being $1{\cdot}7 \times 10^{-4}$ at 0°C. and $2{\cdot}2 \times 10^{-4}$ at 100°C.

Air-meter.—An instrument for measuring the flow of air. It consists of a light " windmill " in which inclined vanes are carried on the spokes of a wheel arranged to rotate about a horizontal axis. A system of counters is provided to show the number of rotations of the wheel. It forms a convenient portable ANEMOMETER for use in light winds.

Air Pockets.—Regions of relatively descending air, upon entering which an aircraft experiences a proportionate decrease of lift. Since air streams tend to follow the normal contour of the earth's surface, descending currents will naturally exist on the leeward side of hills, buildings and other obstructions. These descending currents will vary with the strength and character of the wind, and with strong and squally winds they are frequently considerable. Surface irregularities affect the upper air to a height equal to three or four times that of the object. Well defined regions of descending air will be experienced in the very turbulent atmosphere associated with thunderstorms and squalls generally.

See BUMPINESS.

Air Trajectory.—See TRAJECTORY.

Albedo.—The proportion of the radiation falling upon a non-luminous body which it diffusely reflects. The albedo of the earth is about 0·4, which means that four tenths of the sun's radiation is reflected to space. The greater part of this reflection is due to the clouds, which, according to Aldrich,* have an albedo of about 0·78, but varying with the type and thickness of the cloud. The clouds which cover Venus give this planet a visual albedo of 0·59, while that of the cloudless moon is only 0·07.

Alpine glow.—A series of phenomena seen in mountainous regions about sunrise and sunset.

Two principal phases are generally recognised—

(*a*) *The true Alpine glow.*—At sunset this phase begins when the sun is about 2° above the horizon; snow-covered mountains in the east are seen to assume a series of tints from yellow to pink, and finally purple. As this phase is due mostly to direct illumination by the sun it terminates when the mountain tops pass into the earth's shadow. The Alpine glow is most striking when there are clouds in the western sky and the illumination of the mountains is intermittent.

(*b*) *The after glow* begins when the sun is well below the horizon, 3° or 4°. The lighting is faint and diffuse with no sharp boundary. It is said to occur only when the PURPLE LIGHT is manifest in the opposite sky.

Altimeter.—An aneroid barometer graduated to show height instead of pressure. For a given value of the pressure at ground level, the height corresponding with any other pressure under average conditions of temperature can be determined approximately. It is possible, therefore, to graduate the dial of a barometer to show approximate height directly. If the movement is designed to give a uniform scale of height, it is permissible to provide a zero adjustment to allow for changes in the ground pressure, thus greatly simplifying the use of the instrument.

Altitude.—The angular distance of an object from the horizon, measured in a vertical plane. The word is also commonly used as synonymous with height.

Alto-cumulus (A.-Cu.)—According to the International Classification this cloud differs from CIRRO-CUMULUS in consisting of *larger rounded masses, white or greyish, partially shaded, arranged in groups or lines, and often so crowded together in the middle region that the cloudlets join* (Fig. 9). The separate masses are generally larger and more compact (resembling STRATO-CUMULUS) in the middle region of the group, but the denseness of the layer varies and sometimes is so attenuated that the individual masses assume the appearance of sheets or thin plates of considerable extent with hardly any shading. At the margin of the group they form smaller cloudlets resembling those of cirro-cumulus. The cloudlets often group themselves in parallel lines, arranged in one or more directions.

An important variety is known as alto-cumulus castellatus. The grouping of the cloudlets is similar to that of ordinary alto-cumulus, but many of them develop turreted tops like miniature cumulus. When seen moving from south or west during fine weather these clouds indicate an early change to thundery conditions. (See CLOUDS.)

* *Washington, D.C., Smithson. Misc. Coll.*, **69**, No. 10, 1919.

Alto-stratus (A.-St.).—*A dense sheet of a grey or bluish colour, sometimes forming a compact mass of dull grey colour and fibrous structure* (Fig. 8). At other times the sheet is thin like the denser forms of CIRRO-STRATUS, and through it the sun and the moon may be seen dimly gleaming as through ground glass. This form exhibits all stages of transition between alto-stratus and cirro-stratus, but according to the measurements its normal altitude is about one-half of that of cirro-stratus. (See CLOUDS.)

Amplitude.—The amplitude of a harmonic motion is the maximum swing to either side of the mean position. A harmonic motion can be represented by a sine curve $R \sin px$, where x is the independent variable. R is the amplitude of the function, or of the motion which it represents. It should be noted that the total range of motion is twice the amplitude. See HARMONIC ANALYSIS.

Anabatic.—Referring to the upward motion of air due to CONVECTION. A local wind is called anabatic if it is caused by the convection of heated air: as, for example, the breeze that is supposed to blow up valleys when the sun warms the ground. (See VALLEY BREEZE.)

Anemogram.—The record of an ANEMOGRAPH.

Anemograph.—An instrument for recording the velocity or force, and sometimes also the direction, of the wind. The best known forms are the Robinson cup anemograph, the Dines tube anemograph, the "anemobiagraph" designed by Halliwell for Negretti and Zambra, the Osler pressure-plate anemograph and the Richard "anémo-cinémograph."

The Robinson cup anemograph depends for its action on the rotation, under the action of the wind, of a group of hemispherical cups carried on arms attached to a vertical spindle. In most existing cup anemographs there are four cups, but it is now known that a system of three relatively large cups on short arms gives improved results. In all cup anemographs a definite ratio exists between the travel of the wind and the travel of the cups. This "factor" depends on the dimensions of the cup system and must be ascertained by test in a wind tunnel.

The Dines anemograph makes use of the difference of pressure set up between two pipes, one of which is kept facing the wind, while the other is connected to a system of "suction holes" on a vertical tube. The difference of pressure so produced is arranged to raise a float carrying a pen, the height of which above the zero position may be made proportional to the wind speed. By this method every gust and lull may be shown on the record. The **anemobiagraph** works on similar principles.

The pressure-plate anemograph records the pressure of the wind on a vertical plate facing the wind, while the **anémo-cinémograph** records, by means of an ingenious system of electrical transmission, the rate of rotation of a cup system.

Anemometer.—An instrument for determining the velocity or force of the wind. As in the case of ANEMOGRAPHS various types are in use, the most important being those in which a system of cups is employed. In the Meteorological Office pattern "cup indicating" anemometer, the rotation of the cups operates a train of wheels designed to indicate the total flow of air in miles. In the "cup electric" anemometer an electrical circuit containing a buzzer is arranged to give an audible signal for a fixed flow of air. Similar anemometers have been designed to indicate the rate of rotation of the cups, and, therefore, the air velocity by means of a speed indicator.

Anemoscope.—An instrument for indicating the existence of wind and showing its direction.

Aneroid Barometer.—An instrument, not involving the use of a liquid, for determining the pressure of the atmosphere. It consists of a shallow air-tight metal box, usually nearly exhausted of air. The distance between opposite faces of the box alters with change in the surrounding atmospheric pressure, the alteration being shown on a dial by a hand actuated by a suitable train of levers. An aneroid is light, portable and convenient, but should be compared occasionally with a mercury barometer, as an appreciable change of zero sometimes occurs. Owing to errors introduced by the imperfect elasticity of the metal, etc., the use of aneroid barometers in meteorology is confined chiefly to cases where mercurial instruments are impracticable, e.g. on aircraft or in the construction of self-recording instruments where the highest order of accuracy is not expected. Owing to improved methods of manufacture, considerable progress has been made in recent years towards the production of aneroids comparable in accuracy with mercurial barometers.

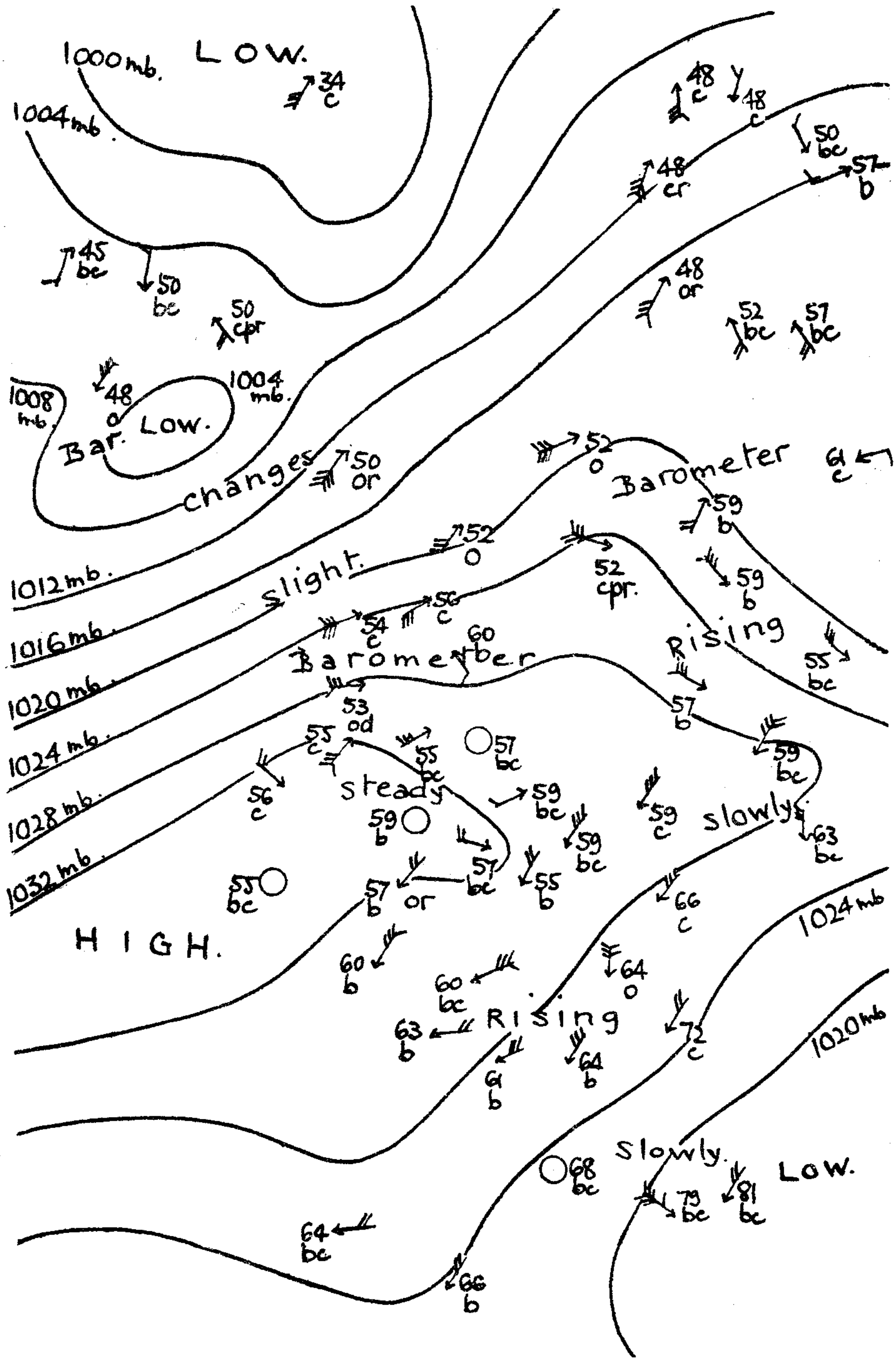
Aneroidograph.—A self-recording aneroid. An aneroid barometer provided with mechanism for recording the variations of pressure of the atmosphere. See BAROGRAPH.

Angular Velocity.—The angular velocity of a moving line is the rate of change of the angle between the line and a fixed line in the same plane. A suitable convention is adopted as to which direction of rotation shall be considered positive. The angular velocity of a moving point about a fixed point is the angular velocity of the line joining the two points. The angular velocity of a moving point about a fixed axis, is the rate of change of the angle between a plane drawn through the fixed axis and the moving point, and a fixed plane passing through the axis ; and the angular velocity of a solid body about an axis is the angular velocity of any point of the solid body about that axis. Angular velocity may be measured in revolutions per minute or per second ; for many purposes it is more convenient to measure it in radians per second or per hour, the symbol for it being ω. Since there are $2\ \pi$ radians in a complete revolution, the connection between ω and the revolutions per minute, N, is $\omega = \frac{\pi N}{30}$ radians per second. The linear velocity of a cloud is determined as a product of the angular velocity of the cloud about the point of the earth's surface vertically beneath it and the height of the cloud above that point. If the height of the cloud is given in miles and the angular velocity in radians per hour the linear velocity will be in miles per hour.

Anomaly.—The departure of a meteorological element from its normal value. In meteorology the word is used chiefly in connexion with temperature, to indicate the departure from the mean value for the latitude. Places that are relatively warm for their latitude, such as the Norwegian coast in winter, have a positive temperature anomaly, places that are relatively cold, such as Siberia in winter, have a negative temperature anomaly.

Anthelion.—A colourless mock sun appearing at the point of the sky opposite to and at the same altitude as the sun. The phenomenon is rare. Rather more frequently oblique arcs crossing at that point are reported. The phenomena are no doubt due to the reflection of light from ice crystals, but the exact explanation is in doubt.

Anticyclone.—An anticyclone is a region in which the barometric pressure is high relative to its surroundings. In temperate latitudes anticyclones are usually isolated and are generally distinguished by a series of closed isobars of roughly circular or oval form, the region of highest pressure being the central region of the anticyclone. The term " anticyclone " was first introduced by Sir Francis Galton in 1861 with the intention not only of conveying the idea that it was an area of high pressure instead of low pressure as in a depression or cylcone, but also that the general weather in the two systems, that of high and low pressure, was entirely different in character. In the depression the wind circulation is, in the northern hemisphere, counter-clockwise, often approaching gale force, and the weather is usually of an unsettled type while in an anticyclone the wind circulation is clockwise and the weather of a quiet and settled type.



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ANTICYCLONE.

There are two extensive belts of anticyclones, approximately in lat. 30°N. and 30°S.; these almost completely encircle the earth and are more or less permanent; they usually drift a little northwards and a little southwards as the sun moves northwards and southwards in its path across the equator. Between these permanent anticyclonic belts there is a belt of low pressure which is relatively uniform and is known as the DOLDRUMS.

Anticyclones are also formed over continental areas in winter time, a noteworthy one being that over Siberia. In the Siberian anticyclone of winter the pressure is often as high as 1,050 mb. or 31·00 in., while in another marked anticyclone—that occupying the North Atlantic in the region of the Azores—pressure is usually about 1,025 mb. or 30·25 in. in the summer and 1,020 mb. or 30·10 in. in winter. During an anticyclone the pressure is as a rule well above the normal for any given place in it and as a consequence pressures of 1,020 mb. (30·10 in.) or over are frequent and such high pressures are usually taken alone as a sign of the presence of an anticyclone.

In a well-defined anticyclone the winds blow spirally outwards in accordance with BUYS BALLOT'S LAW. Near the centre, however, the winds are generally light and very variable in direction, calms being frequent. In the outer regions, away from the centre, the winds increase somewhat, arrange themselves in a clockwise direction, move outwards from the area of high pressure and generally cut the isobars at a small angle. It follows that, in the northern hemisphere, the winds on the northern side of an anticyclone are westerly and on the southern side easterly.

Anticyclonic weather is usually and rightly, regarded as quiet and settled, but in practice considerable variations of weather may be experienced. In summer over the British Isles the weather in an anticyclone is generally fine, sunny and warm but much cloud may occur with some rain in its outer portions. On the other hand in winter there are two distinct types, in one the sky is covered with a layer of STRATO-CUMULUS cloud, conditions which are sometimes referred to as "anticyclonic gloom," and in the other the sky is almost cloudless, the nights are frosty and, in the early morning, fog is thick and often widespread. In the former type the cloud height is often uniform over a large area. The cloud sheet is frequently thin and above it the sky is cloudless.

Temperature observatious taken in the upper air show that there is a temperature inversion or rise of temperature with height just above the cloud. When in the London area in winter the cloud height is low the lower surface of the cloud becomes inky black; the inversion of temperature coupled with the light winds prevents the escape of London's smoke; the light from the sun is almost entirely cut off and the day becomes like night.

Anticyclones usually cover a larger area than depressions and move much more slowly. When once formed they often remain almost stationary for two or three days and sometimes for ten days or more. Their general direction of movement is from west to east. In an anticyclone the upper air layers very gradually sink and become heated by ADIABATIC compression. This results in the inversion of temperature to which reference has already been made and which forms at the base of the subsiding layer.

Sir Napier Shaw has estimated that in a large anticyclone the velocity of the descending air currents is of the order of 300 ft. per day and in small anticyclones the velocity may be as great as 1,000 to 1,500 ft. per day. When the upper air temperatures in an anticyclone are low, that is, when the anticyclone is of little vertical depth, it usually travels more quickly than one which is of greater depth and warm in its upper layers.

There have been many theories as to the cause and method of formation of anticyclones but as yet there is no single satisfactory explanation. Temperature observations in the upper air, however, have shown that between the heights of two and ten kilometres (one and six miles) the temperature in an anticyclone is usually higher, and above ten kilometres lower, than its environment. See Plate I.

Anti-Trades.—At a height of 1,000 metres or more above the surface in trade-wind regions the wind direction is sometimes reversed, giving for example a SW. wind on the Peak of Teneriffe. These winds are believed to be the return currents carrying the air of the TRADE WINDS back to higher latitudes, hence they are termed " anti-trades " or counter-trades, but they are not regularly developed. See also ATMOSPHERIC CIRCULATION.

Anvil Cloud.—Cloud having a projecting point or wedge like an anvil. The form is usually assumed by the tops of fully developed CUMULO-NIMBUS clouds, causing heavy showers or thunderstorms. A small anvil is seen on Fig. 12. The anvil normally consists of ice crystals or snow flakes, and is fibrous or nebulous in appearance. The term is sometimes used for a large mass of cirriform cloud on the top of cumulo-nimbus, even when the lateral extension is slight. (See CLOUDS.)

Aqueous Vapour.—Aqueous vapour is always present in the atmosphere, but it never represents more than a small fraction of the whole. In spite of this fact its presence is of great importance on account of its physical properties.

On account of its ready absorption of long-wave RADIATION, such as is given out by objects at ordinary atmospheric temperatures,* it exercises a strong control over the fall of temperature on clear nights ; when present in large quantities it checks the loss of radiation from the ground and so prevents the surface air from being chilled to the extent that it would otherwise have been. Since, on the other hand, its absorption of the visible radiation of the sun is relatively small, it can to some extent act as a " trap " for the solar radiation in the way that a greenhouse does. Even more important thermal effects arise from the fact that when water vapour is formed as a result of evaporation much heat is absorbed—597 CALORIES for each gram of water evaporated at 273°A—and an equal quantity is given out when condensation occurs. Now a large proportion of the evaporation from the whole earth takes place in the tropics, where most solar radiation reaches the surface ; much of the water vapour so formed finds its way into middle and high latitudes and supplies most of the moisture for the clouds and rain associated with cyclonic depressions. In this process, heat is conveyed from low to high latitudes and the climates of both regions are rendered less extreme. The energy of many meteorological phenomena from the ordinary cumulus cloud to the thunderstorm, and probably of the tropical cyclone also, is derived from the sun only after first being stored as latent heat in water vapour; the latent heat set free during condensation tends to make the air where condensation is going on warmer than its environment, and so favours CONVECTION.

In Volume II of the " Manual of Meteorology " Shaw gives the following figures for the saturation pressure and the corresponding density of aqueous vapour at various temperatures :—

Temperature.	Vapour pressure.	Density.	Temperature.	Vapour pressure.	Density.
°A.	mb.	gm./m³.	°A.	mb.	gm./m³.
225	·052	·050	281	10·65	8·22
230	·096	·091	282	11·40	8·76
235	·16	·15	283	12·19	9·33
240	·28	·25	284	13·02	9·93
245	·47	·42	285	13·91	10·57
250	·78	·68	286	14·85	11·25
255	1·27	1·08	287	15·84	11·96
260	1·99	1·66	288	16·89	12·71
261	2·18	1·81	289	18·01	13·50
262	2·39	1·48	290	19·20	14·34

* Spectrum analysis shows that it absorbs also a small part of the visible radiation of the sun

Temperature.	Vapour pressure.	Density.	Temperature.	Vapour pressure.	Density.
°A.	mb.	gm./m³.	°A.	mb.	gm./m³.
263	2·61	2·15	291	20·44	15·22
264	2·85	2·34	292	21·76	16·14
265	3·10	2·54	293	23·14	17·12
266	3·38	2·76	294	24·62	18·14
267	3·68	2·99	295	26·17	19·22
268	4·01	3·25	296	27·81	20·35
269	4·37	3·52	297	29·53	21·54
270	4·75	3·82	298	31·36	22·80
271	5·16	4·13	299	33·28	24·11
272	5·61	4·48	300	35·29	25·49
273	6·13	4·87	301	37·42	26·93
273	6·09	4·84	302	39·65	28·45
274	6·54	5·18	303	42·01	30·04
275	7·03	5·54	304	44·49	31·70
276	7·55	5·92	305	47·09	33·45
277	8·09	6·33	306	49·83	35·27
278	8·68	6·76	307	52·69	37·18
279	9·29	7·22	308	55·71	39·18
280	9·96	7·70	309	58·88	41·27

The quantity of aqueous vapour present in the air has generally a very small diurnal variation, but its annual variation is large at places where temperature shows a large annual variation. Shaw (*ibid.*) illustrates this point by the following figures for widely different types of climate :—

Diurnal and seasonal variation of vapour pressure in millibars.

Hour.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Barnaoul (Siberia) 53° 20′ N., 83° 47′ E., 162m., 1841–45, 1850, 1852–62.												
1 ..	1·49	1·72	2·49	4·76	7·19	11·11	14·08	12·24	8·31	5·25	3·04	2·11
7 ..	1·48	1·61	2·39	5·09	7·81	11·99	15·12	12·73	8·23	5·09	2·93	2·07
13 ..	1·96	2·47	3·79	5·87	7·95	12·48	15·64	13·91	9·56	6·16	3·61	2·44
18 ..	1·72	2·04	3·29	5·45	7·63	11·83	15·39	13·63	9·33	5·77	3·23	2·23
Paris (Parc St. Maur), 48° 49′ N., 2° 29′ E., 50·3 m., 1891–1910.												
7 ..	6·3	6·4	6·9	8·3	10·5	13·5	14·9	14·7	12·8	10·3	7·9	7·2
13 ..	6·7	6·7	7·1	7·7	10·1	13·1	14·5	14·1	13·1	11·2	8·7	7·3
18 ..	6·7	6·8	7·1	7·9	10·3	13·3	14·7	14·5	13·7	11·5	8·7	7·3
Calcutta, 22° 32′ N., 88° 20′ E., 6·5 m., 1881–93.												
1 ..	15·2	17·1	24·5	29·1	30·4	32·8	32·8	32·6	32·5	29·1	20·5	15·2
7 ..	14·1	16·1	24·0	29·4	31·5	33·5	33·0	32·8	32·8	29·1	19·7	14·3
13 ..	13·8	14·3	19·9	25·8	31·0	33·7	33·7	33·4	32·7	27·4	18·8	14·1
18 ..	15·9	16·6	22·1	27·6	30·6	33·2	33·4	33·0	32·9	29·3	21·5	16·5
Dar es Salaam (East African Coast), 6° 49′ S., 39° 18′ E., 7·6 m., 1901–12.												
7 ..	28·5	27·9	27·9	27·2	25·1	22·3	21·6	21·9	22·5	24·4	27·9	28·3
14 ..	29·3	29·2	29·6	28·5	25·5	22·0	21·2	22·4	24·1	25·9	27·9	29·1
21 ..	29·2	28·9	29·3	28·3	26·0	23·1	22·9	22·8	23·4	24·9	27·4	28·9
Alice Springs (Central Australia), 23° 38′ S., 133° 37′ E., 587 m., 1881–90.												
0 ..	13·9	13·4	10·9	10·9	9·8	6·8	6·3	7·7	8·0	8·6	10·7	13·1
6 ..	14·1	13·5	10·6	10·2	8·8	6·9	5·7	6·6	7·5	8·4	10·4	13·0
12 ..	13·8	13·0	11·1	12·2	10·9	8·8	8·1	8·7	9·0	9·2	11·3	13·5
18 ..	13·0	12·2	10·3	11·4	10·2	9·1	7·7	8·4	8·7	8·8	10·6	12·6

Diurnal and seasonal variation of vapour pressure in millibars—cont.

Hour.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Naha (South of Japan), 26° 13′ N., 127° 41′ E., 10·5 m., 1906–10.												
1 ..	14·1	14·1	15·7	19·4	22·1	28·9	30·3	30·3	28·6	23·6	18·5	14·6
7 ..	14·1	14·2	15·7	19·7	22·8	29·3	30·7	30·5	28·5	23·5	18·5	14·5
13 ..	14·9	15·1	16·3	20·4	23·1	29·4	30·5	30·8	28·7	24·4	19·1	15·4
18 ..	14·5	14·4	15·9	19·8	22·4	29·0	30·2	30·1	28·3	23·9	18·7	15·2
Arctic* *Fram*, 1898–1902.												
0 ..	·27	·63	·41	·83	2·27	5·29	6·23	5·85	2·65	1·32	·64	·47
12 ..	·28	·64	·44	·93	2·44	5·35	6·49	5·81	2·67	1·35	·64	·47
20 ..	·28	·63	·41	·91	2·45	5·36	6·45	5·87	2·71	1·32	·64	·47
† Antarctic, Gauss, 66° 2′ S., 89° 38′ E., Mar. 1902–February, 1903.												
0 ..	4·88	4·33	2·87	1·55	1·75	1·55	1·52	1·04	1·47	1·93	3·15	4·57
12 ..	5·31	4·67	2·97	1·59	1·85	1·61	1·59	1·11	1·72	2·56	3·71	5·21
20 ..	5·20	4·49	2·83	1·56	1·79	1·57	1·55	1·04	1·45	2·01	3·41	5·03

* The position of the *Fram* was as follows :—
September, 1898, to July, 1899 : Rice Strait, 78° 46′ N., 74° 57′ W.
October, 1899, to August, 1900 : Havnefjord, 76° 29′ N., 84° 4′ W.
September, 1900, to August, 1901 : Gaasefjord, 78° 49′ N., 88° 40′ W.
September, 1901, to July, 1902 : Gaasefjord, 76° 40′ N., 88° 38′ W.

† The figures for February represent the mean of 21 days' observations, March 25 days, April 18 days, May 16 days, December 29 days.

Arid.—A climate in which the rainfall is insufficient to support vegetation is termed arid. Köppen‡ has given the following formulae for the limits of rainfall for arid and semi-arid climates :—

Rainfall mainly in cold season .. .. .. $R = t + 22$
Rainfall evenly distributed throughout the year .. $R = t + 33$
Rainfall mainly in hot season .. .. .. $R = t + 44$

where t is the mean annual temperature in °C. If the annual rainfall in cm. is less than R and greater than $\frac{1}{2}R$ the climate is steppe or semi-arid ; if it is less than $\frac{1}{2}R$ the climate is desert or arid.

Atlas, Climatological.—An atlas showing the geographical distribution of some element or elements of climate. Temperature, rainfall and sunshine are most frequently shown, but other elements such as wind velocity and direction, cloudiness, humidity, etc., may be included.

The most usual method of representation is by means of isograms and sometimes in order to aid the eye the areas between consecutive isograms are shown in different colours. Isograms may be drawn to show the mean value of the particular element for any space of time, but the time units most frequently employed in a climatological atlas are the month and the year.

A climatological atlas for the British Isles is included in Section II of the "Book of Normals of Meteorological Elements for the British Isles," giving isograms of temperature, rainfall and sunshine. A more complete climatological atlas for the world is "Bartholomew's Physical Atlas, Vol. III, Atlas of Meteorology." Numerous charts are also included in the "Manual of Meteorology," Vol. II, by Sir Napier Shaw. (Cambridge University Press, 1928.)

Atmosphere.—A name given to the air which surrounds us, and is carried along with the earth. It is a mixture of gases and at levels accessible to measurement the relative proportions of the permanent constituents show no appreciable variations, with the sole exception of water vapour. Local sources of pollution such as factory chimneys may give rise to enhanced proportions of non-permanent constituents, but these slight local variations are not of meteorological importance. It is therefore

‡ W. Köppen : "Klimate der Erde." Berlin and Leipzig, 1923, p. 121.

convenient in meteorology to regard the atmosphere as made up of a homogeneous mixture called "dry air," whose constitution is everywhere the same, at least up to heights accessible to direct observation, to which is added water vapour in varying amounts.

The constitution of the atmosphere at heights above about 30 Km. is uncertain. Theoretical discussion of the change in constitution with height is based upon the assumption of Dalton's Law, which states that the distribution of each element at the higher levels is independent of all the other elements present. The partial pressure of any particular element at, say, 30 Km. must, therefore, support all the mass of that element above 30 Km. In the practical application of this rule, considerable importance attaches to whether hydrogen is regarded as a normal constituent of the atmosphere. In any case theory demands that nitrogen and oxygen should cease to account for an appreciable fraction of the atmosphere at heights of 160 Km. and above. According to Dobson, however, the observation of meteors indicates that up to the greatest heights at which meteors appear, about 160 Km., oxygen and nitrogen remain the chief constituents of the atmosphere.

The presence of OZONE in the atmosphere has been demonstrated spectroscopically by Fowler and Strutt, and observations of absorption of solar radiation in a restricted band of wave-lengths, by Dobson and others, confirm this, and indicate that the ozone occurs in a restricted layer some 30 to 40Km. above the earth's surface. The presence of ozone at these levels appears to be of some meteorological significance, Dobson having found that the pressure at 10 Km. is highly correlated with the amount of ozone.

The variability of water vapour is of the greatest importance in meteorology. The processes of evaporation and condensation of water vapour are among the most potent meteorological factors, not only because they produce a transport of water from one place to another but also because the evaporation of water to form water vapour requires the absorption of latent heat, which is finally liberated and used in heating the air when the water vapour again condenses into waterdrops or snow. The total amount of water vapour which the air could hold if saturated, under summer conditions for the British Isles, would yield 35 mm. of rain if all precipitated. The corresponding figure for winter is about 15 mm.

Nitrogen, which is a constituent of ammonia, nitric acid, and the nitrates which are so important in gunpowder and nearly all other explosives, is quite inert in the atmosphere. It merely dilutes the more important constituent oxygen, which forms about one fifth of the atmosphere. Without oxygen no fire can be maintained and the chemical processes in the body necessary for life cannot go on. But these characteristics of oxygen are of no special importance in meteorology.

The characteristics of the atmosphere which are of importance in meteorology are its pressure, temperature, and humidity. To a high degree of approximation the pressure of the atmosphere at any point is a measure of the mass of a cylinder of air of unit cross section extending to the top of the atmosphere. Increase or decrease of pressure therefore connotes respectively transport of air to, or from, the place of observation. The pressure of the atmosphere at sea level is equal to a pressure of about 14½ lb. per square inch.

The homogeneous atmosphere is the atmosphere which retains throughout the whole of its height the density at sea level, and yields normal atmospheric pressure at the ground. Its height is approximately 8 km.

See also AIR, STANDARD ATMOSPHERE, STRATOSPHERE.

Atmospheric Circulation.—Used in the sense of "general circulation of the atmosphere" for the wind system of the earth as a whole. This wind system is related to the pressure distribution over the earth, so that the two may conveniently be studied together; both depend ultimately on the sun's heat. (The relation of wind to pressure distribution is described under BUYS BALLOT'S LAW.)

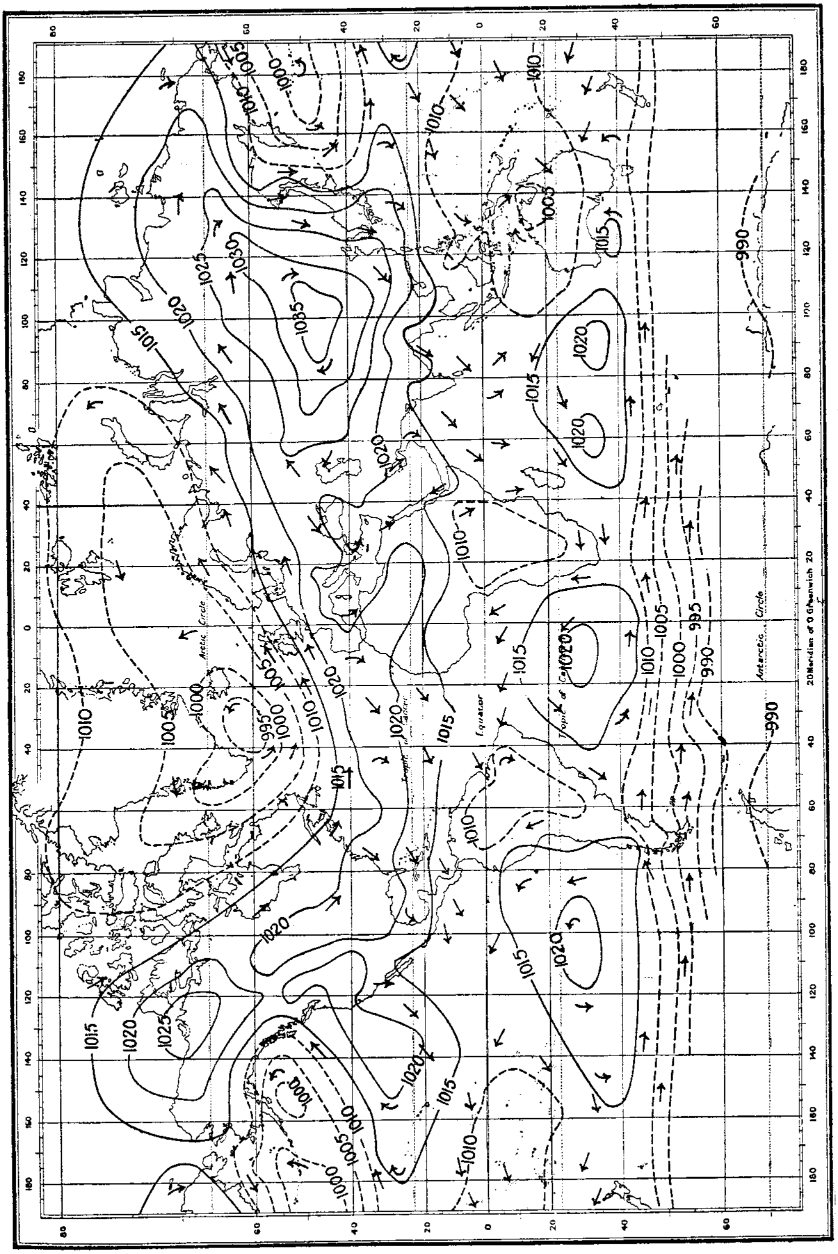


FIG. 2.—Average pressure at mean sea level and prevailing winds at the surface in January.

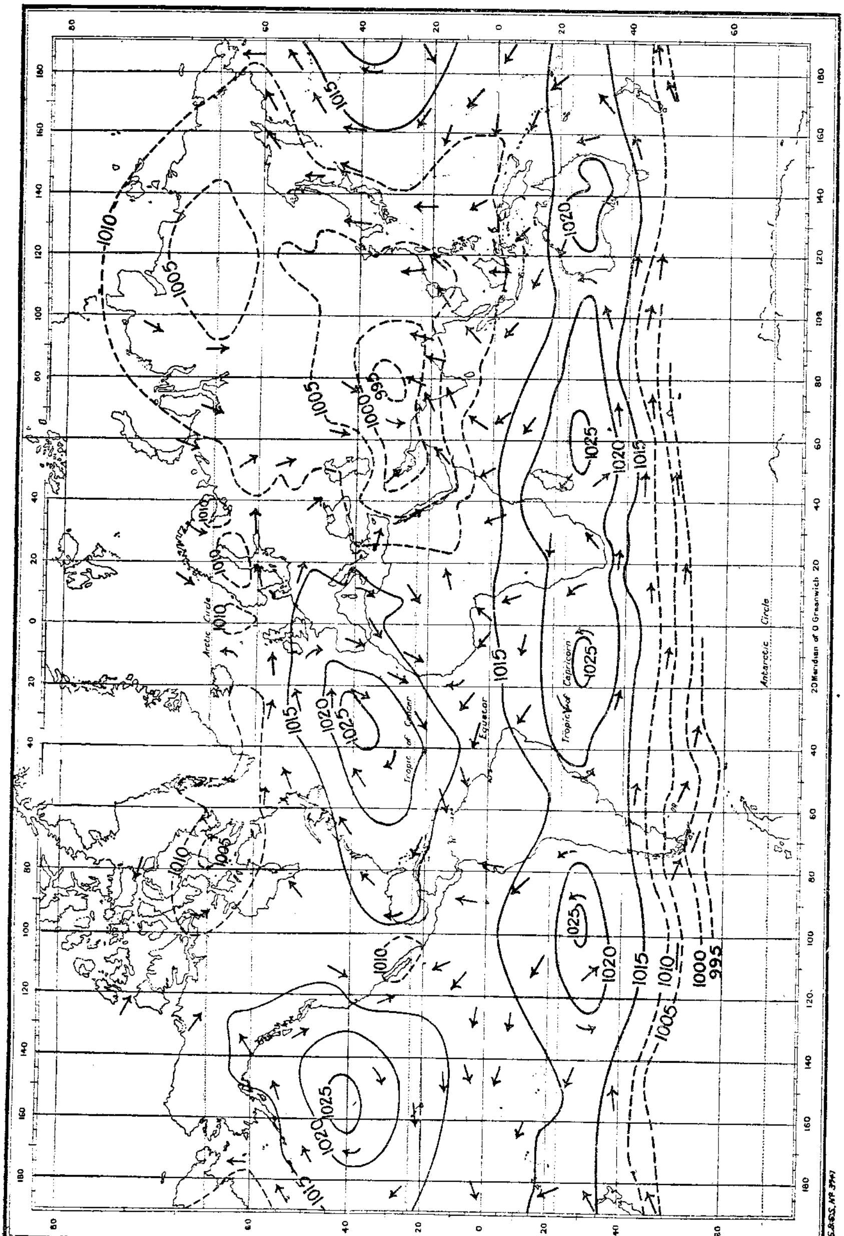


FIG. 3.—Average pressure at mean sea level and prevailing winds at the surface in July.

Examination of a series of synoptic maps of the hemispheres would show that certain features of the pressure and wind distribution over the world are much more variable from day to day than are others. In the northern parts of the British Isles for example pressure not infrequently varies by as much as 20 mb. in a day, and a day of strong south-easterly winds may be succeeded by a day of north-westerly gales, while over parts of the South Atlantic a fresh SE. wind blows with great regularity day after day. If, however, a series of charts is constructed from the normal values of pressure and prevailing winds for periods of a month, a greater degree of regularity appears, and in order to obtain a picture of the general circulation it is necessary to study such maps as those of Figs. 2 and 3.* These maps represent winter and summer conditions in the northern hemisphere and the course of the seasons may be considered as a change from one type to the other.

It is generally agreed that the "planetary circulation," appropriate to a planet like the earth but of uniform surface, would comprise, at the surface—

(*a*) A belt of calms or of light variable winds, with converging air on the equator (DOLDRUMS).

(*b*) Belts of TRADE WINDS between the doldrums and lat. 30°N. and 30°S. blowing from the north-east in the northern and from the south-east in the southern hemisphere.

(*c*) Belts of light variable winds, with diverging air which descends from higher levels in about lat. 30°N. and 30°S. (HORSE LATITUDES).

(*d*) Regions of prevailing south-westerly winds in middle latitudes of the northern hemisphere and north-westerly winds in middle latitudes of the southern hemisphere.

(*e*) Regions round the poles of outflowing winds with a component from E.

Over the oceans an approximation to the planetary circulation is observed, but over the continents conditions are different. There are two effects, one due to the great contrast in the heat capacity and radiating power of land and water masses, the other exemplified in the high, cold Greenland massif, which acts as a barrier to direct flow of air, as well as a source of outflowing cold air. It may be understood therefore that over the continents the planetary circulation may be affected or overruled by local influences (see LAND AND SEA BREEZES, MONSOON, WIND), and these local influences are more marked in the northern hemisphere where the land masses are more extensive than in the southern hemisphere, where most of the surface is water.

The main features of the wind and pressure distribution as shown by the maps are as follows :—

(*a*) The equatorial belt, the oceanic parts of which are known as the DOLDRUMS, appears as a belt of low pressure which in January extends along the equator with local minima on the land areas south of the equator. In July the belt has moved north of the equator, "following the sun," and there is now a pressure minimum over north-west India. Over the oceans although convection is vigorous with the result that heavy rainfall and thunder are frequent, the deflecting force due to the earth's rotation is so small near the equator as to give no tendency for the formation of revolving storms. At the extreme north and south positions of the belt, however, conditions are more favourable for their development, and thus the West Indian hurricanes are most frequent from July to October and the cyclones of the South Indian Ocean in January and February.

(*b*) The low-pressure belt merges irregularly into the two TRADE-WIND belts. In the Indian Ocean in the summer of the northern hemisphere there is a continuous slope of pressure from the "low"

* Owing to the large amount of new material which has recently become available in the publication "World Weather Records" of the Smithsonian Institution, and by the revision of normals for use in the *Réseau Mondial*, these charts have been re-drawn for the new edition of the "Glossary".

centred over north-west India across the equator to the "high" about 30°S. The SE. trade blows as far as the equator; north of the equator the earth's rotation deflects it to the right and it becomes the SW. monsoon of India. By January the northern limit of the SE. trade has retreated a few degrees south of the equator and the NE. or NW. monsoon system occupies the region further north.

(*c*) The trade-wind belts are bounded on their polar sides by the HORSE LATITUDES, the subtropical high-pressure belts. These are regions of light variable winds. In January they show maxima of pressure over the land areas in the northern hemisphere. In the southern hemisphere the high pressure is almost continuous in July but in January there are centres of high pressure over the oceans. The central parts of these anticyclonic regions are marked over the land by desert conditions and over the oceans by high salinity in the surface waters.

(*d*) The regions between the sub-tropical anticyclones and the polar caps are the homes of the barometric depressions which dominate the weather of temperate latitudes. These depressions form mainly at the boundary between the easterly winds of polar regions and the westerly winds which occur on the polar sides of the sub-tropical highs. This boundary is now known as the POLAR FRONT. The term "counter-trades" was formerly applied to these westerlies; in some recent writings, however, "counter-trade" is used as synonymous with ANTI-TRADE for a wind in the upper air above the trade, blowing in a direction which differs from that of the trade (see p. —).
Over the regions affected by depressions the winds vary in direction as the depressions travel, generally from west to east, but the prevailing wind directions are SW. in the northern and NW. in the southern hemisphere.

Over the Southern Ocean in lat. 40°—50°S. the wind circulation is unimpeded by land areas and the westerly winds are extremely strong and persistent, these latitudes being known as the ROARING FORTIES.

Over the British Isles, although the prevailing wind is south-westerly when a long period of observations is considered, great variations of weather are experienced owing to changes in the source of the air supply, thus in south-east England a SE. wind in summer may give a period of Mediterranean climate, while an E. wind in winter may import a steppe climate for two or three weeks on end.

The maps show, over the northern hemisphere in January, areas of low pressure known as the Icelandic and the Aleutian lows, centred over the relatively warm Atlantic and Pacific Oceans, while in July the Icelandic low is of much reduced intensity and the Aleutian low disappears. In the southern hemisphere the region of gradient for strong westerly winds is well marked and almost continuous in the "roaring forties" mentioned above. There are extensions of low pressure from the low-pressure zone, which occurs in about 60°S. latitude, into the Ross and Weddell Seas (of Antarctica).

(*e*) The tendency for outflowing winds and the deflecting force due to the earth's rotation would together produce "caps" of easterly winds at the surface around both north and south poles. These conditions are actually found over a considerable part of the borders of Antarctica, but in the north polar regions the influence of the unsymmetrical position of Greenland and the anticyclones which form in winter over the cold land regions of Siberia and north America prevent the establishment of the simple east-wind system.

Air circulation at higher levels.—Much of the upper atmosphere remains unexplored, so that little more than an outline can be given.

Over the equatorial regions easterly winds are believed to prevail up to the level of the cirrus clouds.

Observations have shown that the trade-wind layers extend upwards to heights which may vary considerably with latitude and season of the year, and that above these layers are situated other layers of winds of which the direction in certain cases may differ by so much as 180° from that of the trades. For this reason the term "anti-trades" has been applied to these winds.

The phenomenon of the "reversal" of the trade wind was observed many years ago on the Peak of Tenerife. The anti-trade has been found at heights varying from about 1,000 to 6,000 metres above Mauritius, while above the Canary Isles the anti-trade has been found at about 2,000 metres in summer, but in winter the trade wind has been found to extend to considerably greater heights.

These reversed winds were at one time regarded as being the "return winds," conveying towards the poles air which after being carried towards the equator by the trade winds, had ascended and turned back directly overhead. Later consideration of the pressure distribution implied by the presence of these winds shows that the explanation must be less simple. (Reference should be made to charts of pressure distribution in the upper air, such as are published in "Manual of Meteorology," Vol. II, by Sir Napier Shaw.)

Above 6,000 metres, surface influences, as of the Indian monsoon, become inappreciable, and towards 10,000 metres the circulation in the temperate and polar regions is thought to tend towards a great "circumpolar whirl" of westerly winds.

Atmospheric Electricity.—The various electrical phenomena occurring naturally in the atmosphere. Of these phenomena the most familiar is the THUNDERSTORM, but there are manifestations which can be studied at all times with suitable apparatus.

Potential gradient.—It is well known that the wire attached to a kite sent up to a considerable height, even in fine weather, becomes electrified so that sparks may be drawn from the wire. This is evidence that there is a large difference of potential between the ground and the air at the level reached by the kite.

The measurement of potential at a moderate height is made most readily by the use of an insulated wire carrying a burning fuse and connected to a suitable electrometer. As long as the fuse is not at the potential appropriate to its position a charge will be induced on it. This charge is dissipated by the burning fuse until the potential has been equalised.

It is found that in the open, potential changes fairly uniformly with height; the rate of change is called the potential gradient. Near the ground in fine weather the potential gradient is of the order 150 volts per metre. In such weather the higher potential is at the greater height and the potential gradient is said to be positive. The gradient fluctuates continually and also shows regular annual and diurnal changes. At most places the diurnal change is such that the gradient has two maxima and two minima in the course of the 24 hours. For example, at Kew Observatory in July, the average value (1905–1912) of the fine weather gradient at 3h. is 153 v./m.; there is a rise to the maximum, 272, which occurs at 9h. The gradient falls steadily until it reaches a value of 179 at 14h. and rises again to 266 v./m. at 21h.

The gradient depends to a great extent on the condition of the atmosphere. It is low when the air is clear, higher when there is haze and very high when fog prevails. In fog the gradient at Kew may be as high as 2,000 v./m.

During rainfall and especially during thunderstorms potential gradient is subject to great fluctuations. In thunderstorms the gradient is of the order 10,000 v./m. positive or negative.

Observations from balloons indicate that on the average as we go up from the earth the potential gradient diminishes. As, however, the contributions are in the same direction, the potential goes on mounting and at the levels attained by aircraft it may reach hundreds of thousands of volts. (In the case of a kite-balloon tethered to the ground by conducting wires the potential of the balloon is practically zero and therefore departs widely from that of the surrounding air. In an extreme case this may lead to discharge by sparking and great danger to the kite-balloon.)

The earth charge.—The existence of a positive potential gradient implies the presence of a negative charge on the ground. With a gradient 100 v./m. the charge is roughly 1 coulomb per 1,000 square kilometres (accurately $\frac{1}{36\pi \times 10^{11}}$ coulomb per cm.^{2}). If the same gradient prevailed over the whole globe the total charge would be 450,000 coulombs. To the electrical engineer this is a very small quantity of electricity. It could only supply a current of one ampere for five days. Of course the gradient is not uniform; at any time there are large areas with negative gradient. We can not give the average gradient and we are therefore unable to determine the total charge.

Air-earth current.—The charge on the earth's surface is continually being neutralised by the communication of positive electricity from the atmosphere. By substituting a metal plate for part of the ground we can measure the current. The average current over flat ground is of the order 1 micro ampère per square kilometre. Small as this current is it would suffice to neutralise the fine-weather charge on the ground in a fraction of an hour. There is, of course, a reverse current at such times as the potential gradient is negative. Electricity is also conveyed to the ground by rain and by lightning. The question whether these causes suffice to preserve a balance between the flow of positive and of negative electricity is still open.

Electricity on rain.—It is found that raindrops are usually electrified. The charges may be positive or negative but positive ones predominate. Drops with charges of either sign may fall simultaneously. The charge per cubic centimetre of rain is generally less than one electrostatic unit ($\frac{1}{3} \times 10^{-9}$ coulomb) but charges approaching 20 e.s.u. per c.c. have been observed. The charges on snow are of the same order of magnitude.

The principal cause of the electrification of rain is probably the breaking up of the drops.* When the velocity with which a large drop is falling through the air exceeds a certain limit the drop is broken up into a number of small drops which become positively charged in the process. According to some investigators the corresponding negative charges are carried away by the finer spray, according to others by the air. The process will be accelerated where there are powerful upward currents of air to break up the drops. Similar effects will occur with snow. G. C. Simpson bases his theory of thunderstorms on these phenomena. In the parts of an active cumulo-nimbus cloud where the upward currents of air are most vigorous large drops are formed by the condensation of water vapour and by the amalgamation of small drops. In the strong currents the large drops are broken up and become positively electrified. The air with its negative charge passes on to other parts of the cloud. Large quantities of electricity, positive and negative accumulate in different regions and the electric forces increase until a lightning flash occurs. The process is repeated as long as the storm lasts.

Ionization of the atmosphere.—The conductivity of the air is due to the presence of charged particles known as ions. The ions which are effective in carrying the current are probably charged molecules of the atmospheric gases. On the average there are five or six hundred of these small ions of each sign in a cubic centimetre of air. The mobility of the small ions is such that they move about one centimetre per second in an electric field of 1 volt per centimetre. The atmosphere contains also more numerous ions (the Langevin ions) with much less mobility. It is thought that these

* "On the electricity of rain and its origin in thunderstorms," by G. C. Simpson, London, *Phil. Trans. R. Soc.*, A. **209**, 1909, pp. 379-413.

sluggish ions are charges attached to Aitken nuclei, the hygroscopic particles on which moisture condenses when clouds are formed. The fact that in general potential gradient falls off as we ascend in the atmosphere is evidence that the net charge on the air is positive. This implies that there must be an excess of positive ions.

The variations in the conductivity of the air are explained by the different proportions of large and small ions. In places where the atmosphere is polluted by the products of combustion of coal Aitken nuclei are frequent, large ions are formed at the expense of small ones, the effective conductivity is reduced and the air-earth current is maintained by a higher potential gradient.

At appreciable heights above ground the conductivity of the air is considerable. At 9 Km. Wigand found the conductivity to be 26 times as great as near the ground. The great conductivity of the Heaviside layer is due to high ionization.

Since free ions of opposite sign will tend to recombine and give up their charges there must be active causes of ionization at work. Of known causes the radiation from radio-active gases and the COSMIC RADIATION from outer space may be mentioned. Combustion and similar processes are also effective and under certain circumstances the breaking of water-drops and the friction of snow or dust driven by the wind. Over the land most of these causes are in operation, over the sea the cosmic radiation is the only one which is known to be effective, but this may suffice to maintain the observed ionization.

Atmospheric Pollution.—The principal source of the pollution of the atmosphere is the burning of coal under such conditions that the combustion is incomplete. When a hydrocarbon, such as one of the constituents of coal, is burned, the hydrogen combines with oxygen to form water vapour, the carbon combines with oxygen to form carbon dioxide. If, however, the temperature is not high enough the second half of the process does not take place; some of the carbon is carried up with the rising air and coagulates into particles of soot. The smoke from a coal fire consists in the main of such particles.

The pollution of the air of cities has been reduced by the introduction for industrial proccesses of more efficient furnaces in which the coal is completely burned and very little smoke is produced. Further great quantities of coal are treated in gas works. By heating the coal in retorts the hydrocarbons are broken up; the hydrogen with other constituents of coal gas is distributed through mains and the coke, which is mostly carbon is sold separately. Both the coal gas and the coke will burn without the production of smoke. The substitution of the gas-cooker for the kitchen range has led to a great reduction in the amount of domestic smoke.

The gaseous products of combustion are mostly water vapour and carbon dioxide, both normal constituents of the atmosphere: but coal generally contains sulphur and the burning of sulphur produces the essential constituents of sulphureous and sulphuric acids. Most of the damage done to buildings by atmospheric pollution is attributed to the action of sulphuric acid.

A Committee of Investigation having been appointed at a Conference held in London in 1912 systematic records of atmospheric pollution have been kept in Great Britain since 1914.

The estimation of the quality and amount of polluting substances in the air at any time presents great difficulties. It is easier and no less instructive to measure the pollution which is deposited. For this purpose a large gauge is used in which rain is collected and also the foreign matter which falls as dust or is brought down with the rain. Month by month the contents of the gauge are taken away for analysis.

As an example of the results the 5-year averages for a gauge in the City of London may be quoted. The quantity of matter deposited in the gauge in the solid form was 82 grams per square metre per annum.

Of this total only 32 gm. was carbonaceous insoluble matter; as such things as pollen would be included in this 32 gm. the amount of soot would be rather less than 32 gm. The amount of insoluble ash, i.e. dust from the roads as well as from fires was 50 gm. The solid matter in solution in the rain water was nearly equal to the insoluble matter. The soluble matter included a high proportion of sulphates; it is the practice of chemists in such cases to estimate the acid without regard to the base with which it may be associated. In this case the average amount of SO_3 was 25 gm. It will be seen that the quantity of SO_3 is not much less than the quantity of soot.

It is found that in places with less pollution than London the ratio of the amount of soluble matter to the amount of insoluble is higher.

At seaside places such as Southport a considerable amount of sea salt is included in the soluble matter.

For estimating the amount of solid matter in suspension in the atmosphere it is found convenient to aspirate a known quantity of air through filter paper and to compare with a set of standard shades the stain left on the filter paper. Dr. J. S. Owens has devised automatic apparatus for making records which are practically continuous.

It is found that in foggy weather the quantity of suspended solid matter in London air may amount to four milligrammes per cubic metre. Generally the maximum on a foggy day is about 2 mg./m^3. whilst the maximum on a non-foggy day in winter is about 0·8 mg./$m.^3$

Pollution varies systematically through the 24 hours: normally the least pollution is in the early morning, when few fires are in operation. There is also a secondary minimum in the middle of the day at the time when the air currents are strongest. The times of maximum pollution are generally about 9 a.m. and 7 p.m.

Dr. Owens has also developed a method of counting the number of solid particles in the air. For this purpose a jet of air is pumped through a slit on to a piece of glass which can be examined under the microscope. The number of particles in fog may be as high as 20 per cubic millimetre. The particles are generally ultra-microscopic.

Atmospheric Pressure.—The pressure of the atmosphere is produced by the weight of the overlying air. If a vertical tube were placed over one square inch of the earth's surface extending to the top of the atmosphere, the air contained within it would weigh about 15 lb. As the weight of the column is borne by the earth's surface at the bottom, the pressure exerted on the earth by the air is therefore about 15 lb. to the square inch. The pressure exerted by a gas is the same in all directions, and it is this pressure of approximately 15 lb. to the square inch but varying a little from day to day and from place to place which is measured by the mercurial or aneroid barometers in ordinary use.

Atmospherics.—Electrical impulses of natural origin which cause crashing or grinding noises in a wireless receiving set. They are believed to originate in the earth's atmosphere, most probably in discharges of the same nature as lightning. Atmospherics of measurable strength are received in England at the rate of about 50 per second at night, and in the tropics about 50 per second during the day and a few hundred, rising occasionally to a few thousand, per second, during the night. By means of radio direction recorders, the sources of many atmospherics have been determined, and it has been found that some radiate from centres 4,000 miles away. The average strength of atmospherics received in England is consistent with their radiation from centres 2,000 miles away, which in turn is consistent with their origin in regions in which thunderstorms are frequent.

Attached Thermometer.—A thermometer attached to a mercurial barometer for the purpose of ascertaining its temperature. When used in conjunction with a marine barometer the attached thermometer may conveniently be mounted in a GOLD SLIDE.

Audibility.—The audibility of a sound in the atmosphere is measured by the distance from its source at which it becomes inaudible. On a perfectly clear, calm day the sound of a man's voice may be heard for several miles, provided there are no obstructions between the source of sound and the listener; but quite a small amount of wind will cut down the range of audibility enormously.

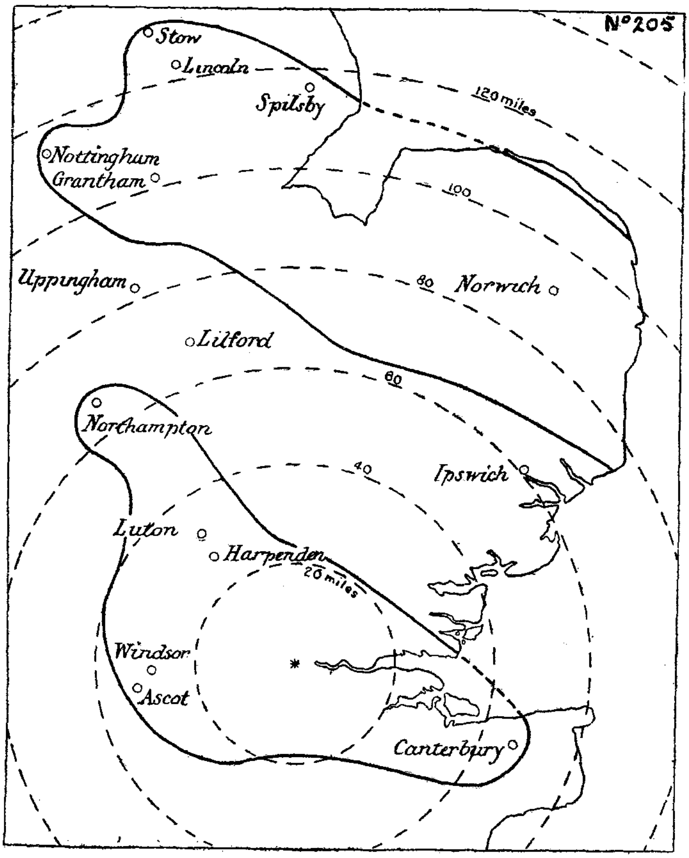
The sound is not cut down equally in all directions; to leeward, for instance, a sound can usually be heard at a greater distance than it can to windward of the source. This is accounted for by the bending which the sound rays undergo, owing to the increase in wind velocity with height above the ground, the rays to leeward of the source being bent downwards while those to windward are bent upwards so that they pass over the head of an observer stationed on the ground. The decrease in all directions in the range of audibility of a sound when there is a wind appears to be due chiefly to the dissipation in the energy of sound as it passes through eddying air. A plane wave-front becomes bent in an irregular manner when it passes through air in irregular or eddying movement. It, therefore, ceases to travel uniformly forward. Part of its energy is carried forward, while the rest is dissipated laterally.

If there were no dissipation of energy in a sound wave the intensity of the sound would decrease inversely as the square of the distance from the source. Experiments show that, under normal conditions when there is a light wind blowing, the rate of decrease in intensity of sound at a distance of half a mile or more is considerably greater owing to the dissipation of energy than would be expected from the inverse square law. If, for instance, a whistle can be heard at a distance of half a mile, four whistles blown simultaneously should be audible at a distance of a mile; but the range is actually only increased to about three quarters of a mile.

Sounds are usually heard at greater distances during the night than during the day. On calm nights the range of audibility of a sound may be as much as 10 or 20 times as great as it is during the day. This effect is due partly to the increased sensitiveness of the ear at night owing to the decrease in the amount of accidental disturbing waves, partly to the inversion of temperature which commonly occurs on calm, clear nights, and has the effect of bending the sound waves downwards, but chiefly to the diminution of the amount of disturbance in the atmosphere at night.

Between the source of sound and the extreme range of audibility areas of silence sometimes appear, in which the sound cannot be heard. This effect has in some cases been attributed to a reversal in the direction of the wind in the upper layers of the atmosphere. The lower wind would bend the sound rays upwards to windward of the source. On entering the reversed upper wind current these rays would be bent down to the earth again, and would reach it at a point separated from the source of sound by an area of silence. This explanation is quite adequate in many cases in which the places, where the sound is heard again, are to the windward of the source. There are, however, many cases in which areas of silence appear to leeward of the source, and many others in which an area of silence occurs in the form of a ring enclosing the source and surrounded by an area of distinct audibility. In most of the cases where a ring-shaped area of silence has been observed the outer region of distinct audibility begins at a distance of about 100 miles from the source, and may extend to 150 miles or more. The explosion at Silvertown on January 19, 1917 is a good example of a case in which a detached area of audibility was separated from the source of sound by an area of silence. In the accompanying map, which is reproduced by permission from the *Quarterly Review*, the two areas of audibility are shown. It will be seen that the outer area, which includes Lincoln, Nottingham and Norwich, lies about 100 miles from the source of sound. The inner area surrounding the source is not symmetrical, being spread out towards the north-west and south-east. Definite evidence was obtained that no sound was heard at various points within the area of silence.

The study of observations made on artificial explosions has shown that the time which the sound takes to reach a point in the inner zone of audibility near the source is such that the apparent velocity differs but little from the ordinary velocity of sound, but that the apparent velocity with which the sound reaches a point in the outer zone is much less. For this reason the outer zone is known as the " zone of abnormal audibility." The probable explanation of abnormal audibility is the presence of a region of high temperature at a considerable height above the ground. Owing to the way in which temperature falls off in the lower atmosphere sound rays are generally bent upwards; in the stratosphere in so far as it is a region of uniform temperature the rays will be straight. For the rays to recurve sufficiently to bring them down again they must enter a region where the temperature is at least as high as that which prevails on the ground. The observations indicate that the rays reach heights of 40 Km. or more. That high temperatures prevail at such levels was first suggested as an explanation of the behaviour of METEORS. The observations of audibility have confirmed the theory.



(*Reproduced by permission from the Quarterly Review, July*, 1917.)

Fig. 4.—Areas of audibility of the explosion at Silvertown on January 19, 1917.

Aureole.—A luminous area surrounding a source of light. The name is used especially with reference to coronae. When there is a corona round the sun or moon a clear space in which the cloud seems to be transparent is seen near the luminary. The first coloured ring, usually a brownish-red, bounds this clear space. The clear space is the aureole. The term may be used legitimately when the corona is not developed beyond the first coloured ring.

The name aureole is also used by some authors for the bright area with no definite boundary seen round the sun when no clouds are present.

Aurora.—In Latin the word aurora stands for dawn. According to the Oxford Dictionary the term *aurora borealis* was introduced by Gassendi in 1621. This term, the northern dawn, is apt enough for a faint glow seen at night near the northern horizon. The same name is given, however, to a wider class of luminous phenomena. On the recognition of similar phenomena in the Antarctic regions, these were called *aurora australis.* The single word aurora is now in general use in either hemisphere.

Aurora takes many forms. Of the accompanying figures one shows an arc with rays, the other a curtain. The quiet arc is the most symmetrical and stable form of aurora, sometimes persisting with little visible variation for several hours, but an arc with ray structure such as is shown in the illustration undergoes rapid changes. The lower edge, both of arcs and curtains, is usually much the better defined. Another striking form of aurora is that known as a corona, in which several beams of luminescence radiate from a point high in the sky. Several forms may occur simultaneously or successively during any auroral display.

Aurora is very rare in southern Europe, and is but seldom seen in the south of England. But the frequency increases rapidly as we go north, and in Orkney and Shetland aurora is a common phenomenon. In those regions it may occasionally be observed to the south as well as to the north.

A zone of maximum frequency passes across the north of Norway, the south of Iceland and of Greenland and surrounds the north magnetic pole ; the distribution in tha Antarctic is more or less similar. Cape Evans, the headquarters of Scott's last expedition, was within the auroral zone ; aurora was seen frequently to east-north-east and comparatively rarely overhead. It is difficult to assign laws for the frequency of occurrence of aurora as weak displays are obscured by moonlight or twilight ; also, in daylight or on nights when the sky is heavily clouded observations of aurora are impossible. In the British Isles and similar northern latitudes it is most common in the late evenings and near the equinoxes; but in the north of Norway and Greenland it appears to be most frequent near midwinter. Of late years Professor Störmer has devised a method of photographing aurora, including reference stars in the photograph, and by means of photographs taken simultaneously at the two ends of a measured base he has obtained numerous results for the altitude. Heights exceeding 200 Km. are not unusual, but a great majority of the heights lie between 90 Km. and 130 Km.

Aurora is undoubtedly an electrical discharge, and we thus infer that at heights of 100 km.—at least in high latitudes—the atmosphere must often, if not always, be a vastly better conductor of electricity than it is near the ground. Some distinguished travellers have claimed to see aurora come down between them and distant mountains. Such observations are generally regarded as illusions. Reports of the audibility of aurora must be placed in the same category.

When visible in England aurora is nearly always accompanied by a magnetic storm, but this is not the case when it is confined to high latitudes.

The spectrum of aurora consists of a number of lines, one of which in the green is particularly characteristic. This line, the wave length of which is 5,577Å, has been shown by McLennan* and his collaborators at Toronto to be due to oxygen. The great height to which aurora is visible is evidence that oxygen extends to 200 Km. or more above the ground.

* "The spectrum of the aurora and the constitution of the upper atmosphere," *London, Proc. R. Soc.* A. 108, 1925, p. 501.

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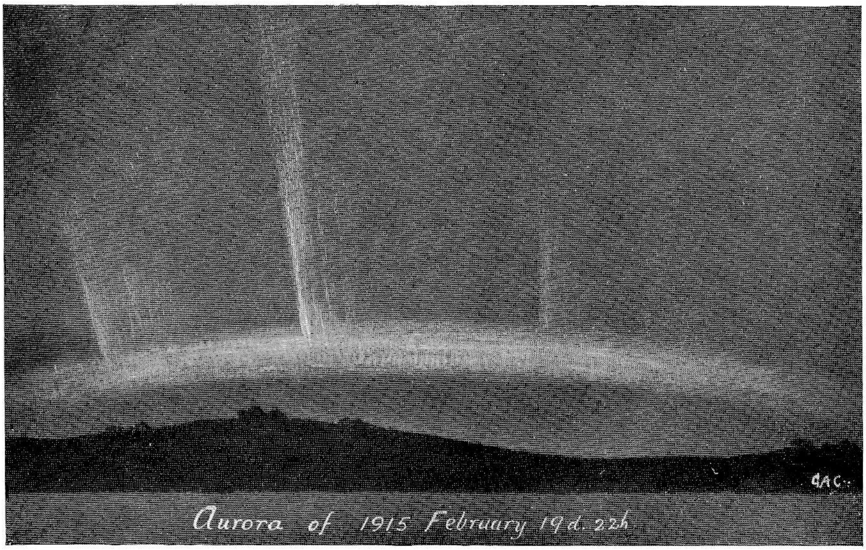


FIG. 5.—Aurora of February 19, 1915. 22h.

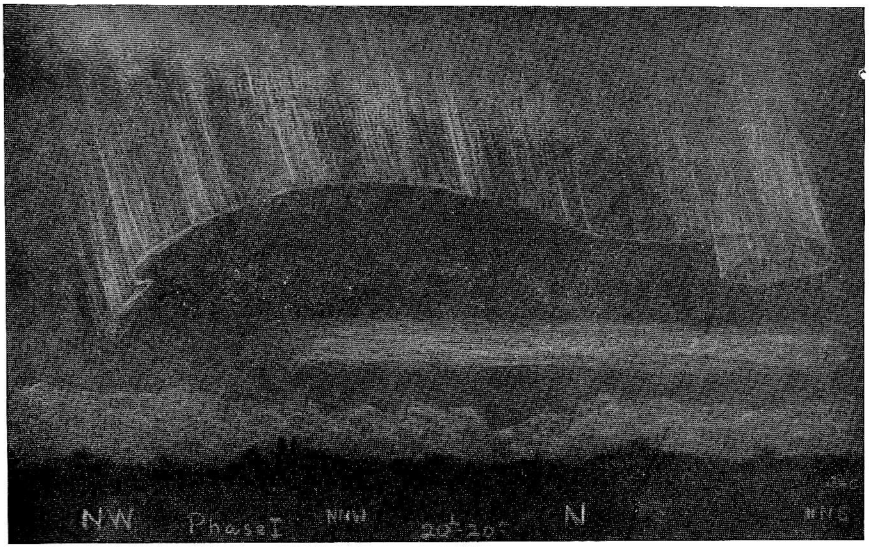


FIG. 6.—Aurora of January 4, 1917. Sketched at Aberdeen by G. A. Clarke.
Phase I. 20h. 20m.

Autumn.—Autumn in meteorology comprises (for the northern hemisphere) the months of September, October and November. See SEASONS.

Avalanche Wind.—An avalanche often carries a mass of air along with it. This rush of air is known as the avalanche wind and is sometimes sufficient to cause destruction at a considerable distance.

Average.—This term originally meant the adjustment between the interested parties of the charges for loss or damage to a ship or cargo at sea. It is now used in another sense. By the average of a series of numerical quantities is understood the result of summing the quantities and dividing the total by their number. The term is thus synonymous with the arithmetic mean. The average value of any meteorological element for a particular station is obtained in this way by making use of a long and complete series of observations of the element. Provided there is no reason to believe that the climate of the station is changing, this average value can be used as the NORMAL with which individual values of the element can be compared. In taking the average of a series of quantities in this way it is necessary that all the quantities should have equal weight, that is, all should be observed equally carefully and in an identical manner. If the observations are not all strictly comparable it may be necessary to give greater stress to those thought to be the best, a process technically known as WEIGHTING.

Azimuth.—The horizontal angular deviation of an object from the true north and south line. Technically it is the angle between the vertical plane passing through an object and the vertical plane passing through the poles of the earth. In meteorology it is almost invariably given in "degrees from true north," going round clockwise, through east, which is 90°, south which is 180°, and completing the circle at north which is 360°.

Azores Anticyclone.—Or North Atlantic anticyclone, part of the subtropical, high-pressure belt of the northern hemisphere. (See ATMOSPHERIC CIRCULATION, ANTICYCLONE.)

Isobaric maps of normal pressure show in summer an area of high pressure centred about lat. 35°N., extending across the Atlantic to south-western Europe and the western Mediterranean. In winter the anticyclone is centred somewhat further south about lat. 30°N., and is less intense, being reduced to a belt of high pressure connecting more intense anticyclones over Siberia and North America. See CENTRE OF ACTION.

Backing.—A wind is said to "back" when it is changing in the opposite direction to the hands of a watch. Thus the wind backs at a place north of the centre of a depression travelling eastwards in the northern hemisphere. The same definition of backing applies to the southern hemisphere but as wind direction in relation to systems of closed isobars is there reversed, a backing wind in the southern hemisphere is equivalent to a veering wind in the northern hemisphere, and conversely.

Baguio.—A local name by which the tropical cyclones experienced in the Philippine Islands are known. A number of the cyclones or typhoons of the western Pacific cross the Philippines and in addition there is a class of cyclone which is especially associated with these islands, occurring from July to November.

Ball Lightning.—An occasional incident during thunderstorms is the appearance of ball lightning. The circumstances vary considerably. The size of the balls varies greatly, from the size of nuts to spheres a foot or two in diameter. The most frequent balls are between 10 cm. and 20 cm. in diameter. Sometimes they occur immediately after a brilliant flash of ordinary lightning, at other times when there has been no flash at all. Sometimes only a single ball is seen, at other times the same observer sees two or three and several are reported in one locality. Sometimes the balls drift through the air and vanish harmlessly, but in some cases a ball has exploded on reaching the ground. Usually there is no sign of heating where a ball has passed yet there is one case where clean holes were bored through several window panes, the glass appearing to have been melted. Ball lightning has been observed in closed rooms, but whether it penetrates the walls or forms inside is not quite certain. The light is seldom brilliant, though occasionally observers have been dazzled. Cases are on record where a ball has broken up into smaller ones, but these are rare. In some cases the balls develop during very heavy rain; in other cases when there has been no rain for several minutes. A ball may last for a few seconds or several minutes. Its movement is never fast, generally the speed is comparable with a walking pace, but it is not clear how the ball lightning is propelled. Probably in most cases it is carried by air currents. Apparently ball lightning does not occur when there is much wind.

Pearl-necklace lightning.—Ball lightning has been associated occasionally with pearl necklace lightning. This phenomenon is a development of an ordinary lightning flash. Immediately after the flash a number of bright lights are seen. These lights are of uniform size and appear like pearls on a string. They last about a couple of seconds.

Phenomena with some likeness to ball lightning have been produced artificially by the use of very powerful electric machines. N. Hesehus* used a transformer giving 10,000 volts and connected one pole to a vessel containing water the other to a copper plate 2 to 4 cm. above the water. The discharge between the plate and the water took the form of flames, now conical, now spheroidal. The fiery spheroids were very mobile, going from side to side of the copper plate at a breath. In these flames atmospheric nitrogen was being burned to nitric oxide, NO, as in one of the industrial processes for "fixing" nitrogen, but the flames did not float away into the free atmosphere. There is therefore no reason to assume that ball lightning is a globe of nitric oxide. The fact that the globular form is maintained by ball lightning seems to require an electrical attraction between the outer layers and a central nucleus so that the mechanism can not be merely chemical. At present the phenomenon is entirely inexplicable.

Ballistics.—The science of gunnery. During the European War a considerable body of new knowledge came into existence with regard to the application of meteorological observations to ballistic science.

Ballistic Temperature.—A particular type of mean temperature of great importance in BALLISTICS. A shell in flight meets air of various temperatures and in computing the ballistic temperature different weights have to be given to the temperatures experienced, according to the type of shell and the circumstances of the firing. In any particular case the effect upon the motion of the shell of the varying temperature distribution observed is the same as the effect which would be produced if the temperature at the ground were equal to the ballistic temperature, and the lapse rate had a certain standard value.

Balloon.—A bag of impermeable fabric, usually spherical in form, and inflated with a gas lighter than air. The modern balloon is usually made of varnished cloth or gold-beater's skin, while over the envelope is a network of fine cord, from which is suspended the passenger car or basket. At the top of the envelope is a gas release valve, operated by means of a cord which hangs down inside the balloon and passes through the neck. A "ripping panel" is fitted for the release of the gas in emergency. An anchor, guide rope, and bags filled with sand for ballast are provided. The modern balloon owes its inception in a practical form to the brothers Montgolfier, who experimented with hot-air or fire balloons in 1783. Many notable ascents have been made in free balloons, in connexion with meteorological observations, some of the earliest being made by John Welsh in 1852, and James Glaisher between 1862 and 1866.

* *Phys. Zs.*, 2, 1[illegible] p. 579.

Although the spherical balloon may be held captive, at small altitudes and during light to moderate winds, it is usual to employ the kite-balloon for this purpose. In connexion with the investigation of the upper air at considerable altitudes, small rubber balloons are used, having a diameter of about four feet when filled with hydrogen (see SOUNDING BALLOON). These balloons carry self-recording instruments, or METEOROGRAPHS. By this method it is possible to obtain information at far greater altitudes than can be reached with balloons carrying an observer. For observations of the direction and velocity of upper winds small rubber balloons are employed, having a diameter of about 18 inches when filled with hydrogen. They are liberated from the observing station, and observed, during free ascent, by means of a theodolite.

Bar.—The unit of atmospheric pressure, being equal to the pressure of one million dynes (one megadyne) per square centimetre. The bar is equal to the pressure of 29·5306 in. or 750·076 mm. of mercury at 273°A. (32° F.) and in lat. 45°. The name was introduced into practical meteorology by V. Bjerknes, and objection has been raised by McAdie, of Harvard College, on the ground that the name had been previously appropriated by chemists to the C.G.S. unit of pressure, the dyne per square centimetre. The meteorological bar is thus one million chemical bars, and what chemists call a bar we should call a microbar. One bar is 100 centibars or 1,000 MILLIBARS.

Baroclinic.—A term used in dynamical meteorology for the field of mass when the surfaces of equal density or of equal specific volume cut the isobaric surfaces in a well defined system of curves of intersection. A field of mass may be represented by either of two variables, the density, defined as the mass per unit volume, or its reciprocal value the specific volume, which is the volume of unit mass. Both are represented by the same family of equiscalar surfaces. When the equisubstantial surfaces coincide with the isobaric, i.e. when the specific volume or density is a function of the pressure, then the field of mass is *barotropic*.

Barograph.—A self-recording barometer, an instrument which records automatically the changes of atmospheric pressure. In one form of mercury barograph the movements of the mercury in a barometer are communicated by a float to a pen in contact with a moving sheet of paper carried by a revolving drum which is driven by clockwork. In another form in use at Kew and other observatories, the position of the mercury MENISCUS is recorded photographically.

The portable barographs which are in common use are arranged to record the variations of pressure shown by an aneroid barometer, and on that account they are sometimes referred to as ANEROIDOGRAPHS. Particulars as to the method of using these instruments are given in the "Meteorological Observer's Handbook." (M.O. Publication 191.)

Barometer.—An instrument for measuring the pressure of the atmosphere. The mercury barometer has been found to be the most satisfactory form for general use. The principle underlying this type of instrument is quite simple. If a glass tube, 3 ft. long, closed at one end, is filled with mercury and the open end is temporarily stopped up and immersed in an open vessel of the same liquid, then if the tube is held in a vertical position and the immersed end is re-opened, the mercury will fall until the level inside the tube stands at a height of about 30 in. above the mercury in the open vessel. The pressure of the atmosphere on the lower mercury surface balances the tendency of the enclosed column to fall, and the height supported in this way represents the atmospheric pressure at the time. In order to compute the pressure, the length or height of the column of mercury has to be measured. Different mercury barometers vary as regards the method of reading this height, and in all, the temperature of the mercury and the latitude of the place must be taken into account.

In the "Fortin" barometer, the zero of the scale consists of a fixed pointer and the cistern is made flexible so that the mercury level in the cistern may be brought into coincidence with the zero before a reading is taken. In the "Newman" pattern the cistern is rigid but the scale is mounted on a movable rod so that a similar zero adjustment may be made by moving the scale instead of the mercury. In the Kew pattern barometer, no zero adjustment is provided, but the scale is graduated in such a way that the changes of level in the cistern are automatically allowed for. Since in such barometers, it is not necessary to see the mercury in the cistern the latter may consist of a solid cup, preferably of stainless steel.

In the ANEROID BAROMETER, changes in the pressure of the atmosphere cause changes in the distance apart of the opposite faces of a closed shallow metallic box, nearly exhausted of air. These changes are communicated to a pointer moving over a suitably engraved scale.

For the purposes of meteorology, the pressure of the atmosphere has to be determined to the ten-thousandth part, which is a much higher degree of accuracy than is required in other meteorological measurements. Special contrivances and precautions are, therefore, required, a description of which will be found in the "Meteorological Observer's Handbook."

Barometric Tendency.—A term used to denote the change in the barometric pressure within the three hours preceding an observation. Entered upon synoptic charts, barometric tendencies are of the greatest value in affording a ready means of identifying the regions where the barometer is in process of rising or in process of falling. Lines drawn through places of equal barometric tendency are termed ISALLOBARS and charts of isallobars are useful for indicating in a clear way the changes in pressure which are taking place.

Barothermograph.—An instrument registering temperature and pressure simultaneously. The best known form is the Dines balloon meteorograph, in which a single recording stylus is caused to move in one direction by a change of pressure and in a direction almost at right angles by a change of temperature. The trace, therefore, shows corresponding values of temperature and pressure, from which the height can be computed. The name has also been applied to instruments in which separate barograph and thermograph movements are arranged to record on the same chart.

Barotropic.—See BAROCLINIC.

Bearing.—An arc of the horizon, less than 90°, measured between the true north or south point and the object whose position it is desired to measure. Thus a bearing will have the form "N.47°E." or "S.89°W." and so on. If the object is situated due west or due east from the point of observation the bearing is given as "W." or "E." Bearing is the nautical equivalent of AZIMUTH.

Beaufort Notation.—A code of letters indicating the state of the weather which was originally introduced by Admiral Sir Francis Beaufort for use at sea, but which is equally convenient for use on land. Some additions have been made to the original schedule and it now stands as follows :—

b blue sky, whether with clear or hazy atmosphere.
bc sky partly cloudy.
c cloudy, i.e., detached opening clouds.
d drizzle.
e wet air without rain falling, a copious deposit of water on trees, buildings, or rigging.
f fog.
fe wet fog.
g gloom.
h hail.
l lightning.
m mist; range of visibility 1,100 yards or more, but less than 2,200 yards.
o overcast, i.e., the whole sky covered with one impervious cloud.
p passing showers.
q squalls.

KQ line squall.
r rain.
rs sleet, i.e., rain and snow together.
s snow.
t thunder.
tl thunderstorm.
u ugly, threatening sky.
v unusual visibility of distant objects.
w dew.
x hoar frost.
y dry air (less than 60 per cent. humidity).
z haze; range of visibility 1,100 yards, or more, but less than 2,200 yards.

Beaufort used small letters in his notation but under the new convention a capital letter is used to denote intensity of the phenomenon to be noted; at the other end of the scale occasions of slight intensity are indicated by a small suffix $_0$. Continuity is indicated by a repetition of the letter and intermittence by prefixing the letter i. Thus we have :—

R heavy rain.
r (moderate) rain.
r_0 slight rain.
RR continuous heavy rain.
rr continuous (moderate) rain.
ir_0 intermittent slight rain.

For further details in the interpretation of the Beaufort Notation see the "Meteorological Observer's Handbook."

Beaufort Scale of Wind Force.—Wind force is estimated on a numerical scale ranging from 0, calm, to 12, hurricane, first adopted by Admiral Beaufort. The specification of the steps of the scale originally given had reference to a man-of-war of the period 1800–50, and therefore now possesses little more than historic interest. Full details of the Beaufort scale, including the original specification, are given in the following table. The introduction of anemometers led to the necessity for a scale of equivalents between Beaufort numbers estimated by experienced observers and the velocity of the wind in miles per hour. Experiments in this country showed that the relation could be expressed approximately by the equation $V = 1{\cdot}87\sqrt{B^3}$ where V is expressed in miles per hour and B is the corresponding Beaufort number; the velocity equivalents in the table are based on this formula. The pressure equivalents are derived from the formula $P = {\cdot}003\ V^2$ where P is expressed in lbs. per square foot, and V in miles per hour.

As the use of the Beaufort numbers spread to other nations it was apparent that different countries were using different scales of equivalents; accordingly, at the meeting of the International Meteorological Committee in 1921, Dr. Simpson was asked to look into the matter of proposing a definite scale of equivalents. Dr. Simpson's proposal as set out in *Professional Notes* No. 44 was adopted by the International Meteorological Committee at its meeting in Vienna in 1926. The following table gives the equivalents proposed by Dr. Simpson.

Code Number.	*Limits of velocity.*	
	Metres per second.	*Miles per hour.*
0	0 – 0·5	0 – 1
1	0·6 – 1·7	2 – 3
2	1·8 – 3·3	4 – 7
3	3·4 – 5·2	8–11
4	5·3 – 7·4	12–16
5	7·5 – 9·8	17–21
6	9·9–12·4	22–27
7	12·5–15·2	28–33
8	15·3–18·2	34–40
9	18·3–21·5	41–48
10	21·6–25·1	49–56
11	25·2–29·0	57–65

SPECIFICATION OF THE BEAUFORT SCALE WITH PROBABLE EQUIVALENTS OF THE NUMBERS OF THE SCALE

Beaufort Number	Specification of Beaufort Scale for use on land, based on observations made at land stations	* Mean pressure (at standard density) on a disc of 1 sq. ft.		Equivalent speed in miles per hour at 33 ft.	Limits of speed. At 10 m. (33 ft.) in the open		
		mb.	Lb. per sq. ft.		Miles per hour	Metres per second	Feet per second
0	Calm; smoke rises vertically	0	0	0	Less than 1	Less than 0·3	Less than 2
1	Direction of wind shown by smoke drift, but not by wind vanes	·1	·01	2	1–3	0·3–1·5	2–5
2	Wind felt on face; leaves rustle; ordinary vane moved by wind	·04	·08	5	4–7	1·6–3·3	6–11
3	Leaves and small twigs in constant motion; wind extends light flag ..	·13	·28	10	8–12	3·4–5·4	12–18
4	Raises dust and loose paper; small branches are moved	·32	·67	15	13–18	5·5–7·9	19–27
5	Small trees in leaf begin to sway; crested wavelets form on inland waters ..	·62	1·31	21	19–24	8·0–10·7	28–36
6	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.	1·1	2·3	27	25–31	10·8–13·8	37–46
7	Whole trees in motion; inconvenience felt when walking against wind.. ..	1·7	3·6	35	32–38	13·9–17·1	47–56
8	Breaks twigs off trees; generally impedes progress	2·6	5·4	42	39–46	17·2–20·7	57–68
9	Slight structural damage occurs (chimney pots and slates removed)	3·7	7·7	50	47–54	20·8–24·4	69–80
10	Seldom experienced inland; trees uprooted; considerable structural damage occurs.	5·0	10·5	59	55–63	24·5–28·4	81–93
11	Very rarely experienced; accompanied by widespread damage..	6·7	14·0	68	64–75	28·5–33·5	94–110
12	.. ..	Above 8·1	Above 17·0	Above 75	Above 75	Above 33·5	Above 110

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

† One millibar = 10^3 dynes per square centimetre = approx. 10 kilograms per square metre.

Beaufort Number, International	Beaufort's description of wind International	Deep-sea criterion, 1874, International		Coastal criterion
0	Calm	—		—
1	Light air	Just sufficient to give steerage way**		Sufficient to give good steerage way to fishing smacks with the "wind free."†
2	Light breeze	That in which a well-conditioned man-of-war with all sail set and clean full, would go in smooth water from	1 to 2 knots	Fishing smacks with topsails and light canvas "full and by" make up to 2 knots.
3	Gentle breeze		3 to 4 knots	Smacks begin to heel over slightly under topsails and light canvas make up to 3 knots "full and by."
4	Moderate breeze		5 to 6 knots	Good working breeze. Smacks heel over considerably on a wind under all sail.
5	Fresh breeze	That to which she could just carry in chase, full and by	Royals, etc.	Smacks shorten sail.
6	Strong breeze		Topgallant sails	Smacks double-reef gaff mainsails.
7	Moderate gale*	That to which she could just carry in chase, full and by	Topsails, jib, etc.	Smacks remain in harbour and those at sea lie to.
8	Fresh gale		Reefed upper topsails and courses.	Smacks take shelter if possible.
9	Strong gale		Lower topsails and courses.	—
10	Whole gale	That with which she could scarcely bear lower maintopsail and reefed foresail.		—
11	Storm	That which would reduce her to storm stay-sails		—
12	Hurricane	That which no canvas could withstand		—

For the purpose of showing the forces of winds by wind roses on Meteorological Charts, winds are grouped as follows:—

Scale Numbers.	
0	Calm.
1 to 3	Light winds
4 to 7	Moderate winds.
8 and above	Gales.

* For statistical purposes Force 7 is not reckoned as a gale.

** A full-rigged ship of 1874.

† Cutter or yawl rigged average-sized sailing trawler, loaded, with clean bottom.

Bishop's Ring.—A dull reddish-brown ring which is seen at certain periods round the sun in a clear sky. In the middle of the day the inner radius of the ring is about 10°, the outer 20°, but when the sun is low the ring becomes larger, the brightest part being about 19° from the sun. After sunset the ring is lost in the warm colours of the sky. Bishop's ring was first observed after the great eruption of Krakatoa in 1883 and remained visible till the spring of 1886, and was no doubt due to minute particles shot out by the eruption and remaining in the atmosphere at great heights. Bishop's ring was seen again after the eruptions of the Souffrière in St. Vincent and Mount Pelée, in Martinique, in 1902. Like the brownish ring surrounding the AUREOLE observed in clouds the phenomenon is explained by diffraction.

Bize.—A cold, dry wind which blows in the winter in the mountainous regions of southern France from the N., NE. or NW. The cold NW. wind which occurs in Languedoc, near the Mediterranean coast, and differs from the MISTRAL in that it is accompanied by heavy clouds has been given the name of "bise noire."

Black-bulb Thermometer.—A mercurial maximum thermometer with blackened bulb, mounted in an evacuated outer glass sheath and exposed horizontally to the sun's rays for the purpose of ascertaining the maximum temperature "in the sun." On account of the difficulty of obtaining comparable results with different instruments and of interpreting the indications of an individual instrument, black bulb thermometers are not now recommended as a means of measuring solar radiation. Such measurements are carried out with a PYRHELIOMETER.

Blizzard.—A term originally applied to the intensely cold northwesterly gales accompanied by fine drifting snow which may set in with the passage of a depression across the United States in winter.

The term has come to be applied to any high wind accompanied by great cold and drifting or falling snow, especially in the Antarctic, where, however, the blizzards often cause a rise of temperature by removing the surface layer of very cold air formed during calms.

Blood-rain.—Rain of a red colour which leaves a red stain on the ground. The coloration is due to the drops containing small dust particles which have been carried by currents in the upper air, sometimes for long distances, from some sandy region. The phenomenon has been most frequently observed in Italy, but it has been known to occur in this country.*

Bloxamize.—A method of smoothing mean values adopted by J. C. Bloxam.† By this method ten consecutive daily means are grouped together and the mean taken, this mean applies to the centre of the period, which is dated 5½. Similarly, the mean of days 2—11 is dated 6½, etc. In this way a series of 365 means centring at the half dates is obtained. If the process is repeated a new series is obtained centring at the whole dates. Bloxam applied this process an even number of times until a smooth curve of values was obtained. In the case of temperatures at Newport, in the Isle of Wight, to obtain a series of values of continuous ascent and descent, he found it necessary to apply the process 22 times.

Blue of the Sky.—The blue of the sky is due mainly to the scattering of sunlight by the individual molecules constituting the air. It was demonstrated mathematically by the fifth Lord Rayleigh that if light of different wave-lengths were to pass through a medium containing very small particles the proportion to be scattered would be greater the shorter the wave-length of the light. Thus the short waves composing the blue and violet end of the spectrum are scattered more than the long red and yellow waves. Hence light passing through a medium containing a great

* See *London, Q.J.R. Meteor. Soc.*, **28**, 1902, pp. 229–52 and **30**, 1904, pp. 57–91.

† The Meteorology of Newport, I.O.W., Ryde, 1858, p. 16.

number of such particles is left with an excess of red, whilst light emerging laterally has an excess of blue. It is for this reason that soapy water looks yellowish when one looks through it at a source of white light and bluish when one looks across the direction of illumination.

That a column of air viewed across the direction of illumination also appears blue was demonstrated in the laboratory by the present Lord Rayleigh. Accordingly there is no need to assume the existence of grosser particles suspended in the air to explain the normal blue of the sky. Where large particles due to smoke or dust are present the light scattered by them does not contain so high a proportion of blue, in other words the blue of the sky is diluted with white. The sky as seen from high mountains is of a deeper but purer blue because there are fewer large particles in suspension than at lower altitudes.

For systematic comparisons of the depth of colour in the blue sky, a scale has been devised by F. Linke, of the Meteorologische-Geophysikalische Institut, Frankfurt. On this scale white is 0 and ultramarine blue is 14. The scale is used in book form. By this means sky colour can be compared with other variables such as the amount of dust in the atmosphere.

Bolometer.—An instrument for the determination of the intensity of radiation of a definite wave-length, employing a blackened conductor whose change of resistance with temperature furnishes a measure of the quantity required. The instrument is largely employed in the investigation of the distribution of energy in the spectrum, especially in the infra-red region.

Board of Trade Unit.—See KILOWATT-HOUR.

Bora.—A cold north-easterly wind of KATABATIC origin which blows on the northern shore of the Adriatic. It occurs mainly in winter when the temperature is low and pressure is high over the high land to the north and north-east of the Adriatic. The initial temperature of this air is so much lower than that of the air over the sea that in spite of the adiabatic warming due to its descent from the high ground to sea level, it reaches the coast as a cold wind. When high pressure over Central Europe coincides with the passage of a depression along the Mediterranean this wind may attain gale force, velocities up to 85 miles per hour and gusts up to 134 miles per hour having been experienced at Trieste.

The bora also occurs at Novorossiisk, on the north-east coast of the Black Sea.

Bouguer's Halo.—In the eighteenth century descriptions were published independently by Bouguer and by Antonio de Ulloa of a phenomenon which they had seen together on near-by clouds on the Andes. Each observer reports seeing on many occasions his shadow (which we should call the Brocken Spectre), rainbow-coloured rings round the shadow of his head (i.e., a glory), and outside the coloured rings and somewhat removed from them a fourth ring of pure white. This outer ring, which has been called Ulloa's Ring, and also Bouguer's halo, was presumably a fog bow or white rainbow. The theory of Bidhu Bhusan Ray* explains how the reflection of light from small drops should produce simultaneously a glory and a white rainbow. In Bouguer's description it is stated that the phenomenon was to be seen only on clouds and even (même) on those of which the particles were frozen, not on drops of rain. It was, therefore, assumed that the outer ring was produced by reflection from ice crystals. This idea is embodied in the name Bouguer's halo, and numerous attempts have been made to determine the shape of crystals which would serve to reflect the light in the right way. It is likely, however, that even though crystals were present the clouds which Bouguer observed consisted mostly of supercooled water drops. There is no mention of simultaneous observations of an ordinary halo round the sun, and Bouguer's wording implies that on some occasions at least the particles were *not* frozen.

* *Calcutta, Proc. Indian Assoc. Cult. Sci.*, **8**, 1923, pp. 23–46.

Brave West Winds.—A nautical expression denoting the prevailing westerly winds of temperate latitudes. The region of westerly winds of the southern hemisphere is termed the Roaring Forties.

Breeze.—A wind of moderate strength. (See Beaufort Scale.)

The word is generally applied to winds due to convection, which occur regularly during the day or night; of this type the following may be mentioned—land and sea breezes, mountain breeze, valley breeze, glacier breeze.

British Summer Time (B.S.T.).—The standard of time in common use and that to which all legal and business transactions are referred in the British Isles during a period in summer which is defined by the Summer Time Act, 1925. British summer time is one hour in advance of Greenwich mean civil time, so that 9 h. G.M.T. is the same as 10 h. B.S.T. From 1926, the period of summer time in Great Britain, northern Ireland, the Channel Isles and the Isle of Man begins at 2 h. Greenwich mean time on the morning of the day next following the third Saturday in April (or if that day is Easter Day the day next following the second Saturday in April) and ends at 2 h. Greenwich mean time (3 h. B.S.T.) on the morning of the day next following the first Saturday in October.

Summer time was first introduced in 1916. From 1916 to 1925 the periods during which summer time was in operation were fixed year by year by Orders in Council and were as follows :—

	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925
From–	May 21	Apr.8	Mar.24	Mar.30	Mar.28	Apr. 3	Mar.26	Apr.22	Apr.13	Apr.19
to —	Oct.1	Sept.17	Sept.30	Sept.29	Oct. 25	Oct. 3	Oct. 8	Sept.16	Sept.21	Oct.4

In order that the statistics for the diurnal variation of meteorological phenomena may not be affected by the introduction of the disturbing effect of summer time, meteorological observations are normally made at fixed hours by G.M.T. throughout the year.

Brocken Spectre.—When an observer stands on a hill partially enveloped in mist and in such a position that his shadow is thrown on to the mist he may get the illusion that the shadow is a person seen dimly through the mist. The illusion that this person or "spectre" is at a considerable distance is accompanied by the illusion that he is gigantic. The Brocken is a hill in Germany. (See Glory.)

Brontometer, from *bronte*, a thunderstorm, a combination of apparatus for following and noting all the details of the phenomena of weather during a thunderstorm.

Brückner Cycle.—A recurrence of periods of cold and damp alternating with warm and dry years, the average interval between two successive maxima being 35 years, though individual cycles may range in length from 25 to 50 years. This recurrence was known to Sir Francis Bacon in 1625 but was rediscovered in 1890 by A. Brückner, who calculated its average length as 34·8 years. Since then periodicities of about this length have been found in many series of meteorological data. The last epoch of cold and rain was due in Europe about 1916 to 1920, but the amplitude is not large enough to dominate the irregular year to year variations.

Bumpiness.—A word used to define flying sensation in an unstable atmosphere. A state of turbulence of the atmosphere, in which both ascending and descending currents occur. Bumpiness may be due to vertical currents, set up as the result of irregular heating of the earth's surface, or to air streams following the well defined contours and irregularities of the ground. It may extend to considerable altitudes, but generally it is greatest in the lower layers up to about 3,000 ft. It varies with the character and strength of the wind, and is more common over the land than over the sea. Surface irregularities seldom affect the upper air to a height greater than three to four times that of the obstruction. (See Air Pockets.)

Buoyancy.—A term used to denote the load, including the envelope and fittings, which can just be supported by a balloon or an airship. This buoyancy arises from the difference between the density of the light gas inside the envelope and the heavier air outside. The vessel will just rest in equilibrium when the total weight is the same as that of the air displaced ; the load which can just be supported is thus the difference between the weight of the gas in the envelope and that of the volume of air displaced.

Buran.—A strong NE. wind which occurs in Russia and central Asia. It is most frequent in winter, when it is very cold and often raises a drift of snow, but strong NE. winds in summer are also termed buran. The winter snow-bearing wind is also termed *poorga.*

Buys Ballot's Law.—A study of synoptic charts caused Professor Buys Ballot, of Utrecht, to enunciate, in 1857, the law which states that if, in the northern hemisphere, you stand with your back to the wind, pressure is lower on your left hand than on your right, whilst in the southern hemisphere the reverse is true. Meteorologists often put the same law in a slightly different way by saying that in the northern hemisphere winds go anti-clockwise around low-pressure centres and clockwise around high-pressure centres, the reverse holding true in the southern hemisphere.

C.G.S.—Abbreviation for Centimetre Gram Second, used to denote the organised system of units for the measurement of physical quantities by units which are based upon the centimetre, the gram, and the second as fundamental units.

Calendar.—The word is derived from the Roman "Kalends," and connotes an arrangement of time into ordered sequences of hours, days, months, years, etc. Many attempts to secure simple calendars have been made and the form of the calendar has been frequently changed. There are three principal natural periods of time which have been used for the purposes of the calendar from time immemorial, viz., the (solar) day, the month and the year ; corresponding respectively and more or less exactly with the mean period of rotation of the earth in reference to the sun, the period of the revolution of the moon round the earth (about 29½ days), and the period required by the earth to revolve in its orbit around the sun (365 days, 5 hours, 48 min. and 46 sec.). Difficulties in constructing calendars arise from the facts that the year is an exact multiple neither of the solar day nor of the period of the moon's revolution. The former difficulty is very nearly overcome in the existing calendar by allocating 366 days instead of 365 to every fourth year (leap year), with the proviso that three times in every 400 years, a year which would normally be leap year reverts to a duration of 365 days. The practical rule is :—Every year of which the number is divisible by 4 without remainder is a leap year, excepting the centurial years, which are only leap years when the figures are divisible by 400 without remainder. The difficulty about the months was settled in the manner which is now current by the Roman Emperor Augustus, by whose vanity it was decreed that a regular sequence of months in pairs with 30 and 31 days respectively should be interrupted at August, the month which bears his name. The names of the months September (i.e. seventh) to December (tenth) are explained by the fact that at an earlier time the year commenced at March.

The definitions of other terms used in the calendar, such as hour, week, century, depend on the definitions of the day and year.

For purposes of meteorological statistics the division of the year into the twelve calendar months has become universal, but the unequal lengths of the months is inconvenient and is sometimes a factor which has to be borne in mind. The week is used in this country as unit of time for certain meteorological and agricultural purposes, while for more detailed work the day and even the hour are employed as units. A period of 5 days was used in the Meteorological Office for the years 1887 to 1899 owing to the facilities which this unit offered for the seasonal harmonic analysis of statistical data.

Calibration.—The name ordinarily given to the process of ascertaining the corrections to be applied to the indicated readings of an instrument in order to obtain true values.

Calm.—Absence of appreciable wind. Smoke rises vertically. On the BEAUFORT SCALE OF WIND FORCE calm is accorded the figure 0.

Calorie—or **gramme-calorie.**—The heat required to raise the temperature of 1 gram of water by 1°A. at 288°A. The calorie is often used in connexion with measurements of solar radiation. Thus the SOLAR CONSTANT is usually expressed as having a mean value of 1·93 calories per square centimetre per minute.

A "large calorie" or "kilogram-calorie" is the heat required to raise the temperature of 1 kilogram of water by 1°A. at 288°A.

1 gram calorie $= 4\cdot18$ joules $= 4\cdot18 \times 10^7$ ergs $= 4\cdot18$ watt-sec.

Cap.—A name frequently given to the transient patches of cloud which sometimes form on or just above the tops of growing cumulus clouds, and are soon absorbed into them. It is also used for clouds on hill tops. (See LENTICULAR.)

Catchment Area.—The area of the earth's surface from any part of which rain falling thereon, if the ground were impermeable and no rain re-evaporated, would flow by gravitation past a certain part of a natural watercourse. (See FLOW-OFF.)

Celsius, Anders.—A Swedish astronomer and physicist, born at Upsala on the 27th November, 1701. He held the chair of astronomy at the University of his native town from 1730 until his death in 1744. His thermometer was first described in a paper to the Swedish Academy of Science in 1742. He divided the interval between the freezing and boiling points of water into 100 parts, the lower fixed point being marked 100. The present system whereby the freezing point is marked 0 and the boiling point 100 was introduced by Christin, of Lyons, in 1743.

This particular scale is now generally referred to as the CENTIGRADE scale or the Celsius scale, and sometimes the centesimal scale.

Centigrade.—A modification of the thermometric scale introduced by ANDERS CELSIUS. It has its zero at the melting point of ice, while 100° represents the boiling point of pure water at a pressure of 760 mm. of mercury. A centigrade degree is $\frac{9}{5}$ of a Fahrenheit degree. On the centigrade "absolute" scale the freezing point of water is at 273·1°A., the unit being the same as a centigrade degree. (See ABSOLUTE TEMPERATURE.)

Centimetre.—The hundredth part of a METRE.

Centre of Action.—In discussing the abnormally cold winter of 1879–80 in France, Teisserenc de Bort concluded that the character of any winter was determined by the relative positions and intensities of the Icelandic "low" and the Azores and Siberian anticyclones. He accordingly (in 1881) designated these and similar areas of low and high pressure as "the great centres of action of the atmosphere." The term was brought into general use by the writings of H. H. Hildebrandsson; originally it was applied to depressions and anticyclones seen on an ordinary daily synoptic chart, as well as to those more permanent lows and highs represented on charts of monthly averages, but the former, transitory features are not now generally included in the term "centre of action." On the other hand, the term is sometimes extended to include areas such as South America or the Mediterranean, which are not occupied by semi-permanent lows or anticyclones, but where the barometric pressure is closely correlated with the contemporary or subsequent pressure of many other parts of the world. The idea may be extended still further to include areas where the important element is not pressure, but temperature, rainfall or ice. Sir Gilbert Walker defines centres as "active" if they are highly correlated with *subsequent* conditions at other centres, and "passive" if they are correlated with *preceding* conditions.

Chart.—A map of an area of the earth showing lines of latitude and longitude, and the more important physical features of the area (sometimes only the coast line appears), upon which is superposed a representation of the distribution of some physical quantity over the area. Examples are weather charts, isobaric charts, charts of ocean currents, etc. Sometimes the word chart is applied also to what are more properly termed diagrams or graphs.

Chinook.—A warm dry wind, similar in character to the FÖHN, which occurs on the eastern side of the Rocky Mountains. It blows from the west across the mountains and is warmed adiabatically; it usually occurs suddenly, a large rise in temperature takes place, and the snow melts very rapidly.

Circulation of the Atmosphere.—See ATMOSPHERIC CIRCULATION.

Cirro-cumulus (Ci.-Cu.) (Mackerel Sky)—*Small rounded masses or white flakes of cloud without shadows, or showing very slight shadow, arranged in groups and often in lines.* (See CLOUDS.)

Cirro-stratus (Ci.-St.).—*A thin sheet of whitish cloud; sometimes covering the sky completely and merely giving it a milky appearance; it is then called cirro-nebula or cirrus haze; at other times presenting more or less distinctly a fibrous structure like a tangled web.* This sheet often produces halos around the sun or moon. (See CLOUDS.)

Cirrus (Ci.).—*Detached clouds of delicate appearance, fibrous (threadlike) structure and feather-like form, generally white in colour* (Fig. 7). Cirrus clouds take the most varied shapes, such as isolated tufts of hair, i.e. thin filaments on a blue sky, branched filaments in feathery form, straight or curved filaments ending in tufts (called cirrus uncinus), and others. Occasionally cirrus clouds are arranged in bands, which traverse part of the sky as arcs of great circles, and as an effect of perspective appear to converge at a point on the horizon, and at the opposite point also if they are sufficiently extended. CIRRO-STRATUS and CIRRO-CUMULUS also are sometimes similarly arranged in long bands. (See CLOUDS.)

Clear Sky, Day of.—In a resolution adopted at the International Meteorological Meeting at Utrecht in 1874, a "day of clear sky" is defined as one on which the average CLOUDINESS at the hours of observation is less than two-tenths of the sky.

Climate.—The average weather conditions of any locality. A climatic table should include data for each month and for the year, for all the elements of weather which affect human health or activity. Under temperature should be given the mean daily temperature, the mean daily maximum and minimum, the average extreme values and the highest maximum and lowest minimum temperatures recorded in each month; temperatures at different depths in the soil are also useful if available. Other data are the average relative humidity and amount of cloud at different hours, the duration of bright sunshine, the average rainfall with the maximum amount recorded in 24 hours, the frequencies of days of rain, snow, hail, thunder, frost, fog and gale, and the frequencies of winds from different directions, with the average velocity of the wind. Barometric pressure is not an important climatic element except at great altitudes. The table should be accompanied by a description of the characteristic weather of the different seasons, the average and extreme dates of first and last frosts and falls of snow, the duration of the snow cover, or in regions with definite wet and dry seasons, the onset of the rains. In some places the weather goes through a fairly regular series of daily changes, especially in connexion with the alternation of land and sea breezes, and this should be noted. The climate of a locality is governed by three factors, its latitude (see CLIMATIC ZONES), its position relative to the continents and oceans, and the local geographical conditions. The interiors and eastern parts of the great continents generally have a small rainfall, a low humidity and a great range of temperature, both from day to night and from summer to winter, giving a *continental* climate. Oceanic islands and the western parts of the continents generally have a heavier rainfall, a greater humidity, and a more uniform temperature, forming an *oceanic* or *insular* climate, but there are numerous exceptions, as on the western coasts of continents in sub-tropical latitudes, which have a desert climate. Local climates are modified by altitude above sea level and by the neighbourhood of mountain ranges or large lakes. Great towns are usually characterised by a local deficiency of bright sunshine due to the presence of smoke.

Climatic Changes.—During geological ages, the climate of any area such as England has not remained constant, but has varied over a wide range. Twenty million years or so ago the climate of England was warmer than at present, but a few hundred thousand years ago the climate was glacial. It is now generally admitted that there have been variations of temperature and rainfall in north-western Europe since the close of the ICE AGE, and that about 3,000 to 1,500 B.C. the temperature was higher than at present, forming the "Climatic Optimum," while a period of cold rainy weather began about 850 B.C. There are indications of a dry period in the north temperate belt in the sixth to eighth centuries. and of a period of great storminess and heavy rainfall in the twelfth to fourteenth centuries, but the changes during the Christian era are not universally accepted. The principal evidence for them is, in Europe, fluctuations of Alpine glaciers and in the traffic across Alpine passes ; in Asia, variations in the level of the Caspian Sea and other salt lakes ; in North America, variations in the rate of growth of the *Sequoias* of California, some of which are more than 3,000 years old. As a rule instrumental meteorological observations do not reveal any indications of climatic changes, but the series of rainfall measurements in England, which have been standardized over a period of 200 years, point to a pronounced dry period in the first half of the eighteenth century. Very little is known as to the causes of these climatic changes ; the later ones of small extent are probably to be attributed to variations of solar radiation, but no generally accepted explanation has yet been found for geological changes of climate.

Climatic Zones.—The word CLIMATE is derived from a Greek word meaning "to incline," and the original zones of climate were zones in which the inclination of the sun's rays at noon was the same ; that is, zones of latitude. The accumulation of meteorological data has shown that winds and rainfall, as well as temperature, have a zonal arrangement, but that the true climatic zones do not run strictly parallel with lines of latitude. Eight principal zones are distinguished :—near the equator a zone of tropical rain climate, then two sub-tropical zones of STEPPE and DESERT climate, then two zones of temperate rain climate and, in the northern hemisphere only, an incomplete zone of boreal climate with a great annual range of temperature ; finally, two polar caps of snow climate. The equatorial zone is divided into the equatorial rain-forest zone, which extends over the Atlantic and Pacific Oceans as the DOLDRUMS, with rain in all seasons, and a belt of Savanna climate on either side, with a well-marked alternation of dry and rainy seasons, the latter occurring in the "summer" months. The sub-tropical zones include most of the world's great deserts—the Sahara and Arabia, Arizona, the Kalahari and the deserts of South America and Australia ; over the oceans they include the TRADE WIND belts and the HORSE LATITUDES. The temperate zones are divided into the Mediterranean climates, with mild rainy winters and hot dry summers, and the temperate rain belts, with rain in all seasons. On the eastern margins of the continents, especially in Asia, the sub-tropical desert zone and the Mediterranean climate are replaced by areas with a MONSOON climate. For a detailed classification of climates consult "Die Klimate der Erde," by W. Köppen, Berlin and Leipzig, 1923.

Climatology.—The study of CLIMATE.

Cloud-burst.—A term commonly used for very heavy rain, usually associated with thunderstorms. Extremely heavy downpours are sometimes recorded, which in the course of a very short time tear up the ground and fill up gulleys and watercourses; this may happen at any place, but it occurs frequently in hilly and mountainous districts, where it may sometimes be due to the sudden cessation of convectional movement, caused by the supply of warm air from the lower part of the atmosphere being cut off as the storm moves over a mountain range. With the cessation of the upward current, the raindrops and hailstones which it had been supporting must fall in a much shorter time than they would have done had the ascensional movement continued.

Cloudiness.—Amount of sky covered by cloud, irrespective of the type of cloud; estimated by eye-observation and usually expressed by a scale of tenths of sky covered. On this scale 10 represents a sky totally covered by cloud, and 0 an entirely cloudless sky. Observers are usually advised to subdivide the sky mentally into four quadrants, and to combine estimates of the amount of sky covered in each quadrant.

Charts showing the distribution of mean cloudiness over the earth in each month and the year are given in the "Manual of Meteorology," Vol. 2, by Sir Napier Shaw (Cambridge University Press, 1928).

Clouds.—The number of forms which clouds may take is almost infinite, but for purposes of description it is necessary to adopt some kind of classification, though whatever classification is used there must at times be border-line cases when a cloud seems to fall half-way between two classes and perhaps to belong to neither.

The systems of classification which have been proposed have sometimes been based on the observed appearance of the cloud and at other times on the supposed method of formation. There can be no doubt that the former is the correct method since an observer is able to judge definitely of the appearance while the method of formation of a given cloud must be to some extent a matter of opinion. The international cloud classification is based upon the appearance of clouds and consists of 10 forms which for convenience are sometimes separated into three classes of high clouds, medium clouds and low clouds as follows:—

High clouds—cirrus, cirro-stratus, cirro-cumulus.
Medium clouds—alto-cumulus, alto-stratus.
Low clouds—strato-cumulus, nimbus, cumulus, cumulo-nimbus, stratus.

Other forms which, though not at present included in the international classification are in fairly common use, are lenticular clouds and mammato-cumulus.

The definitions of these various cloud forms will be found under the individual names. Some general remarks on clouds and their method of formation are given here. The heights of clouds, even of one type, vary within very wide limits, and "high clouds" of the above classification may sometimes be found below "medium clouds." The level at which high clouds are generally found is between 25,000 ft. and 35,000 ft., while medium clouds are found between 10,000 ft. and 25,000 ft., and low clouds are usually below 10,000 ft. although the tops of large cumulus and cumulo-nimbus may rise much above this level. These average heights refer to temperate latitudes. The heights of clouds tend to be greater in summer than in winter, and greater in the tropics than in high latitudes. Clouds are almost entirely confined to the TROPOSPHERE and seldom penetrate into the STRATOSPHERE, the base of which is on the average at a height of about 35,000 ft. over the British Isles, though it is as high as 45,000 ft. in extreme cases.

Apart from surface fogs, clouds are due mainly to the air being cooled below its DEW-POINT by a reduction of pressure (see ADIABATIC), and by far the most effective cause of this is upward movement. There are three main types of vertical movement, and observations of the three-dimensional structure of clouds, which aviation has rendered possible, show that many of the more important cloud forms can be grouped together according to the nature of the vertical motion, in the following manner :—

(*a*) Slow upward movement of a large mass of air, due to orographic causes or to CONVERGENCE in the horizontal motion of the air underneath. This process is responsible for clouds of alto-stratus type and for continuous precipitation.

(*b*) Small air masses rising up through the atmosphere causing cumulus or cumulo-nimbus clouds and showers.

(*c*) Churning up of a layer of air by small eddies, which causes the upper part of the layer to be cooled and cloud to be formed if there is sufficient moisture. This gives rise to horizontal cloud sheets, i.e., stratus, strato-cumulus, alto-cumulus, cirro-cumulus.

In some cases two or three of these types of vertical motion operate together, and there are no sharply defined limits which separate the one from the other. If we try to trace out the life history of any particular cloud with the factors which have operated in the more remote as well as the immediate past to lead to its formation, we shall frequently find that more than one of the above processes must be involved.

The clouds associated with the three methods of formation may be considered in greater detail—

(*a*) Alto-stratus clouds are some thousands of feet thick, usually continuous but occasionally in a succession of layers. If the clouds are nebulous or fibrous in appearance, they normally consist entirely of ice crystals or snowflakes. There is some reason to think that the blurred appearance of the sun or moon (see Fig. 8) can only be produced by ice-crystal clouds; when seen through clouds of waterdrops, the edges of the disc are sharp. There is often an ill-defined base to the cloud where falling snowflakes evaporate or melt into rain. The clouds have no great opacity, and the sun can usually be seen dimly through several thousand feet of cloud.

Cirro-stratus cloud is of the same type as alto-stratus but is higher and more nebulous. It is frequently the advance guard of a large cloud mass which is formed in a current of air rising up a surface of DISCONTINUITY.

(*b*) Heap clouds: cumulus and cumulo-nimbus. Cumulus clouds are normally formed when the LAPSE rate of temperature below them is equal to the dry ADIABATIC rate (near the earth's surface this rate may be exceeded) so that air slightly warmer than its surroundings rises up like a bubble. They develop over the land on the majority of summer days, and dissolve in the evening. They also form in a cold current passing over a warmer sea surface. Once condensation takes place in a mass of rising air, latent heat is set free and the air cools at the adiabatic rate for saturated air. The growth of the cloud depends on whether the lapse-rate of temperature in the surrounding air is greater or less than the saturated adiabatic rate. If it is less, conditions are stable since the rising air becomes colder and therefore heavier than its surroundings and tends to fall back again. The clouds then tend to assume flat shapes and often spread out into a layer of strato-cumulus or alto-cumulus. If, however, the lapse-rate is greater than the saturated adiabatic the rising air remains warmer and lighter than its surroundings so that conditions are unstable, the clouds tend to tower upwards and develop into cumulo-nimbus. The cumulo-nimbus clouds usually develop from large masses or long banks of cumulus, and a group of clouds often amalgamates into one large mass, the whole process being spread over a few hours. It is not easy to fix the limit between large cumulus and cumulo-nimbus. Probably the occurrence of heavy precipitation furnishes the best criterion, but this cannot always be seen from a distance, and the development of precipitation does not depend only on the height

To face page 42.

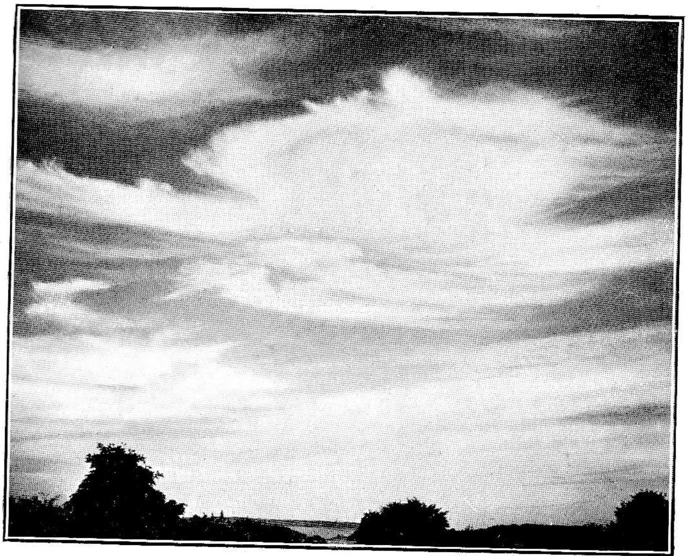


FIG. 7.—Cirrus clouds, thread or feather clouds at a height of from five to six miles, and generally of a white colour. They are composed of ice crystals.

The picture gives an idea of rather more massive structure than is usual with cirrus clouds, but the sweeps and wisps are very characteristic.

FIG. —8. Alto-stratus.

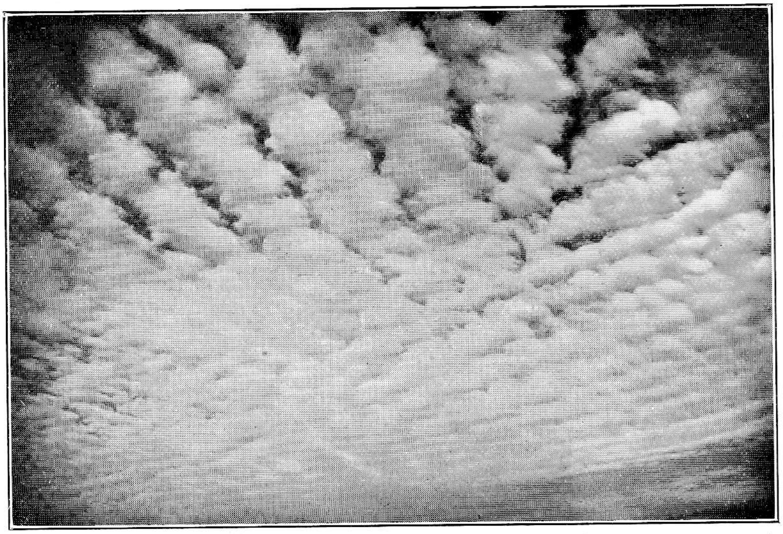


FIG. 9.—Alto-cumulus.

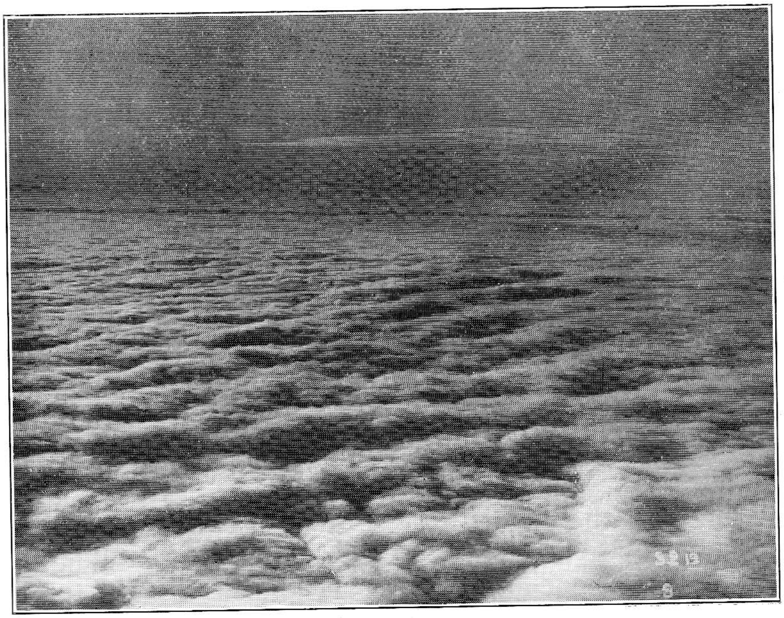


FIG. 10.—Strato-cumulus from an aeroplane.

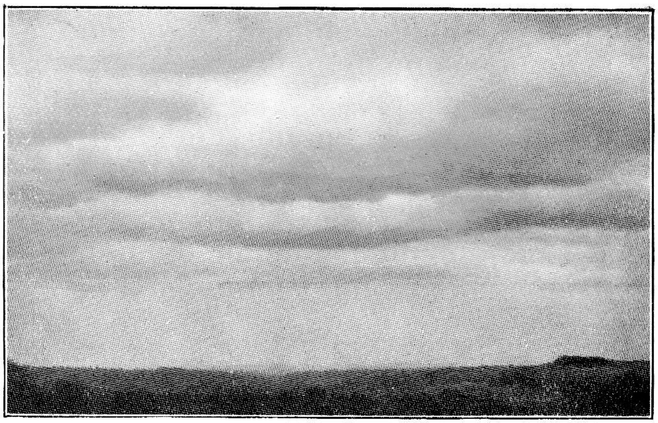


FIG. 11.—Strato-cumulus from below.

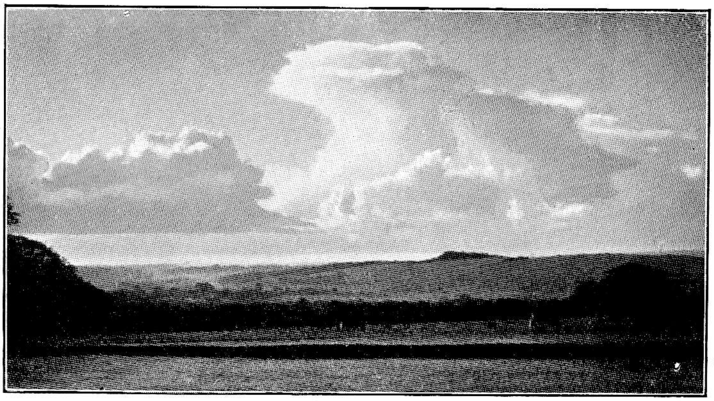


FIG. 12.—Cumulo-nimbus (Thunder-cloud) with "Anvil" extension of false cirrus, 30th October, 1915.

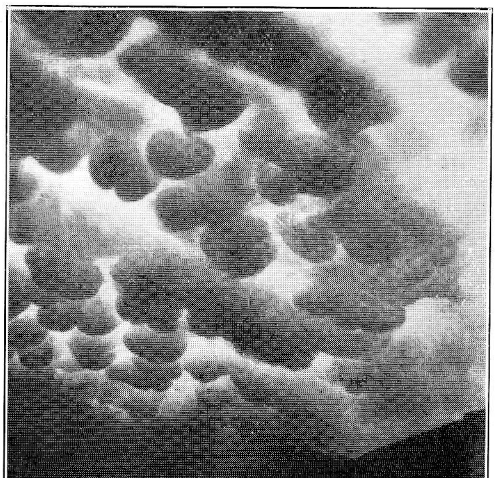


FIG. 13.—Mammato-cumulus.

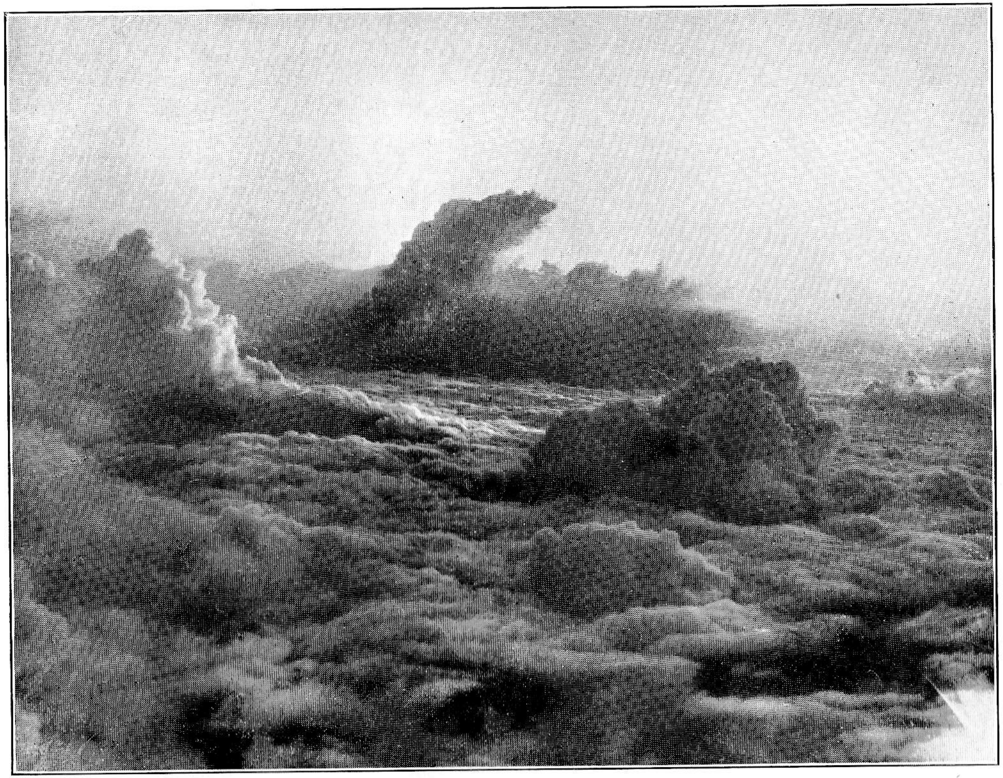


Fig. 14.—Cumulus protruding through strato-cumulus.

attained by the cloud summit, which may considerably exceed 10,000 ft. without showers. If the top becomes cirri-form (fibrous), the cloud is certainly cumulo-nimbus, but in the case of some heavy showers there is no cirri-form top. The tops of severe summer thunderstorms frequently reach a height of 25,000 ft., and probably sometimes 35,000 ft. or even more. The ANVILS consist mainly of snow and may remain after the storms die out, in the form of dense masses of cirrus or alto-stratus.

When the atmosphere is stable in the lower layers, but damp and unstable for saturated air above, cumulus clouds, and often eventually cumulo-nimbus, may develop from a layer of stratified clouds (formed by process (*a*) or (*c*) or both combined). The cloud known as alto-cumulus castellatus consists of a layer of small turreted clouds grouped like ordinary alto-cumulus and formed in this way. It is also possible for large cumulus or cumulo-nimbus to develop at relatively high levels, independent of convection from the earth's surface. The base of cumulo-nimbus may be above 10,000 ft., but in the British Isles such cases are rare and thunder and lightning are unlikely to develop. Clouds developed in a similar manner with a base at about 6,000 ft. may give rise to severe thunderstorms.

(*c*) Flat cloud sheets : stratus, strato-cumulus, alto-cumulus, cirro-cumulus. There is an essential similarity of structure between all these clouds, though the higher sheets are usually thinner than the lower, and have smaller cloudlets. The lower sheets often exceed 1,000 ft. in thickness, but layers less than 50 ft. thick may occur over limited areas at any height, often with quite small ripples. As a rule there is a definite arrangement of ripples or rounded cloudlets, and from above the clouds often resemble the sea (Fig. 10). Even low stratus is frequently rippled on its upper surface. The lower surface usually appears uniform, but even if structure existed it might be difficult to see, owing to bad lighting. If there are definite ripples or waves, the maximum condensation occurs at the crests of the waves, where the air is subject to the maximum decrease of pressure.

It is found that the lapse-rate of temperature is high below these cloud sheets but relatively low just above them, often with an INVERSION (see also SURFACE OF SUBSIDENCE). Such a condition is accompanied by much TURBULENCE (i.e., a thorough churning up of the air by eddies) below the clouds and very little turbulence above them, and this is verified by observations of bumpiness by aeroplane pilots. It can readily be shown that this state of affairs favours the development and maintenance of a cloud sheet.

Sometimes a single sheet of strato-cumulus cloud causes dull weather for several successive days, especially in winter anticyclones. On summer days, and in suitable conditions over the sea, independently of time of day or season, there are frequently cumulus clouds below the strato-cumulus, whose tops may protrude through the latter (Fig. 14) breakng up the regularity of the sheet to some extent.

Cirrus clouds cannot at present be adequately discussed from the point of view of physical causes, though certain large tufts of great vertical extent have evidently a cumuliform structure, whether or not they are developed from the tops of cumulo-nimbus. A well marked thread-like structure indicates ice crystals, and sometimes cirrus clouds are formed by snow falling from alto-cumulus clouds, which consist of super-cooled water drops. There are certain very delicate forms of cirrus and cirro-stratus (with no long threads) which may cause brilliant CORONAE and IRIDESCENCE, and probably consist of very small spherical globules, and not of ice crystals. Cirro-cumulus clouds are also normally of this type.

Clouds, Weight of Water in.—Measurements on the Austrian Alps of the quantity of water suspended in clouds have given $0 \cdot 35$ gm./m^3 to $4 \cdot 8$ gm./m^3.

The water suspended as mist, fog or cloud may be taken as ranging from 0·1 to 5 gm./m^3. (See A. Wegener, "Thermodynamik der Atmosphäre," Leipzig, 1911, p. 262.)

Coefficient.—The number or known quantity prefixed as a multiplier to a variable or unknown quantity, as in coefficient of EXPANSION. The coefficient of CORRELATION is a measure of the relation between two quantities.

Col.—The saddle-backed region occurring between two anticyclones and two depressions, arranged alternately. Frequently on a weather map only two anticyclones appear, then the col is the region of relatively low pressure between them and may be likened to a mountain pass between two peaks. In a similar way the col may appear when only two depressions are shown on the weather map.

The wind circulations associated with the neighbouring anticyclones or depressions bring light airs from very different directions into close contact with one another in the col. The weather which results is occasionally brilliantly fine, but on account of the convergence of the winds cols are more usually cloudy or dull and gloomy. In summer thunderstorms are frequent and may occur in any part of the col, while conditions are favourable for the development of fog in winter.

The anticyclones, between which a col lies, are generally stationary or slow-moving, and the col occupies a region through which an approaching depression may readily pass. Hence, although a col does not usually move rapidly in itself, it does not as a rule form an abiding feature on the pressure map. (Plate II.)

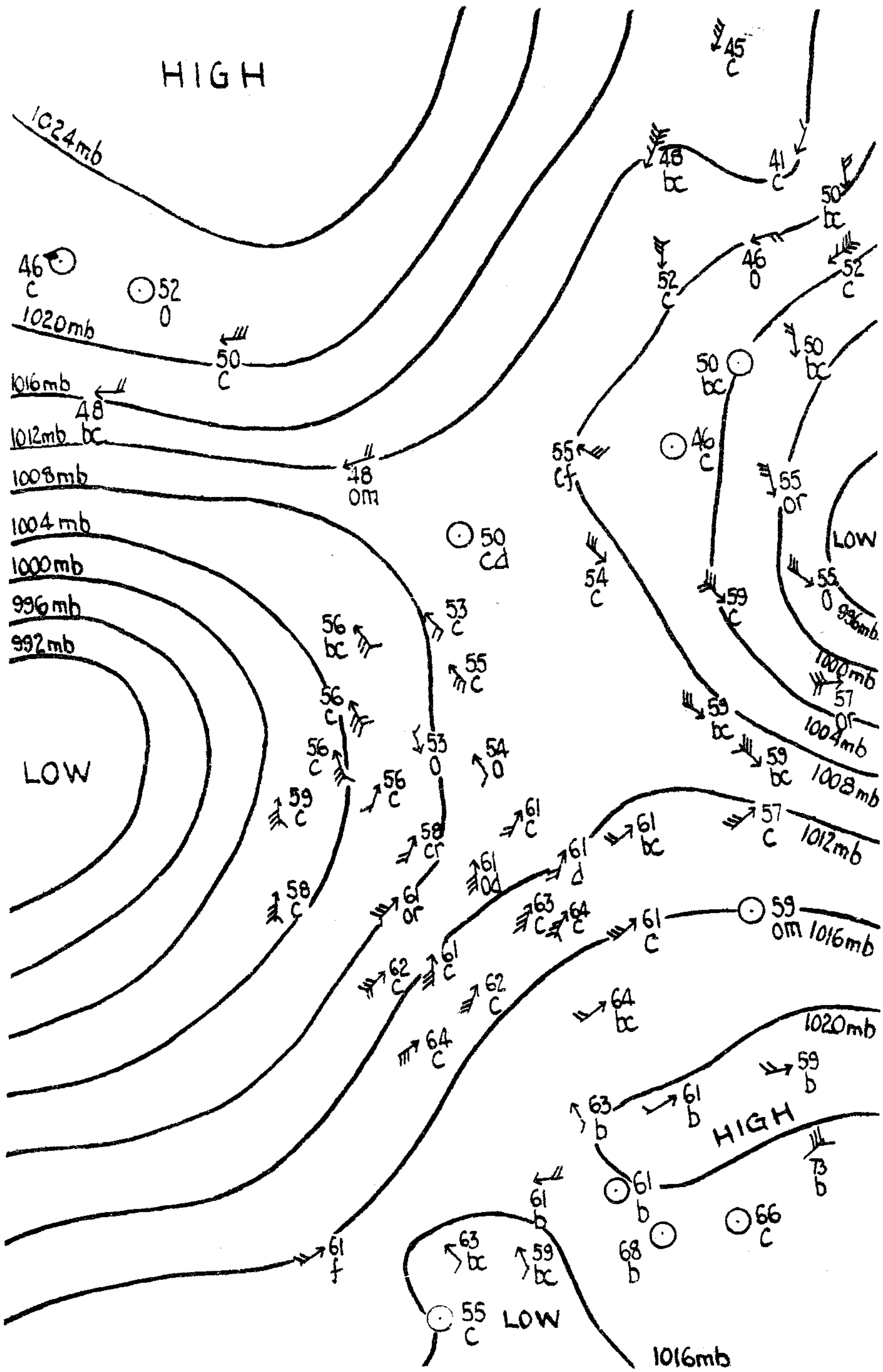
Cold Front.—The boundary line between advancing cold air and a mass of warm air under which the cold air pushes like a wedge. The surface of separation is called the frontal surface and this meets the earth in the cold front. Its passage is normally accompanied by a rise of pressure, a fall of temperature, a veer of wind, a heavy shower and sometimes a LINE-SQUALL, perhaps with thunder. The front is not always sharply defined, and sometimes it is not clearly shown by surface temperatures, but only by upper air temperatures, weather, wind, and barometric tendencies. Occasionally the barometer continues to fall behind the front, though at a much reduced rate.

The normal direction of slope of the frontal surface is at about 1 in 50 back from the cold front, but the point of the wedge may become rounded owing to friction holding back the advance of the cold air on the surface so that the direction of slope is reversed below about 2,000 ft. (See DEPRESSION.)

Cold Sector.—That part of a DEPRESSION occupied by cold air on the earth's surface, usually about half to three quarters of a recently formed depression, and the whole of an old one.

Cold Wave.—The fall of temperature associated with the cold NW. wind which sets in behind a passing depression in the northern hemisphere. The term is used in a technical sense by the United States Weather Bureau, with the meaning of a fall of temperature by a specified amount in 24 hours, to a minimum below a certain temperature. The amount of fall and the limit of minimum are different for different times of the year and for different parts of the country.

Compass.—The magnetic or mariner's compass consists in its simplest form of a graduated circular card at the centre of which a magnetized steel needle is suspended so that it may turn freely in a horizontal plane. The card is divided into 32 equal parts of 11¼° each, called points. The points are N, N. by E, NNE., NE. by E., NE. and so on. They are often called orientation points. The compass needle points to the magnetic north (see TERRESTRIAL MAGNETISM), not to the geographical north. At the present time the magnetic north lies 13° to the west of true north in



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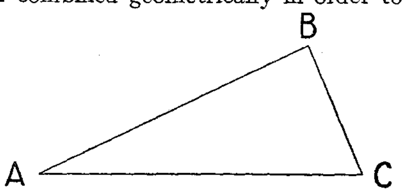
London and 18° to 19° west in the west of Ireland. Along two irregular *agonic* lines, one passing through North and South America and the other through parts of Europe, Asia and Australia there is at present no variation. In Arctic and Antarctic regions the variation is very large and in places the direction may even be entirely reversed, the north-pointing end of the needle indicating the south. Modern navigational compasses have to be so designed as to be unaffected by magnetic material in their vicinity, and the deviation and correction of the compass are matters of primary importance to seamen and air pilots. Erratic deviation may ensue from special causes, e.g. if a ship be struck by lightning or passes over a region of peculiar magnetic character.

Compensation of Instruments.—An instrument designed to measure changes in a particular physical quantity (e.g. pressure) may be affected also by some other influence (e.g. temperature). To eliminate or minimise the influence of the disturbing element, a device may be introduced for the purpose of rendering the instrument insensitive to changes in the latter, in which case it is said to be compensated. Thus, chronometers and aneroid barometers are ordinarily compensated for temperature.

Component.—A word used to indicate the steps, in their various directions, which must be compounded or combined geometrically in order to produce a given displacement. In the diagram, AC is the geometrical sum or resultant of the two components AB, BC wherever B may be. It is not necessary that the components should be at right-angles to each other. The above law of the composition of displacements is applicable to the composition of velocities, accelerations and forces.



Condensation.—The process of formation of a liquid from its vapour. In a closed space wherever there is a free surface of ice or water, EVAPORATION or condensation takes place until the water vapour exerts a definite "pressure of saturation," depending only upon the temperature, and not upon the pressure of the surrounding air. This pressure of saturation is very much greater at high than at low temperatures, as is shown in the following table :—

Temperature		Pressure of saturation	Temperature		Pressure of saturation
°F.	°A.	mb.	°F.	°A.	mb.
10	260·8	2·4	60	288·6	17·6
20	266·3	3·7	70	294·1	24·7
30	271·9	5·8	80	299·7	34·6
40	277·5	8·5	90	305·2	47·8
50	283·0	12·2	100	310·8	65·0

Aitken has shown that condensation occurs when saturated air is cooled, provided suitable nuclei are present, but not otherwise. In the atmosphere such nuclei are rarely if ever absent.

It is easily seen from the figures in the above table that saturated atmospheric air must at once yield waterdrops or ice particles if cooled, and even air that does not contain all the aqueous vapour possible will ultimately deposit moisture if sufficiently cooled.

In the passage from the liquid to the gaseous state great quantities of heat are absorbed, 539 calories for every gram of water evaporated at the boiling point, and even more if the water is initially cold. Conversely much heat is yielded up when condensation occurs.

The principal causes of cooling, such as may lead to condensation, are :—

(1) contact with solid bodies which are at a lower temperature,
(2) dynamical cooling due to rarefaction,
(3) mixing with air at a lower temperature.

The result of (1) is most often visible as dew or hoar frost, while (2) and (3) yield cloud or fog, and if carried far enough (2) will yield rain, snow, etc.

Conduction.—The process by which HEAT is transferred by and through matter, from places of high to places of low temperature, without transfer of the matter itself, the process being one of " handing on " of the heat-energy between adjacent portions of matter. It is the process by which heat passes through solids ; in fluids, although it occurs, its effects are usually negligible in comparison with those of CONVECTION.

Constant.—A quantity which does not vary within the limits of space or time (or both) under consideration. See also SOLAR CONSTANT and RADIATION (Stefan's Constant).

Continentality.—In meteorology, a measure of the extent to which the climate of any place is influenced by its distance from the sea. The influence of continentality is most clearly shown on the diurnal and annual ranges of temperature, the reason being that since water has a large capacity for heat and only relatively slight powers of absorption and radiation, its temperature can vary only slowly, while since land absorbs and radiates readily, its temperature can vary through a considerable range even within twenty-four hours. From some investigations by R. Spitaler and G. Swoboda, Brunt* has derived as a measure for continentality the expression :

$$\frac{\Delta t}{130 \cdot 61 \, \Delta S} - 0 \cdot 12$$

where Δt is the annual range of monthly mean temperature, and ΔS is the annual range in the intensity of solar radiation, expressed in arbitrary units at the latitude of the station. This expression gives values which range from very small negative figures in mid-ocean in the southern hemisphere up to + 1·30 in central Siberia, the latter being interpreted as a " super-continentality " of 30 per cent. The line along which this expression has a value of 0·5 separates the continental climates from the oceanic ; where the prevailing wind blows from the sea, as in Europe, it is found some distance inland.

Convection.—In convection heat is carried from one place to another by the bodily transfer of the matter containing it. In general, if a part of a fluid, whether liquid or gaseous, is warmed, its volume is increased, and the weight per unit of volume is less than before. The warmed part therefore rises and its place is taken by fresh fluid which is warmed in turn. Conversely, if it is cooled it sinks. Consequently, if heat is supplied to the lower part of a mass of fluid, the heat is disseminated throughout the whole mass by convection, or if the upper part is cooled the temperature of the whole mass is lowered by a similar process.

There are two apparent and important exceptions in meteorology. Fresh water, when below the temperature of 39·1°F., 277°A., expands instead of contracting on being further cooled. Hence a pond or lake is cooled bodily down to 39·1° but no further, as winter chills the surface before it freezes. Secondly, heat applied to the bottom of the atmosphere may stay there without being disseminated upwards when the atmosphere is exceptionally stable in the circumstances explained under ENTROPY.

Convectional Rain.—Caused by the heating of the surface layers of the atmosphere which expand and rise, giving place to denser cool air. The warm air is frequently heavily charged with moisture taken up from the ground or vegetation. The THUNDERSTORM rain of the summer afternoon

* *London, Geogr. J.*, **64**, 1924, p. 43.

is typically convectional rain. As in the case of OROGRAPHIC RAIN, condensation occurs when the process of expansion under diminishing pressure has reduced the temperature of the rising mass beyond its dew-point. The intensity of the rain in severe thunderstorms is much greater than that in any other type of rainfall. In the British Isles the intensity for a few minutes in a few cases has exceeded the rate of 10 in. per hour. (See also INSTABILITY SHOWERS.)

Convergence.—Consider a portion of the earth's surface, for convenience a square with sides 100 miles long running north to south and east to west, though the argument is applicable to any area. If the wind is uniform over the whole area as much air will flow into it on the sides which face the wind as flows out of it on the other sides. If, however, the wind is not uniform a case may arise when more air flows in than flows out. There is then said to be convergence. For example, suppose the wind is on the whole westerly. If along the south side of the square the wind is blowing a little from the S. of W. while along the north side it is blowing from the N. of W., there will be an inflow along both these sides. The amount of air which flows out on the eastern side of the square will, however, be equal to that flowing in on the western side, assuming the wind to be the same in both regions. Taking account of all four sides more air will therefore flow into the square than flows out of it, and there will be convergence over the area. The air cannot go on accumulating, and the excess will have to flow out at the top thus leading to a rising air current. It is this which gives convergence its importance. Rising air expands and is cooled (see ADIABATIC). If the cooling is continued long enough and the air contains moisture, this moisture will condense and cause cloud and rain. Except in arid climates, prolonged convergence of the lower currents of the atmosphere must therefore eventually give precipitation. Further, since these layers hold more moisture than those above, convergence without precipitation steadily increases the total water content contained in the whole column of air over a given area. It is important to note that geostrophic winds (see GRADIENT WIND) can give no appreciable convergence, for if the wind obeys the geostrophic law the amount of air which flows out of any area will be almost exactly equal to the amount which flows into it. There are two main causes of convergence. One is surface friction, which causes a flow of air near the ground across the isobars from high to low pressure, resulting in convergence in certain conditions, notably in the centre of a depression or along a trough of low pressure. Secondly, convergence takes place into a region of falling barometer, owing to lack of perfect balance between the wind and pressure gradient. This effect is smaller at the earth's surface than the frictional inflow into a depression, but as it extends much higher it is probably often more important.

Corona.—A series of coloured rings surrounding the sun or moon. The space immediately adjacent to the luminary is bluish white while this region is bounded on the outside by a brownish red ring, these two together forming the aureole. In most cases the aureole alone appears, but a complete corona has a set of coloured rings surrounding the aureole, violet inside followed by blue, green, yellow to red on the outside. The series may be repeated more than once, but the colours are usually represented merely by greenish and pinkish tints.

The corona is produced by DIFFRACTION of the light by waterdrops. If the colours are pure it is an indication that the drops are uniform in size. The radius of the corona is inversely proportional to the size of the droplets. Thus a corona, whose size is increasing, indicates that the water particles are diminishing in size.

A corona is distinguished from a halo which is due to REFRACTION by the fact that the colour sequence is opposite in the two, the red of the halo being inside, that of the corona outside. In applying this criterion it must be remembered, however, that the dull red which is the first notable colour in the aureole ranks as outside the bluish tint near the luminary. An alternative criterion is that the colours of the halo are at the inner edge of a luminous area, whilst those of a corona are at the outer edge.

Correction.—The alteration of the reading of an instrument in order to allow for unavoidable errors in measurement. The measurement of nearly all quantities is an indirect process, and generally takes the form of reading the position of a pointer or index on a scale. When we wish to know the *pressure* of the atmosphere we read an index on the scale of a barometer; when we wish to know the *temperature* of the air we read the position of the end of a thread of mercury in a thermometer.

Almost all measurements are ultimately reduced to reading a position or length on a graduated scale. Generally speaking, the reading depends mainly on the quantity which the instrument is intended to measure, but also partly upon other quantities. Thus the readings of barometers are generally affected by temperature as well as pressure, those of thermometers by alterations in the glass containing the mercury or spirit.

In most cases the amount of the error has to be determined and allowed for by a suitable "correction." An ANEROID BAROMETER is often compensated for temperature (see COMPENSATION OF INSTRUMENTS), and for a mercury barometer the effect of temperature is made out and tabulated and a correction introduced, which is derived from a table, when the temperature of the "ATTACHED THERMOMETER" has been noted. In a similar manner the correction of a barometer reading for the variation of GRAVITY at different parts of the earth's surface is worked by means of tables, the variation of gravity with latitude having been previously reduced to a formula, by means of observations from which the figure of the earth has been determined and the change of gravity has been ascertained.

In some measurements, such as the determination of height by the use of an aneroid barometer, corrections are numerous and complicated: the uncorrected reading may even be only a rough approximation not sufficiently accurate for practical purposes.

Correlation.—The method of correlation is a mathematical process for determining the degree of relationship between two variable quantities or *variates*. For example, it is found that when pressure at sea level at any place in Europe is unusually high, pressure at a height of 9 Km. above that place is generally high also. Let $x_1, x_2, \ldots x_n$ be the departures of n values of pressure at sea level from their mean, and $y_1, y_2, \ldots y_n$ the corresponding departures of the pressures at 9 km. The average variation of the y's about their mean is smaller than the average variation of the x's, but we can make the figures comparable by dividing each series by its "standard deviation" given by the expression:

$$\sigma_x = \left\{ (x_1^2 + x_2^2 + \ldots . x_n^2) / n \right\}^{\frac{1}{2}} = \left\{ \Sigma (x^2) / n \right\}^{\frac{1}{2}} \ldots (1)$$

The square of the standard deviation, $\sigma_x^2 = \Sigma (x^2) / \mathrm{n}$, is known as the *variance*.

If now the variations of x were strictly proportional to the values of y, knowing the one we could calculate the values of the other exactly, by means of the relationship:

$$x / \sigma_x = y / \sigma_y \quad \ldots\ldots\ldots \quad (2)$$

Such exact relationships rarely if ever occur in meteorology, but we can regard the variations of x as made up of two components, a part r which is strictly proportional to the variations of y, and another part c, which is independent of y. That is to say, we can write:

$$x / \sigma_x = r\, y / \sigma_y + c \quad \ldots\ldots\ldots \quad (3)$$

The figure r is a measure of the closeness of the relation between the two quantities x and y. It is accepted that the best value which can be given to r is that which gives the smallest possible figure for the sum of the squares of the values $c_1, c_2 \ldots c_n$ resulting from the substitution of $x_1, x_2 \ldots x_n$ and $y_1, y_2 \ldots y_n$ in (3), and this value of r is known as the *Correlation Coefficient.* When the two quantities x and y are exactly proportional, c is always zero, equation (3) reduces to (2) and r becomes $+ 1$. On the other hand if the two quantities are inversely proportional, c is again zero, but r is $- 1$. If there is no relationship at all between x and y, r is zero and $c = x$. The correlation coefficient obtained by the late W. H. Dines between pressure at sea level and that at 9 km., was $+ \cdot 68$.

The value of the correlation coefficient r is given by the expression:

$$r_{xy} = \frac{\Sigma\,(xy)}{n\,\sigma_x\,\sigma_y} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (4)$$

where $\Sigma\,(xy)$ is the sum of the products $x_1\,y_1$, $x_2\,y_2\;.\;.\;.\;x_n\,y_n$; n is the number of observations and σ_x, σ_y are the standard deviations of x and y obtained by (1).

The relation between x and y is generally expressed in the form:

$$x = b_{xy}\,y \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

$$\text{where } b_{xy} = r\,\sigma_x\,/\,\sigma_y$$

Equation (5) is the REGRESSION EQUATION of x on y, and b is known as the regression coefficient.

It should be noted that while the correlation coefficient between x and y is the same as that between y and x, and is independent of the units in which x and y are expressed, the regression coefficient of x on y is not the same as the regression coefficient of y on x, and neither are independent of the units.

It sometimes happens that we wish to take account of the effect of some third variate. For example, theoretically the pressure at sea level should be determined almost entirely by the pressure at 9 Km. and the temperature of the air between sea level and 9 Km. If we wish to see how far this is shown by the observations, we must calculate the partial correlation coefficient between pressure at sea level (x) and pressure at 9 Km. (y), eliminating the effect of variations of temperature in the intervening air layer (z). This partial correlation coefficient is usually denoted by $r_{xy\cdot z}$ and is given by the expression:

$$r_{xy\cdot z} = \frac{r_{xy} - r_{xz}\,r_{yz}}{(1 - r^2_{xz})^{\frac{1}{2}}\,(1 - r^2_{yz})^{\frac{1}{2}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

The values found by W. H. Dines were: $r_{xy} = + \cdot 68$, $r_{xz} = + \cdot 47$, $r_{yz} = + \cdot 95$. To calculate the partial coefficient accurately it would be necessary to employ three places of decimals in the original correlation coefficients or *coefficients of zero order* as they are called, but using the figures as given we find from (6) that $r_{xy\cdot z} = + \cdot 85$. The result obtained shows that when allowance is made for variations of temperature, the agreement between pressure at sea level and at 9 Km. is much closer than when no such allowance is made.

The regression equation of x on y and z gives the amount of variation of x which is associated with the variation of y, z being supposed constant, *plus* the amount of variation of x which is associated with the variation of z, y being supposed constant. It thus takes the form:

$$x = b_{xy\cdot z}\,y + b_{xz\cdot y}\,z \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

$$\text{where} \quad b_{xy\cdot z} = r_{xy\cdot z}\,\frac{\sigma_x\,(1 - r^2_{xz})^{\frac{1}{2}}}{\sigma_y\,(1 - r^2_{yz})^{\frac{1}{2}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

Partial correlation coefficients and regression equations between four or more variates can be obtained by an extension of the method given above, but as the number of variates becomes greater, the amount of arithmetic involved increases at a very rapid rate, and it is not usually practicable to work with more than six quantities.

Care needs to be exercised in attaching significance to correlation coefficients. If two random and entirely unrelated series of figures are correlated, the coefficient obtained will not usually be zero; if a large number of such trials be made it will be found that half of the coefficients are numerically larger than $0 \cdot 67/\sqrt{n}$ where n is the number of observations in each series. Any one coefficient therefore has an even chance of reaching or exceeding this value, so that with a small number of observations appreciable coefficients may occur between unrelated series. Similarly, if between two sets of related observations we obtain a correlation coefficient r, the most we can say is that the true correlation coefficient, which would be given by an infinitely large number of pairs of observations, has an even chance of being within the range $0 \cdot 67\ (1 - r^2)/\sqrt{n}$ on either side of the coefficient r actually found. This is known as the *probable error* of the coefficient.

Unless it is confirmed by physical reasoning or other independent evidence, a correlation coefficient should not be accepted as significant unless it exceeds three times its probable error, in which case the odds in favour of significance are 20 to 1. If a number of trial correlations are made, the chance of obtaining a single large coefficient is obviously greatly increased, and such an isolated coefficient should not be accepted unless it is four or five times its probable error.

If we calculate a series of values of x by means of the regression equation (5), the standard deviation of the difference between these calculated values and the observed values is $\sqrt{(1 - r^2)}$ of the standard deviation of the latter. Since this expression only differs appreciably from unity when r is large, it follows that single small correlation coefficients are of little value for forecasting purposes.

Examples of some large coefficients in meteorological work are:

Between mean temperature of the air from 1 to 9 km. and pressure at 9 Km., $+ \cdot 95$.

Between change of barometric pressure in 3 hours and corresponding change in level of water in a well at Richmond, $- \cdot 88$.

Between the number of thunderstorms in Central Siberia and the square root of the sunspot number, $+ \cdot 92$.

Cosmic Radiation (Hess Radiation).—The measurement of the flow of electricity through a closed metal vessel containing air indicates that the current is carried by ions formed within the vessel under the influence of a "penetrating radiation" from outside. This penetrating radiation has been found by Hess, Kolhörster and Millikan, to increase rapidly at great heights. It is more penetrating than radiation from radio-active substances, as may be demonstrated by sheathing the electrometer with many layers of lead or sinking it in deep water. The radiation does not come from the sun, for it is independent of the time of day. According to Millikan the radiation is generated in interstellar space, as protons and electrons combine to form atoms. On the other hand Jeans maintains that the radiation is produced by the simultaneous annihilation of protons and electrons and holds that Millikan's theory is inconsistent with the Second Law of Thermodynamics.

Crepuscular Rays.—Occasionally soon after sunset the sky is divided up into lighter and darker areas by lines which diverge from the position (below the horizon) of the sun. The lighter areas indicate parts of the atmosphere illuminated by sunshine, the darker areas those from which the sunshine is cut off by intervening mountains or by clouds. The phenomenon is essentially the same as that seen in the daytime when the sun is hidden by cloud and "ladders" diverging from the sun appear where there are gaps in the cloud. The "crepuscular rays" are coloured, the illuminated areas being pink and the shadows appearing greenish by contrast. The divergence of the "crepuscular rays" is an optical illusion as light rays from the sun are practically parallel.

Under favourable circumstances the shadows are thrown right across the sky and to an observer with his back to the sun the rays appear to converge to a point which is a little above the horizon. These anti-crepuscular rays are generally ill-defined and may be mistaken for patches of cloud.

Cumulo-Nimbus (Cu. Nb.). The Thunder Cloud; Shower Cloud.—*Great masses of cloud rising in the form of mountains or towers or anvils, generally having a veil or screen of fibrous texture (false cirrus) at the top and at its base a cloud-mass similar to nimbus* (Fig. 12). From the base local showers of rain or of snow, occasionally of hail or soft hail, usually fall. Sometimes the upper margins assume the compact form of cumulus and form massive heaps round which the delicate false cirrus floats. At other times the margins themselves are fringed with filaments similar to cirrus clouds. This last form is particularly common with spring showers. The front of a thunderstorm of wide extent is frequently in the form of a large low arch above a region of uniformly lighter sky. (See CLOUDS.)

Cumulo-Stratus.—A name formerly used to denote a cloud combination produced when CUMULUS clouds spread out on top to form a layer of STRATO-CUMULUS or ALTO-CUMULUS. It is not recognised in the International Classification.

Cumulus (Cu.) (Woolpack or Cauliflower Cloud).—*Thick cloud of which the upper surface is dome-shaped and exhibits protuberances while the base is generally horizontal.*—These clouds appear to be formed by ascensional movement of air in the daytime which is almost always observable. When the cloud and the sun are on opposite sides of the observer, the surfaces facing the observer are more brilliant than the margins of the protuberances. When, on the contrary, it is on the same side of the observer as the sun it appears dark with bright edges. When the light falls sideways, as is usually the case, cumulus clouds show deep shadows.

True cumulus has well defined upper and lower margins; but we may sometimes see ragged clouds—like cumulus torn by strong wind—of which detached portions are continually changing; to this form of cloud the name FRACTO-cumulus may be given. (See CLOUDS.)

Curve Fitting.—Two main types of problems arise in connexion with curve fitting. We may either require to represent a variable quantity as a function of some independent variable such as time, distance, latitude, etc., by drawing a curve to represent the functional relationship, or we may require to represent the frequency of occurrence of different values of a quantity, whether measured directly or indirectly, by means of a curve whose formula must be obtained. The simplest example of the first type is the fitting of a straight line to represent the relationship between pairs of measurements of two quantities, as is done in the normal treatment of CORRELATION between two variables. When the graphical representation of the observations indicates that the relationship is not linear, no general rule can be laid down for the subsequent procedure. Examination of the graph will in some cases indicate what must be the next step. If, for example, the graph indicates a repetition of the values of one variable at equal intervals of the other variable, there is a periodic relationship between them, and the data can be analysed by the methods of HARMONIC ANALYSIS. If the relationship is represented by a fairly smooth curve, it is frequently possible to derive an idea of the exact nature of the curve by plotting the data on logarithmic or semi-logarithmic paper. If the relationship is of the nature $y = Ax^n$, plotting on logarithmic paper will yield the values of A and n; while if it is of the nature of $y = Ae^{bx}$, plotting on semilogarithmic paper will yield the values of A and b.

In fitting curves to frequency distributions, we look in vain for any general rule. The method of least squares lays down a procedure for fitting the closest fitting normal error curve. Pearson has also developed a general formula:

$$\frac{1}{y}\frac{dy}{dx} = \frac{x + a}{b_0 + b_1x + b_2x^2}$$

which can be made to fit a wide variety of frequency curves by the choice of appropriate values for a, b_0, b_1, b_2, etc. For details of this type of treatment reference should be made to Elderton's " Frequency Curves and Correlation " (C. and E. Layton).

Cyclone.—A name given to a region of low barometric pressure. In temperate latitudes the cyclone is now usually spoken of as a DEPRESSION and the term " cyclone " is taken to refer only to a " tropical cyclone." In this restricted form the term cyclone reverts to its original meaning. Cyclonic storms are confined to very definite regions and occur on the western sides of the great oceans. The principal regions where these storms occur and the names by which they are known are :—(*a*) The Gulf of Mexico, the West Indies and the coasts of Florida where they are known as HURRICANES ; (*b*) the Arabian Sea and the Bay of Bengal (cyclones) ; (*c*) the China Sea and the coasts of Japan (TYPHOONS) ; (*d*) the Indian Ocean to the east of Mauritius and Madagascar (cyclones), and (*e*) the Pacific Ocean to the east of Australia and Samoa (hurricanes). In the Philippines they are known as BAGUIOS. The storms usually originate over the ocean and their paths, generally keep to the ocean ; if the path crosses from the ocean to the land the storms soon die out and they quickly lose their destructiveness.

The cyclone and the depression are in essentials alike ; their winds in the northern hemisphere circulate in a counter-clockwise direction and in the southern hemisphere clockwise, the only difference being that of their strength. Winds of force 12 on the BEAUFORT SCALE of wind force frequently accompany the cyclone while in the depression winds of this strength are rare. This difference is due largely to the difference in pressure gradient.

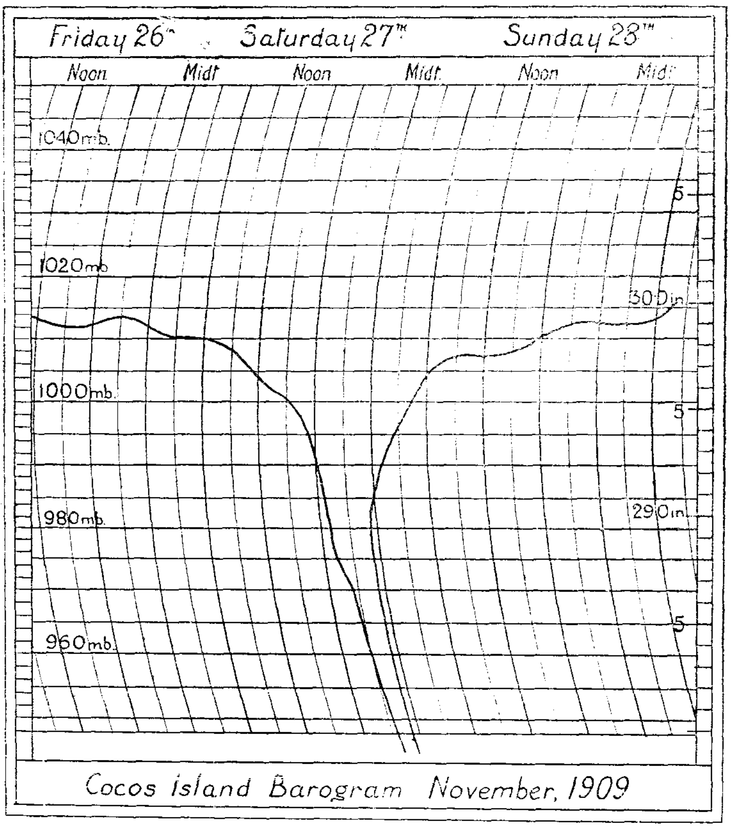


FIG. 15.

At the centre of a cyclone the pressure is frequently about 960 mb. and in its outer edge about 1,020 mb. The diameter of such a storm may reach 600 miles, but it is more often much less. In a depression similar differences of pressure occur between the centre and the outer edge, but the diameter of the depression may be 1,000 or even 2,000 miles.

In the centre of a cyclone there is usually a very limited region, only a few square miles, in which there is a complete calm with only a narrow strip of moderate winds separating it from the winds of hurricane force. This calm region is recognised as the EYE of the cyclone. In it the weather is usually fine while in the other parts of the cyclone there are cloudy skies and torrential rain. Frequently before a cyclone approaches the weather is fine and quiet, but the skies soon cloud over, the barometer falls quickly and the air becomes oppressive and sultry, the wind freshens rapidly and soon heavy rain commences. After the passage of the storm the weather quickly resumes its peaceful form.

The velocity of translation of the cyclone is usually under 15 miles per hour; the velocity varies in different cyclones as in depressions in temperate latitudes, but the velocity of translation is generally less than that of the depression.

Cyclones are of a seasonal nature, they occur principally towards the end of the hot seasons. In the West Indies August to October are the months of greatest frequency. In the Southern Pacific and in the South Indian Ocean they occur most frequently between December and March, in the Bay of Bengal and in the Arabian Sea between April and June and again between September and December. In the China Sea and the Antilles they occur between July and October. These are the principal periods for the occurrence of cyclones, but they may occur also in the months adjacent to those mentioned above. The following table, compiled from various sources, shows the numbers of recorded occurrences of cyclones, hurricanes and typhoons in different parts of the world.

Numbers of Occurrences of Cyclones, Hurricanes, and Typhoons in Various Parts of the World

Region and Period	January	February	March	April	May	June	July	August	September	October	November	December	Total
West Indies, 1887–1923.	0	0	0	0	1	16	17	39	78	71	15	2	239
South Indian Ocean, 1848–1917, omitting 1849, 50, 53.	113	115	98	68	25	3	2	0	0	7	33	58	522
Bombay 25 years ..	1	1	1	5	9	2	4	5	8	12	9	5	62
China Sea, 1880–1901.	9	2	5	10	25	41	74	74	88	65	51	24	468
Arabian Sea, 1890–1912.	2	0	0	2	5	11	3	0	2	10	8	2	45
Bay of Bengal, 1877–1912.	0	0	0	7	21	42	65	55	70	51	37	17	365
South Pacific 160°E. to 140° W., 1789–1923.	69	48	64	18	2	2	1	1	2	4	8	31	250

Near the centre of a cyclone the fall of pressure is often very rapid. The illustration shows a reproduction of a barogram during a cyclone which passed over Cocos Island (Keeling I.), on November 27th, 1909. It is interesting to notice that in spite of the rapid fall of pressure with the onset of the cyclone the diurnal variation of the barometer is still apparent, and it reappears before the normal level is recovered.

The lowest known pressure in the centre of a cyclone is 886·8 mb., reduced to mean sea level; it was recorded about 400 nautical miles east of Luzon (Philippines) on August 18th, 1927.

Cyclonic Rain.—The rainfall associated with the passage of atmospheric low pressure systems. (See DEPRESSION, OROGRAPHIC RAIN.)

Cyclostrophic.—See GRADIENT WIND.

Damp Air.—As distinguished from dry air, damp air implies in meteorology a high degree of RELATIVE HUMIDITY. When its relative humidity equals or exceeds 85 per cent of saturation air may fairly be called damp. It will deposit some of its moisture in dry woollen fabrics, cordage or other fibrous material, though its water will not condense upon an exposed surface until 100 per cent is reached.

Dawn.—(O.E. *dagian,* to become day), the time when light appears (*daws*) in the sky in the morning or the interval between the first appearance of light and the rising of the sun (see TWILIGHT).

Day.—A solar day is the interval of time which elapses between successive occasions on which the sun is in the meridian of any fixed place. These occasions are known as "transits" of the sun. A sidereal day is the corresponding interval between successive transits of a distant fixed star. Since the earth moves in an orbit round the sun in the same sense of rotation as that of its rotation about its axis, the length of the solar day is slightly greater than that of the sidereal day.

Owing to the eccentricity of the earth's orbit, solar days are of slightly unequal lengths at different times of the year. The average length of the solar day is 86,400 seconds. This is called the "mean solar day" and it is taken as the length of the civil day, or, the "day" of ordinary parlance. The sidereal day contains 86,164 seconds nearly.

The epoch of the beginning and end of the civil day is fixed by the civil power. In this country a civil day in winter begins and ends at midnight *Greenwich Mean Time* ; in other words, the standard longitude for purposes of civil time reckoning is that of Greenwich. During the operation of BRITISH SUMMER TIME, however, the civil day begins and ends at 23 h. G.M.T.

Débâcle.—The breaking up in the spring of the ice in the rivers. The term is chiefly applied to the great rivers of Russia and Siberia and of the North American Continent. Débâcle lasts from two to six weeks ; during the period the rivers often overflow their banks inundating the surrounding country. In southern Russia débâcle begins about the middle of March, in latitude 55°—60°N., it begins early in April, but in the north it does not begin until May and in the extreme north of Siberia not until June. In Canada in Ontario the débâcle takes place in March and the water is free by April, in the St. Lawrence it is a little later, the river being free of ice in May.

Declination, Magnetic.—The angle between the magnetic meridian (the direction of the magnetic axis of a freely suspended or pivoted magnetic "needle") and the geographical meridian. This angle is sometimes confusingly referred to as the "magnetic variation." Declination is subject to a regular diurnal variation, to irregular comparatively short-period changes, and to secular change. (See TERRESTRIAL MAGNETISM.)

Dekad.—In meteorology, a period of ten days, but *decade* is often used for ten years.

Density.—The mass of unit volume of a substance. The density of pure water, for example, is 1·000 grams per cubic centimetre at a temperature of 277°A. It is necessary to specify the temperature in stating the density as at any other temperature the same sample of water will occupy a greater volume, so that the mass per c.c. is then less. At 283°A. the density is 0·998 gm./c.c. Strictly, the pressure also should be stated as the volume of a sample of water alters with the pressure to which it is subjected ; but for ordinary pressure changes these alterations in the case of a liquid or of a solid are so slight as to be of no practical consequence.

In meteorology we are concerned more particularly with the density of the air, and it is necessary to specify not only the temperature and pressure when stating a numerical value for it, but also its constitution. Dry air is a mixture of gases of which oxygen and nitrogen form about 99 per cent., the remainder consisting of carbon di-oxide and a number of rare gases of which argon is the chief (see ATMOSPHERE). For all practical purposes the relative proportions of these gases in the atmosphere remain constant, so that dry air may be regarded as a single gas when considering questions of density; but atmospheric air is never completely dry, as it always contains a quantity of water vapour which, though relatively small, is variable and, in consequence, causes appreciable changes in the density.

The factors which affect air density are, therefore, pressure, temperature and the proportion of water vapour present. An increase of pressure, if temperature and water vapour content remain unaltered, will increase the density. An increase of temperature, if pressure and water vapour content remain the same, will result in a decrease in the density. If the proportion of water vapour is increased, temperature and pressure remaining the same, the density will be diminished; the pressure in this case is the sum of the air pressure and the pressure exerted by the water vapour, so that for the total pressure to remain unaltered the addition of water vapour, which exerts its own pressure, must be made by displacing some of the air. As the density of water vapour is less than that of air at the same pressure the average density of the mixture after the introduction of more water vapour is lower than the original density. A more usual feature of the practical problem is perhaps the loss of water vapour by condensation. If the original sample of air is saturated a fall of temperature will result in an increase of density if pressure remains the same, not merely on account of the direct effect of the lower temperature alone, but also by the lowering of the proportion of water vapour present in the sample, following the condensation which results from the fall of the temperature below the dew point.

The effect of each of these factors is quite definite and has been determined by measurements. These measurements result in the following formula for the calculation of the density of any given sample of air, or the density of atmospheric air, when the temperature, pressure, and pressure of the aqueous vapour present are known:

$$\Delta = \Delta_0 \frac{p - \frac{3}{8}e}{p_0} \frac{T_0}{T}$$

where

Δ is the density of the sample of air, to be computed,
Δ_0 is the density of dry air at pressure p_0 and temperature T_0, absolute,
p is the barometric pressure of the sample,
T is the temperature, in degrees absolute, of the sample,
e is the pressure of aqueous vapour in the sample.

The density of dry air at a pressure of 1,000 mb. and a temperature of 290°A. is 1,201 grams per cubic metre, so that the formula may be written:

$$\Delta = 1201 \cdot \frac{p - \frac{3}{8}e}{1000} \frac{290}{T}$$

p and e being measured in millibars.

The numerical value of e is readily determined from the readings of a dry and wet bulb psychrometer, from which the vapour pressure for the temperature of the sample, that is, the dry-bulb reading, is obtained by reference to suitable hygrometric tables.

The question of air density is of importance in meteorology, as it is because of the different densities of adjacent masses or converging currents of air that convection takes place in the atmosphere; the less dense air rising while that with the greater density tends to descend. In this way vertical circulation, as seen in such phenomena as land and sea breezes, is brought about. The rain and cloud in certain parts of low-pressure systems, or depressions, are also due to the rising of air of comparatively low density over currents of denser and usually cooler air. KATABATIC winds may also be mentioned as important meteorological phenomena due primarily to a difference between the density of the air on the slopes of a hill and that of the air in the valley below.

Atmospheric density varies with both time and place. At a height of about eight kilometres, however, the density is uniform. Above this height the density at any level decreases as we go from the equator to either pole, while below this height the density increases from equator to pole. At a height of eight kilometres, also, the density does not change appreciably throughout the year. Above this height density is normally greatest in summer, while below this level density is at its maximum in winter.*

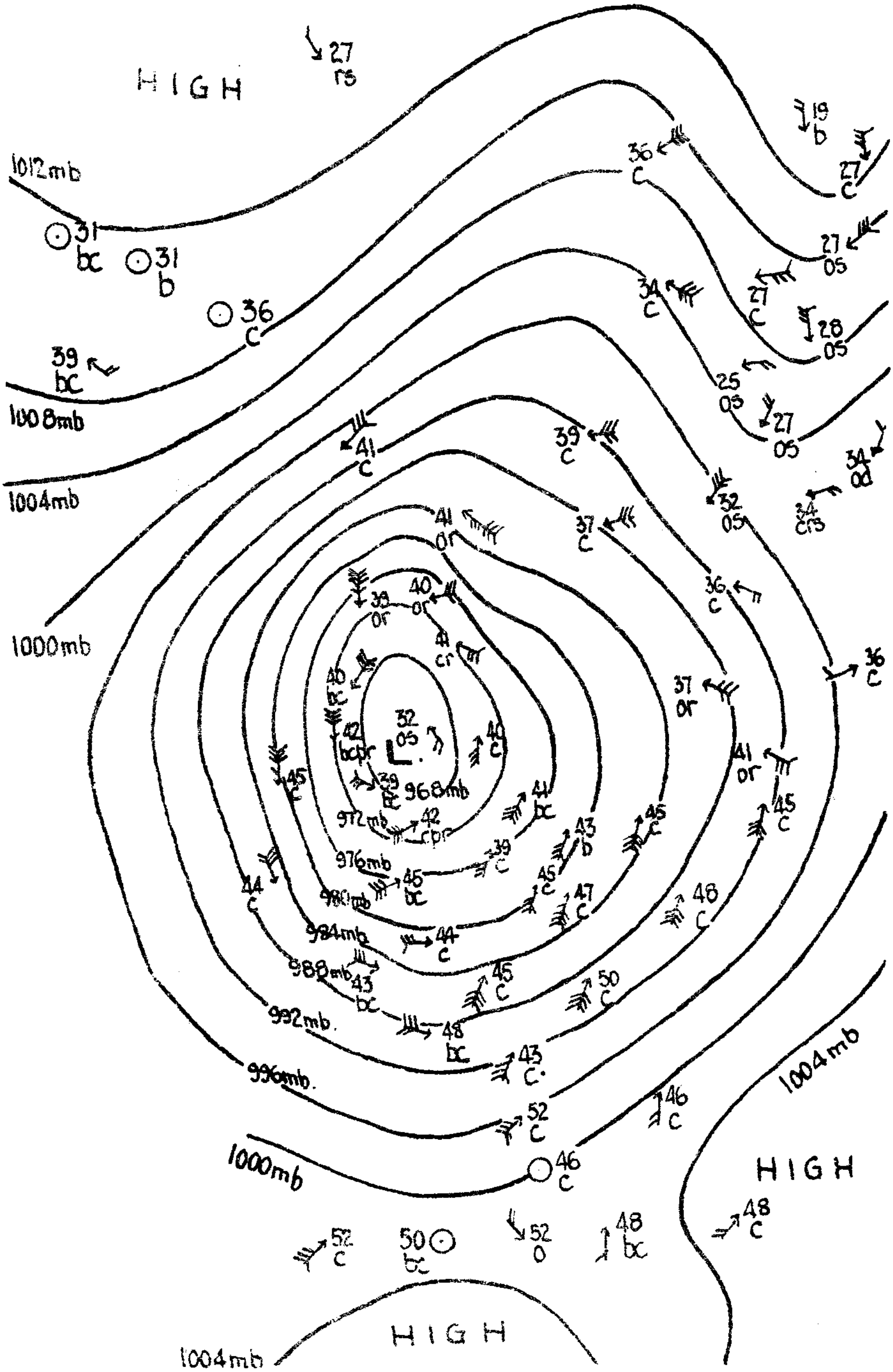
Normally density is approximately uniform in a horizontal plane, but this does not hold where local circulations exist. For different types of pressure distribution the late W. H. Dines has given the following values for the density at the heights stated over the British Isles. The relative humidity is assumed to be 75 per cent.

Height	Anticyclone	Depression	Height	Anticyclone	Depression
Km.	gm./cu. m.	gm./cu. m.	Km.	gm./cu. m.	gm./cu. m.
10	421	382	5	736	724
9	474	444	4	818	807
8	531	514	3	911	893
7	595	583	2	1,012	992
6	662	652	1	1,137	1,100

Depression.—A depression is a part of the atmosphere where the barometer is lower than in the surrounding parts. It is occasionally called a " cyclone " or simply a " low." The isobars round such an area of low pressure are more or less circular or oval. Depressions vary enormously in size, one may be only a hundred miles in diameter and another over two thousand miles ; some are deeper than others, a deep depression being one in which the pressure is very much lower near the centre than on the outside while, on the other hand, a shallow depression is one where the pressure, although perhaps low near the centre, is not very much lower than in the surrounding districts. North of the equator the wind blows round the depression in a counter-clockwise direction, with some motion inwards across the isobars ; its strength is in all cases closely related to the steepness of the barometric gradient, the steeper the gradient the stronger the wind. The weather in a depression is of an unsettled type. Depressions in middle latitudes usually move in an easterly direction but any direction may be followed. The velocity of translation varies with each depression, and in any single one the velocity is never constant. Some depressions may move as much as 600 or 700 miles per day, while others remain practically stationary. Depressions, in their movement carry their weather with them, but the weather is subject to changes due to changes which take place in the depression itself.

The origin of a depression has formed an interesting study to many investigators. It used to be thought that some local cause of heating of the air led to a rising column of warm air which owing to its reduced weight gave low pressure at the base. A wind circulation was set up around the area of low pressure and the depression was formed. This theory was generally held until upper air observations showed that in the free air depressions tend, on the average, to be cold not warm, and that at the centre of a well marked depression, pressure is low not only on the surface of the earth but at the base of the STRATOSPHERE which in well marked

* S. N. Sen.: " On the distribution of air density over the globe." *Q.J.R. Meteor. Soc.*, **50**, 1924, pp. 29–51.



30TH. MARCH, 1928. 7h.
DEPRESSION.

depressions is found some five miles above the surface. This suggested that depressions were not phenomena of the lower atmosphere only, and that it might be necessary to seek their cause either in the layers above a height of five miles which form the stratosphere or at the surface of separation between the lower layers, the TROPOSPHERE and the upper layers, the stratosphere. The impossibility of obtaining a network of day-to-day observations in the stratosphere hampered and still hampers investigation on these lines, and in the last ten years attention has again been concentrated on the troposphere by the ingenious theories

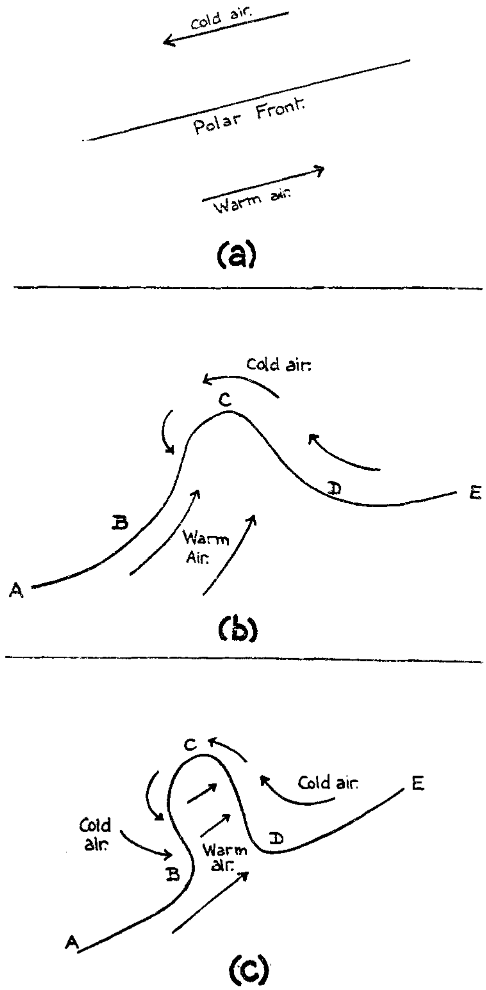


Fig. 16.

put forward by the Bjerknes, father and son, of Bergen, and by Professor Exner, of Vienna. Both these theories ascribe depressions to the interaction between warm and cold air masses, and as the Bjerknes theory has been widely adopted among European meteorologists a brief account of it will be given. The temperate regions of the earth where undisturbed by depressions or anticyclones, are regarded as being occupied by a stream of cold or polar air flowing from the east or north-east in their northern part, separated by a fairly sharp SURFACE OF DISCONTINUITY from a parallel stream of warm equatorial air flowing in the opposite direction on their southern side. The surface of separation between these currents slopes up at a small angle from south to north and cuts the earth's surface in a line known as the POLAR FRONT (Fig. 16 (*a*)). The stability of the system pictured is easily disturbed and waves develop on the surface of separation which are shown on the earth by tongues of warm air projecting into the polar air and deflecting the polar front as in Fig. 16 (*b*), where ABCDE is the polar front, the tongue of warm air being shown at BCD. Under these conditions the currents no longer flow parallel and side by side. The warm air current cuts the cold air at CD, and by reason of its lower density climbs over it while the cold denser air along BC undercuts the warm air. Pressure falls at C at the tip of the tongue of warm air and the isobars begin to assume the form associated with depressions. The line CD, where warm air is climbing over cold air, is termed the WARM FRONT of the depression, the line BC, where cold air undercuts warm, the COLD FRONT. The rising of the warm air along CD and undercutting of the warm air along BC tend to narrow down the tongue of warm air which takes a shape as shown in Fig. 16 (*c*) and ultimately the warm air is driven from the surface altogether, the cold air along BC in the rear catching up the cold air along CD in the front. The depression is then said to be occluded (see OCCLUSION), and soon begins to decrease in intensity. Such in brief outline is the life history of a depression as viewed by the Bergen School. The rainfall, which forms such a notable feature of most depressions, is chiefly confined to the region along the polar front. Warm-front rain falls along the line CD where warm air is rising over cold, and cold-front rain which often takes the form of short heavy showers accompanied by squalls falls along BC, where the cold air is undercutting the warm.

It may be asked why if depressions can be divided into warm and cold sectors in this way, synoptic charts had been drawn daily for some 40 or 50 years before meteorologists discovered the fact. The answer undoubtedly is that depressions generally reach Europe from the Atlantic and are nearly always occluded before entering the land area where detailed analysis of the conditions becomes possible. It is thus rare to find well-marked warm sectors with their attendant warm and cold fronts on the daily weather maps prepared by the European meteorological services, and only by careful study and expert knowledge can the position of the fronts be located.

It may be pointed out that at times depressions appear on the weather map which seem to have formed entirely within polar air, and it may be necessary to return to the older local heating theory or to look in the stratosphere for the origin of these depressions.

It would seem to follow therefore that depressions not only differ amongst themselves but also differ in their origin, so that ultimately it may be found necessary to recognise two classes of depressions, those which have formed at the surface of separation of polar and equatorial currents and those which have formed entirely in polar air.

The life of a depression is very varied and may extend from one or two to five or more days. When a low pressure system appears to maintain its existence for a long period it frequently happens that it is reinforced from time to time by combining with associated SECONDARY DEPRESSIONS which have developed on its southern side. (See Plate III.)

Desert.—A region in which the high temperature and small rainfall render the evaporation in excess of the precipitation, and consequently there is insufficient moisture to support vegetation. Deserts may be caused by any of the following conditions : (1) the presence of a persistent anti-cyclone, an example due to this cause occurs in northern Africa, where the Sahara coincides with the average position of the sub-tropical belt of high pressure ; (2) a cold current on the western coast of a large mass of land such as occurs in Peru ; and (3) a configuration of ground which shuts out the moisture-bearing winds, for example Gobi, in central Asia.

For Köppen's formula for the limit of rainfall which constitutes a desert climate, see ARID.

Desiccation.—The permanent disappearance of water from an area due to a change of climate and especially a decrease of rainfall. Large areas in central Asia, Africa and western America have been desiccated since the Glacial period, but there does not appear to have been much progressive desiccation during the past 2,000 years.

Deviation.—The difference of an observation from the mean value of the series of which it forms a part. For example, the mean January pressure at Kew is 1017·6 mb., the mean in January, 1928, was 1010·0 mb., and the deviation −7·6 mb. The deviations of a series of observations can be summarised by finding either the *mean deviation* or the STANDARD DEVIATION. The mean deviation is the arithmetic mean of the individual deviations taken without regard to sign; the standard deviation is the square root of the arithmetic mean of the squares of the individual deviations. In most series of observations the standard deviation is about $1\frac{1}{4}$ times the mean deviation.

The angle between the surface WIND and the direction of the isobars is sometimes termed the deviation of the wind.

Dew.—The name given to the deposit of water which forms upon grass, leaves, etc., when they become cooled, by radiating heat to the sky on a clear night, to such an extent that their temperature is below the saturation or DEW-POINT of the air which surrounds them.

Dew-point.—The temperature to which air can be cooled without causing CONDENSATION. It is the temperature for which the saturation vapour pressure is identical with the pressure of the vapour in the air.

Dewpond.—A pond on high ground on chalk downs which retains its water during all but the most prolonged droughts, after ponds at lower levels are dried up. A dewpond is artificially constructed, a watertight bottom being made of about 9 in. of puddled chalk or clay treated with lime; a layer of chalk rubble is placed over the bottom to protect it from the feet of cattle. Sometimes a layer of straw is placed below the watertight bottom, sometimes it is placed above—between the bottom and the chalk rubble; in a few ponds there are two or three alternate layers of straw and puddled clay, in others there is no layer of straw at all.

The chief interest in dewponds lies in the mystery of their supply of water; they do not dry up in hot summer weather in spite of the watering of cattle. The idea that gave the ponds their name was that they were replenished at night by dew, the theory being that the non-conducting layer of straw prevented the outward radiation from the heated earth from reaching the water, and that the water therefore was kept cool and dew condensed on it. Careful experiment, however, seems to show that only very rarely in the short summer night does the temperature of the water fall below the dewpoint. Another suggestion was that the water was replenished by the heavy night mists which enshroud the higher part of the downs during hot summer weather, the mist condensing on surrounding shrubs and dripping into the pond.

But probably the true explanation is that their situation on high ground renders the dewponds less exposed to evaporation than the ponds at lower levels, while at the same time they receive more rain.

Diathermancy—Diathermanous.—(Based on B. Stewart. Treatise on Heat. 2nd Ed., pp. 183–5). The discovery by Melloni, that rock salt is a body which transmits heat freely, sufficiently indicates that most substances which are transparent for light are not so with regard to heat. This is expressed by saying that most substances are "athermanous" and that rock salt is almost the only "diathermanous" solid, these two words corresponding to the terms opaque and transparent in the science of optics. Tyndall found that a solution of iodine in bisulphide of carbon has the property of completely stopping the light rays, while it allows dark heat to pass in great quantity. He found that a fluid lens formed of this solution and enclosed in rock salt will stop all the light from an electric lamp but permit the dark rays to pass in abundance.

Oxygen and nitrogen are diathermanous, water vapour and carbon dioxide absorb heat rays of certain wave-lengths so that atmospheric air is only partially diathermanous.

Diffraction.—Ordinary experience with light suggests that it always passes through the air in straight lines, and that it cannot go round an obstacle. This is an apparent contrast with sound; for we hear without difficulty round a corner. There are, however, numerous phenomena which indicate that light can be diverted from the straight course by obstacles. These phenomena are grouped under the name of diffraction. They can be explained by the wave theory of light. According to this theory the contrast between the behaviour of light and sound is a matter of scale, the wave-lengths of light being very small in comparison with those of sound.

Light is diffracted by waterdrops to produce CORONAE, as well as other colour effects observed on clouds. A rarer phenomenon, BISHOP'S RING, is explained by diffraction by dust particles in the upper atmosphere. The blue of the sky is due to the scattering of light by the molecules of which the air is constituted. Scattering of this type is regarded by some authors as covered by the term diffraction.

Diffusion.—The term diffusion is used in meteorology to indicate either molecular diffusion or else eddy diffusion.

Molecular diffusion is the process by which contiguous fluids mix slowly even in spite of differences in their density. The process of molecular diffusion follows certain definite laws which are similar to those for the diffusion of heat by thermal conduction. This process is so slow, however, that in practice the effects due to it are usually negligible compared with those produced by eddy diffusion.

Prof. G. I. Taylor has shown that eddy diffusion, or mixing in the atmosphere by turbulent motion (see TURBULENCE) follows the same type of law as molecular diffusion in certain respects. More recent work, particularly that of L. F. Richardson, has shown that this similarity or analogy extends only up to a point. The laws relating to eddy diffusion appear to be more complex than those for the better-known type of diffusion. This difference is due, at least partially, to the fact that the eddies which cause the diffusion vary over a wide range of size.

Discontinuity.—As a rule the fundamental atmospheric variables, pressure, wind velocity, temperature and humidity, are continuous functions of space and time. Occasionally, however, their variation in a small distance (or in a short time at a fixed point) is so much above normal that their distribution is regarded as discontinuous. For example, a fall of 10°F. in temperature, usually spread over some hours at least, may take place in a few minutes and this indicates what may be regarded as a discontinuity in the atmosphere. (See also SURFACE OF DISCONTINUITY.)

Diurnal.—This word is used to indicate the changes in the course of an average day of the magnitude of a meteorological element. If we have a series of hourly values of the element for a large number of days, and if we determine the average values for those days of the element at 1h., 2h., ... 24h. it will be found that the averages show steady and regular variations, sometimes increasing, sometimes decreasing from the beginning to the end of the twenty-four hours, and that irregular fluctuations which may appear on any of the days are eliminated from the averages provided the number of days taken is large enough. Thus the characteristic feature of the diurnal variation of atmospheric pressure is a 12-hourly oscillation which has its maxima at the same local time all over the intertropical and temperate zones. In the polar regions the oscillation has its maxima at the same absolute time along a circle of latitude. The amplitudes of those waves are greatest at the equator and diminish towards the poles. This double wave of pressure may be seen occurring with great regularity each day on the traces from a self-recording barometer in the tropics, the maxima occurring approximately at 10h. and 22h. and the minima at 4h. and 16h. In the British Isles non-periodic changes in pressure, due to the passage of cyclones and anticyclones, are as a rule so relatively large that they obliterate the twelve-hourly oscillations, but the latter may be recognised in periods of quiet settled weather, and are evident when averages are taken of hourly values as explained above. Other elements showing conspicuous diurnal variations, especially during the warmer months of the year, are air temperature and relative humidity. Diagrams showing the diurnal variation in each month of air temperature, based on data for 25 years at Aberdeen, Richmond (Kew Observatory), Cahirciveen (Valentia Observatory) and Falmouth are given in "Temperature Tables of the British Isles," M.O. Publication 154 (1902). Temperature is normally at a maximum about two hours in winter and about three hours in summer after local mean noon and at a minimum about sunrise. Relative humidity depends not only on the amount of moisture which the air contains, but on the temperature of the air, and on days when the temperature range is large relative humidity also exhibits large variations; it is normally at a minimum in the afternoon about the time of occurrence of maximum temperature, and at a maximum in the early morning about the time of occurrence of minimum temperature. The "Book of Normals of the Meteorological Elements for the British Isles," Section VI, contains diagrams showing the diurnal variation of relative humidity in each month at eleven stations in the British Isles. The *Observatories' Year Book*, a serial publication of the Meteorological Office, contains many data relating to the diurnal variations of meteorological and geophysical elements.

Divergence.—Divergence is the opposite of CONVERGENCE the article on which should be consulted. If the winds are such that more air flows out of a given area than flows into it there is said to be divergence. The deficiency of air must be made good by a downward current from the upper layers. Such a downward current is termed SUBSIDENCE. The chief effects are absence of precipitation and the frequent development of INVERSIONS with dry air above them. Since the lower layers of the atmosphere hold most moisture, divergence tends to cause a steady decrease in the total water content in the column of air over a given area. No appreciable divergence can take place with a system of geostrophic winds (see GRADIENT WIND). The two chief causes are, firstly, surface friction, which causes a flow of air near the ground from high to low pressure, with divergence from an anticyclone or ridge of high pressure. Secondly, there is divergence from a region of rising barometer, owing to lack of perfect balance between wind and pressure gradient. This effect is smaller near the ground than the frictional divergence from an anticyclone, but it extends much higher and is probably often more important.

Doctor.—See HARMATTAN.

Doldrums.—The equatorial oceanic regions of calms and light variable winds accompanied by heavy rains, thunderstorms and squalls. These belts are variable in position and extent, and as a whole move north and south with the annual changes of the sun's declination. The movement is considerably less than that of the sun and is of the order of 5° on either side of the mean position, with a lag of from one to two months behind the sun.

Drizzle.—Precipitation in which the drops are very small. If the drops are of appreciable size although the rain is small in amount the term adopted is "slight rain."

Drops.—See RAIN-DROPS.

Drosometer.—An instrument for measuring the quantity of dew deposited. A self-recording type ("drosograph") used in Italy consists of a light horizontal pan to receive the dew the weight of which is made to actuate the recording pen, through a system of levers.

Drought.—Dryness due to lack of rain. Certain definitions have been adopted in order to obtain comparable statistical information on the subject of droughts. Thus an *absolute drought* is a period of at least 15 consecutive days, to none of which is credited ·01 in. of rain or more. A *partial drought* is a period of at least 29 consecutive days, the mean daily rainfall of which does not exceed ·01 in. A *dry spell* is a period of at least 15 consecutive days to none of which is credited ·04 in. of rain or more. During the 62 years 1858–1919 there were 69 absolute droughts and 163 dry spells at Camden Square (London). The definitions of absolute drought and partial drought were introduced in *British Rainfall*, 1887, p. 21, while that of dry spell was first used in *British Rainfall*, 1919, p. 15. A chapter is devoted to the subject in each volume of *British Rainfall*.

Dry Air.—When a meteorologist speaks of "dry air" he does not normally mean air that contains no AQUEOUS VAPOUR, although a chemist or physicist, speaking of laboratory experiments, would generally use the words in that sense: the atmosphere, even in the driest parts of the world, always contains some aqueous vapour, but in the laboratory air can be made perfectly dry, hence the distinction. In meteorology we may take it that air referred to as "dry" has at least a sufficiently low RELATIVE HUMIDITY for EVAPORATION to be taking place actively from earth, rock, etc., as well as from vegetation. In the Beaufort Notation a more precise meaning has been attached to the words, which are applied only to air with a relative humidity of less than 60 per cent: the Beaufort letter for such air is "y."

Dry- and Wet-Bulb Hygrometer.—See PSYCHROMETER.

Dry Season.—A period of a month or more with little or no rain, which recurs regularly every year. Thus on the north coast of Africa summer is the dry season, while on the coast of West Africa the dry season occurs in winter of the northern hemisphere. (See also CLIMATIC ZONES.)

Dry Spell.—See DROUGHT.

Duration of Sunshine.—The number of hours in any period (e.g. a day, month or year), estimated according to long-established practice from the records of a SUNSHINE RECORDER, during which the sun was sufficiently intense to scorch the standard card when concentrated by the standard glass sphere. Normal values of mean daily duration of sunshine for some 100 stations are given in the "Book of Normals of Meteorological Elements for the British Isles," Section I.

Dusk.—The time when civil twilight ends, the darker stage of twilight or the interval between the time of ending of civil twilight and the onset of complete darkness. (See TWILIGHT.)

Dust.—The atmosphere carries in suspension, often for long distances, solid particles of varying character and size. The chief sources of these particles are volcanic eruptions, meteors, sand raised by storms of wind over deserts and, in the neighbourhood of towns, industrial and domestic smoke. This atmospheric dust is of considerable importance meteorologically. If present in sufficient quantity it weakens the sunlight, this usually occurs in calm weather in large cities.

Volcanic eruptions of an explosive type, such as that of Krakatoa in 1883, project into the higher levels of the atmosphere enormous quantities of very fine dust, so fine that it takes more than a year to settle. The volume of dust from Krakatoa has been estimated as 18 cubic kilometres. This dust interferes with the passage of the sun's radiation through the atmosphere, and the measurements made at the

Smithsonian Astrophysical Observatory on Mount Wilson after the eruption of Mt. Katmai, Alaska, in 1912, showed a decrease of 20 per cent. Terrestrial radiation to space is also intercepted and partly returned to the earth, but W. J. Humphreys has shown that this process is less effective than the interception of solar radiation, so that volcanic dust lowers the temperature. Humphreys suggests that in this way it may be one of the causes of ICE AGES. Another effect of volcanic dust is the unequal diffraction of light rays, producing brilliant sunsets. (See SUNRISE AND SUNSET COLOURS.)

Whether ordinary dust particles act as nuclei for the condensation of water vapour in the air is not clearly understood. There are present in the atmosphere, as well, particles of hygroscopic substances such as common salt, sulphuric acid, etc.; these are known as "hygroscopic nuclei," and molecules of water will condense on them when the air is only 75 per cent. saturated.

The amount of dust present in the air can be measured by a DUST COUNTER.

Dust Counter.—An instrument for counting the dust particles in a known volume of air. In Aitken's dust counter condensation of water is made to occur on the nuclei present and the number of drops is ascertained. Hygroscopic nuclei as well as true dust particles are, therefore, recorded. In Owens' dust counter a jet of damp air is forced through a narrow slit in front of a microscope cover glass. The fall of pressure due to expansion of the air after passing the slit causes the formation of a film of moisture on the glass, to which the dust adheres, forming a record which can be studied under a microscope.

Dust Devil.—A whirlwind, formed by strong convection over a dry sandy region, which carries up the dust into the air with it. Dust devils have been observed to rotate both in clockwise and counter-clockwise directions. Their estimated heights vary considerably, in some cases they are said to reach as high as 2,000 or 3,000 ft. The speed with which they move also varies very much, it may be as low as 4 miles an hour, or it may reach 30 miles an hour.

Dust Storm.—See SANDSTORM.

Dynamic Cooling.—The fall of temperature produced by expansion due to diminished pressure. (See ADIABATIC.)

Dyne.—The C.G.S. unit of force. It is the force which, applied to a mass of one gramme during one second will produce a velocity of one centimetre per second.

Earth Currents.—The existence of electric currents flowing in the earth's crust and the association of abnormally high values of such currents with magnetic storms and notable auroral displays have been known since the early days of telegraphy. Apart from observations of the current in ordinary telegraphic lines, systematic information is obtained by recording continuously the potential difference between a pair of similar electrodes buried in the earth, under as nearly as possible like conditions, and separated by a convenient distance which should not be much less than a mile. In order to obtain data as to the resultant current, or potential difference, it is desirable to have two pairs of electrodes situated respectively in and perpendicular to the meridian. Because of lack, until recently, of reliable data as to the conductivity of the earth's crust in the neighbourhood of recording stations, it is customary to express the observational results not in terms of current density but in terms of potential gradient between the pairs of electrodes. Owing to various inherent difficulties (electrode effects, local peculiarities, etc.), there is considerable uncertainty as to average values and resultant direction of the earth potential gradient. It appears that in normally quiet times the average potential gradient may be as high as 0·2 or 0·3 volt/Km., although the values found in several places are very considerably less than this ; while at times of disturbance values of at least 1 volt/Km. have been observed. Data as to the general direction of flow of earth currents are somewhat confusing. A number of the earlier observations made in Europe and North America appear to show the favoured direction to be approximately from south-west to north-east, but according to more recent observations at Tortosa (Spain), on relatively short lines, the gradient appears to be directed from about north-north-west to south-south-east. Meteorological and atmospheric electrical factors may operate in producing local modifications of the general earth-current system, as, for example, in the tendency for earth currents to flow uphill.

Diurnal variation.—The earth potential gradient undergoes a regular solar diurnal variation, which varies in magnitude and type with locality and season. In the vicinity of Berlin and of Tortosa the mean diurnal variation for the year shows, in both the northward and westward components, two maxima and two minima. In both components the principal minimum occurs at about 11h. and the principal maximum at about 16h., and the regular changes of diurnal variation are largest in the day-time hours. The latter feature is not found in some localities in northern Europe. Recent observations at Waterloo, Western Australia, indicate that there may be a certain symmetry in diurnal variation with reference to the equator. The amplitude of the diurnal variation of the earth potential gradient is found to vary considerably with locality; this is probably largely due to variation in earth resistivity from place to place. In many regions the amplitude is found to be much less in winter than in other seasons, but in other places (e.g. in southern Sweden) there appears to be no definite seasonal variation. The results obtained during several years at Tortosa afford evidence that the magnitude of the daily variation increases with sunspot frequency; also, and again as in TERRESTRIAL MAGNETISM, that there is a tendency for disturbed and for quiet conditions to recur at intervals of approximately 27 days.

Connexion with terrestrial magnetism.—A close connexion exists between certain earth current and terrestrial magnetic phenomena. This is in accordance with the theory which attributes the regular and disturbance magnetic changes to the combined action of primary electric currents in the upper atmosphere and of the secondary currents induced in the earth. Attempts to make out a detailed, comparatively small time-scale, quantitative relationship between earth current and magnetic variations have not been entirely successful. This is probably due to lack of sufficient observational data, particularly in respect of earth potential gradient and the resistivity of different earth strata. Theory indicates that the amplitude of surface earth-current oscillations relative to magnetic oscillations increases with the frequency.

Earthquake.—Any rapid movement of the ground may be called an earthquake. The term is usually restricted however to movements which originate naturally and below the surface. There is an enormous range in the intensity of earthquakes. In a destructive earthquake the range of oscillation of the ground may be as much as four inches, and the maximum acceleration of the movement may be comparable with the acceleration due to gravity. Permanent changes of level may occur. Such a great earthquake may be felt by sensitive persons 1,000 miles from the central area.

The initial displacement which results in an earthquake usually occurs at some considerable depth below the surface. The place where this initial displacement occurs is called the focus or hypocentre. The spot on the ground vertically above the focus called the epicentre. The depth of the focus is only a mile or so for volcanic earthquakes. The small earthquakes experienced in the British Isles (e.g., Hereford and Jersey, 1926) have focal depths of less than 6 miles.* For greater earthquakes the depth is probably comparable with 30 miles. There is reason to believe that in some cases the depth is nearly 200 miles.†

* H. Jeffreys : *Mon. Not. R. Astr. Soc.*, Geoph. Supp., Vol. I, No. 9.
† H. H. Turner : *Mon. Not R. Astr. Soc.*, Geoph. Supp., Vol. I, No. 1.

Each year there are on the average about 5,000 earthquakes large enough to be felt.* Of these about 100 are more or less destructive. The number of earthquakes the waves from which are registered by seismographs in England is about 300. Nearly half of these have their origins under the sea.

The larger earthquakes are all to be attributed to the yielding of the rocks under the influence of such forces as produce the folding of strata and the growth of mountains. Probably the fracture usually occurs along an existing fault, one part of the rock shearing over another. In some cases the shearing movement extends to the surface; the amount of the displacement may be as much as 20 ft., vertically or horizontally. The dislocation which takes place in a single earthquake may not relieve the strain entirely. A great earthquake is usually followed by a series of after-shocks.

To the question whether the frequency of earthquakes depends on the influence of the moon or on the weather no very definite answer can be given except that such influences are by no means dominant.

The waves which are propagated from an earthquake and are recorded by seismographs pass through the body of the earth or round the crust. The first to reach a distant station are body-waves of compression and expansion, these are followed by body-waves of distortion and these again by the surface waves. Thus when the distance from the epicentre is one-quarter of the earth's circumference the times of passage are approximately 13 min. 16 sec., 24 min. 14 sec. and 43 min. 30 sec. for the three types of wave. The superficial waves are generally much larger than the body-waves which together constitute the "preliminary tremors." The discussion of the behaviour of the different waves has thrown much light on the constitution of the interior of the earth.

Earth Temperature.—The temperature of the interior of the earth is very high, and in consequence heat flows by conduction from the interior towards the cooler surface. If the temperature of the surface layer were constant the flow of heat would be constant, and a steady gradient of temperature would be established right up to the surface. In these circumstances, the temperature differences at different depths would be approximately proportional to the differences between the depths and temperature would always increase as the depth increased.

This simple régime is profoundly affected by the fact that the temperature of the surface layers of the earth is subject to large changes, some of which are periodic and some irregular. By far the largest variations are increases due to solar radiation and decreases due to terrestrial radiation, but conduction of heat from the superincumbent air also plays a minor part. The two principal types of periodic variation are (1) seasonal and (2) diurnal.

If the surface layer is subjected to a steadily increasing temperature the gradient of temperature in the first few inches of the soil is reversed, and heat commences to flow downwards from the surface towards the layer of minimum temperature. Below that layer the flow remains upwards from the heated interior. The establishment of a flow of heat downwards takes time, but, on the other hand, when the flow is once established it will persist after the increase of temperature at the surface has disappeared. If now the temperature of the surface layer is steadily reduced the temperature gradient in the first few inches becomes such that heat again flows upwards, and we have a peculiar arrangement in which temperature downwards increases at first, reaches a maximum, then diminishes, reaches a minimum and finally increases again steadily towards the interior. Every variation of temperature at the surface leads to a corresponding propagation of heat upwards or downwards, but the rapid variations have not time to extend very far down. The diurnal variation disappears at a depth of less than 3 ft. as a rule, but the seasonal variation has time to spread down

* A. Sieberg: "Erdbebenkunde," Gustav Fischer, Jena, 1923.

much further, to about 30 or 40 ft. At some such depth the temperature is sensibly constant and below that depth there is a steady increase of temperature downwards, the conditions being now unaffected by surface fluctuations of temperature.

The following average values of temperature in the soil at Oxford illustrate some of the above statements : At six inches, earth temperature is lowest (38·5°F.) in December and highest (69·4°F.) in August; at ten feet, earth temperature is lowest in April (47·5°F.) and highest in September (57·5°F.). In April and also in September there is not much difference between earth temperature at six inches and at ten feet, but at five feet earth temperature in April is less than at six inches or ten feet, while in September it is greater. In the summer months the temperature at six inches is much in excess of that at ten feet, while in the winter months temperature steadily rises from six inches to ten feet.

The variations of earth temperature produced by periodic variations of the temperature of the surface layers have been studied mathematically, and the results of the investigations have been verified by observation.

Earth Thermometer.—A thermometer for ascertaining the temperature of the soil at a known depth. The commonest form (Symons's) consists of a mercurial thermometer with its bulb embedded in paraffin wax, suspended in a steel tube at depths of one foot or four feet. For depths of a few inches only a mercurial thermometer with its stem bent at right angles, for convenience in reading, is employed.

Eclipse Weather.—The influence which the eclipse exercises on solar radiation received depends on a number of factors, but broadly speaking the radiation at any time is proportional to the extent of the unobscured sun. Light diminution is very gradual in the early partial phases, and very rapid just before totality. During the total phase light is received from two sources, the solar appendages, chiefly the corona, and the partially illuminated atmosphere lying at the moment just outside the umbral shadow. Of these the former is by far the largest contributor, but the illumination from both causes varies with the circumstances of individual eclipses.

The fall of temperature is one of the most clearly defined phenomena, but is influenced by many factors. A table compiled by H. H. Clayton of 12 total eclipses from 1878 to 1905, after correction for diurnal variation, shows maximum falls varying from 1·5°F. to 8·1°F. The amount of fall varies with the character of the station, being for the eclipses cited 1·5°F. over the open ocean, 3·2°F. on a small tropical island, and 5·5° to 8·1° over large land areas. Over land areas the fall shows a latitude effect with a minimum in high latitudes and a maximum at the equator. The recovery of normal values appears to take place simultaneously with the end of the eclipse, in the upper air, over the ocean and on small islands, but is delayed from 1 to 2½ hours after the end of the eclipse in continental situations. The temperature normally begins to fall 20 minutes after first contact. and the minimum occurs from 2 to 20 minutes after totality. Kite-meteorograph observations from the " Otaria " in 1905 gave a fall of only 1°F. at 300m. above the Atlantic Ocean. Temperature variation is therefore probably confined to a very shallow layer not exceeding 300m. or 400m. above the earth's surface. At hill stations the fall is usually less than at low-level stations, but comparisons are not always consistent.

Changes of vapour pressure are more difficult to distinguish, but there appears to be an increase of vapour pressure up to a time 30 to 50 minutes preceding totality, a minimum pressure at totality, and a second maximum about 30 minutes afterwards. This is characteristic only of stations in or near the total belt, but applies both on the ground and at 300m. The decrease is as large over the ocean as over large land areas. Relative humidity is acted on by opposing factors, the decrease in vapour pressure and the decrease in temperature. Over land areas the relative humidity usually rises to a maximum at the time of minimum temperature through preponderance of the second factor. Dew is often formed on the ground near the time of mid-eclipse. Cloud changes which appear to be definitely associated with the eclipse and also the formation of fog have been noted.

The variation of atmospheric pressure is not conspicuous with ordinary instruments, but observations with these and with microbarographs have produced considerable but not conclusive evidence to show that the eclipse curve has two minima and three chief maxima, the latter occurring at totality and about 75 minutes before and after it. The fluctuation is of the order of 0·2 mb.

A diminution in wind velocity is a feature almost as marked as the temperature fall. The minimum usually agrees closely with the time of minimum temperature. There are also strong evidences of maxima represented by gusts of increased velocity occurring 30 to 50 minutes before and 40 to 60 minutes after totality.

The production of winds with definite cyclonic circulation has been observed on some occasions but not on others. The resultant eclipse wind, however, frequently shows a definite succession of changes, with a reversal of direction before and after totality; it can never be large as the temperature gradient produced by the shadow is comparatively small.

The optical phenomena are of considerable interest; the colours of sky, clouds and landscape are usually very striking and subject to rapid changes about the time of totality. While the sun is completely obscured the light is of very peculiar quality, and appears to justify adjectives such as "livid" and "unnatural," by which it is usually described. Vitiation of distance estimates is a noticeable feature at this time. The approaching umbral shadow is indigo or blackish, and may be seen, from an elevated position, to pass points at known distances. As it reaches the observer definite pulsations, probably diffraction phenomena, may be observed. The best known of eclipse optical phenomena are the "shadow-bands." These are observed about 5 minutes before totality, and therefore definitely before the umbral shadow has reached the observer, and again after it has left him. The shadow-bands thus have no connexion with the pulsation of the shadow edge. The phenomenon consists of undulating dark bands, separated by light spaces, following one another in a direction usually normal to the tangent to the crests. The bands are visible on the ground, but are best seen if a sheet is laid down, or on snow, or on the walls of white houses. The bands appear to flicker and, while sometimes of considerable regularity, are often very vague and confused. Their speed is also inconstant, varying from about 3 to 25 m.p.h., and, therefore, very much slower than the speed of the moon's shadow. This is one of several facts which have disproved the theory that the bands are diffraction fringes bordering the moon's shadow. The bands were photographed for the first time in 1925 in the United States, and they have been observed up to a height of 3,800 m. on sheets hung below manned balloons. The general inference is that they are caused by the diminishing crescent of light penetrating air strata differing in their thermal and hygrometrical conditions, and, therefore, in their refractive power.

Eddy.—A name given to the deviation from steady motion which occurs in any viscous fluid which flows past any obstacle, or in which neighbouring streams flow past or over each other. Certain types of eddies, such as those formed in water at the side of a moving vessel, and those which sometimes form at street corners, are of the nature of whirls, but in meteorology the restriction of the use of the name eddy to whirling motions is not justifiable. (See TURBULENCE.)

Electrical Units.—The definitions of the absolute electrical and magnetic units will be found in treatises on electricity. We note here that the fundamental relation for the electrostatic group is the definition of a unit of charge, viz., the repulsion between two unit charges of electricity at unit distance is unit force, whilst the fundamental relation for the electromagnetic group is the definition of the unit magnetic pole, viz., the repulsion between two unit magnetic poles at unit distance is unit force.

The number of electrostatic units in an electromagnetic unit is v^n where v is the number which represents the velocity of light (which number is 3×10^{10} in the C.G.S. system) and the index n is 0, $\pm$ 1 or $\pm$ 2.

The practical electrical units are defined by their relations to the corresponding C.G.S. electromagnetic units. The relations to the electrostatic units are also shown in the following list.

	n.	Practical unit.	Electromagnetic C.G.S.	Electrostatic C.G.S.
Quantity of Electricity ..	1	Coulomb ..	10^{-1}	3×10^9
Electric current	1	Ampere ..		
Potential	−1	Volt ..	10^8	1/300
Resistance	−2	Ohm ..	10^9	$1/(9 \times 10^{11})$
Induction	−2	Henry ..		
Energy	0	Joule ..	10^7	10^7
Power	0	Watt ..		
Capacity	2	Farad ..	10^{-9}	9×10^{11}

In terrestrial magnetism the unit of magnetic force denoted by γ is given by $1\,\gamma = 10^{-5}$ C.G.S. unit. It is half the strength of the magnetic field produced by a current of one milliampere in a straight wire at a distance of one metre.

In atmospheric electricity the relation between potential gradient and induced charge is frequently required. This relation is

$$F = 36\pi \times 10^{11}\,\sigma$$

where σ the density of the charge is measured in coulombs per square centimetre and F the strength of the field is measured in volts per centimetre.

Electricity.—See ATMOSPHERIC ELECTRICITY.

Electrometer.—An instrument for measuring electromotive force or potential difference. Its function is, therefore, similar to that of a voltmeter but electrometers are distinguished by the fact that their action depends on electrostatic force, whereas ordinary voltmeters depend for their action on the magnetic or heating effects of an electric current. The indications of an electrometer do not involve the passage of a current through the instrument, and they can, therefore, be used for such purposes as the determination of the electrical potential of a point in the atmosphere. The types of instrument mainly employed for the latter purpose are the Kelvin portable electrometer, the Wulf bifilar electrometer, the electrostatic voltmeter, and the Dolezalek quadrant electrometer. If the needle of a quadrant electrometer is connected to a suitable "collector" and provided with a reflecting mirror, the variations of the electrical potential at the collector may be recorded continuously by photographic methods. (See ATMOSPHERIC ELECTRICITY.)

Element.—In meteorology one of the components which determines the state of the atmosphere at any given time and place. The chief meteorological elements are temperature, pressure, wind, precipitation, humidity, cloudiness. Atmospheric electricity and atmospheric pollution are sometimes included.

Energy.—Used frequently in meteorology in the general sense of vigour or activity. Thus, a cyclone is said to develop greater energy when its character, as exhibited by a low barometer, steep gradients and strong winds, becomes more pronounced. But there is a technical dynamical sense of the word, the use of which is sometimes required in meteorology, and which must become more general when the physical explanation of the phenomena of weather is studied, because all the phenomena of weather are examples of the "transformations of energy" in the physical sense.

The most important conception with regard to energy is its division into two kinds, kinetic energy and potential energy, which are mutually convertible. A clock weight gives a good idea of potential energy. When the clock is wound up the weight has potential energy in virtue of its position; it will utilise that energy in driving the clock until it is "run down" and can go no further. Potential energy must be restored to it by winding up before it can do any more driving. The potential energy in this case is measured by the amount of the weight and the vertical distance through which it is wound up. In dynamical measure the potential energy of the raised weight is mgh, where m is the mass of the clock weight, h the vertical distance through which it is wound up, g the acceleration of gravity. It is to the mysterious action of gravity that the energy is due:—hence the necessity for taking gravity into account in measuring the energy.

Using the simple product mgh as a measure of the potential energy of gravitation, by a simple formula for bodies falling freely under the action of gravity, we have

$$mgh = \tfrac{1}{2} mv^2$$

where v is the velocity acquired by a body falling through a height h, or, speaking in terms of energy, by losing the potential energy of the height h. It thus obtains a certain amount of motion which represents kinetic energy, in exchange for its potential energy. The kinetic energy is expressed by the apparently artificial formula $\tfrac{1}{2} mv^2$. In virtue of its motion it has the power of doing "work": if it were not for unavoidable friction the mass could get itself uphill again through the height h by the use of its motion, and thus sacrifice its kinetic energy in favour of an equivalent amount of potential energy.

The exchange of potential and kinetic energy can be seen going on in a high degree of perfection in a swinging pendulum. At the top of the swing the energy is all potential, at the bottom all kinetic. The swings get gradually smaller because in every swing a little of the energy is wasted in bending the cord or in overcoming the resistance of the air.

What we get in return for the loss of energy in friction is a little HEAT, and one of the great conclusions of physical science in the middle of the nineteenth century was to show that heat is also a form of energy but a very special form, that is to say, its transformation is subject to peculiar laws. Heat is often measured by rise of temperature of water (or its equivalent in some other substance). Calling this form of energy thermal energy and measuring it by the product of the "water equivalent," M, and the rise of temperature $A - A_0$ produced therein, we have three forms of energy all convertible under certain laws, viz.:—

Potential energy	$m\,g\,h$.
Kinetic energy	$\tfrac{1}{2}\,m\,v^2$.
Thermal energy	$M\,(A - A_0)$.

We have mentioned only a lifted clock weight as an example of potential energy, but there are many others, a coiled spring that will fly back when it is let go, compressed gas in a cylinder that will drive an engine when it is turned on, every combination, in fact, that is dormant until it is set going and then becomes active.

From the dynamical point of view, the study of nature is simply the study of transformations of energy.

In meteorology kinetic energy is represented by the winds; potential energy by the distribution of pressure at any level, by the electrical potential of the air and by the varying distribution of density in the atmosphere, causing convection; thermal energy by the changes of temperature due to the effect of the sun or other causes. It is the study of the interchange of these forms of energy which constitutes the science of dynamical meteorology.

Entropy.—A term introduced by R. Clausius to be used with TEMPERATURE to identify the thermal condition of a substance with regard to a transformation of its HEAT into some other form of ENERGY. It involves one of the most difficult conceptions in the theory of heat, about which some confusion has arisen.

The transformation of heat into other forms of energy, in other words, the use of heat to do work, is necessarily connected with the expansion of the working substance under its own pressure, as in the cylinder of a gas engine, and the condition of a given quantity of the substance at any stage of its operations is completely specified by its volume and its pressure. Generally speaking (for example, in the atmosphere) changes of volume and pressure go on simultaneously, but for simplifying ideas and leading on to calculation it is useful to suppose the stages to be kept separate, so that when the substance is expanding the pressure is maintained constant by supplying, in fact, the necessary quantity of heat to keep it so, and, on the other hand, when the pressure is being varied the volume is kept constant; this again by the addition or subtraction of a suitable quantity of heat. While the change of pressure is in progress, and generally also, while the change of volume is going on, the temperature is changing, and heat is passing into or out of the substance. The question arises whether the condition of the substance cannot be specified by the amount of heat that it has in store and the temperature that has been acquired just as completely as by the pressure and volume.

To realise that idea it is necessary to regard the processes of supplying or removing heat and changing the temperature as separate and independent, and it is this step that makes the conception useful and at the same time difficult.

For we are accustomed to associate the warming of a substance, i.e. the raising of its temperature, with supplying it with heat. If we wish to warm anything we put it near a fire and let it get warmer by taking in heat, but in thermodynamics we separate the change of temperature from the supply of heat altogether by supposing the substance is "working." Thus, when heat is supplied the temperature must not rise; the substance must do a suitable amount of work instead; and if heat is to be removed the temperature must be kept up by working upon the substance. The temperature can thus be kept constant while heat is supplied or removed. And, on the other hand, if the temperature is to be changed it must be changed dynamically not thermally, that is to say, by work done or received, not by heat communicated or removed.

So we get two aspects of the process of the transformation of heat into another form of energy by working, first, alterations of pressure and volume, each independently, the adjustments being made by adding or removing heat as may be required, and secondly, alterations of heat and temperature independently, the adjustments being made by work done or received. Both represent the process of using heat to perform mechanical work or vice versa.

In the mechanical aspect of the process, when we are considering an alteration of volume at constant pressure, $p\ (v-v_0)$ is the work done, and in the thermal aspect of the process $H - H_0$ is the amount of heat disposed of. There is equality between the two.

But if we consider more closely what happens in this case we shall see that quantities of heat ought also to be regarded as a product, so that $H - H_0$ should be expressed as $T\ (\phi - \phi_0)$ where T is the absolute temperature and ϕ the entropy.

The reason for this will be clear if we consider what happens if a substance works under adiabatic conditions, as we may suppose an isolated mass of air to do if it rises automatically in the atmosphere into regions of lower pressure, or conversely if it sinks. In that case it neither loses nor gains any heat by simple transference across its boundary; but as it is working it is drawing upon its store of heat, and its temperature falls. If the process is arrested at any stage, part of the store of heat will have been lost through working, so in spite of the adiabatic isolation part of the heat has gone all the same. From the general thermodynamic properties of all substances, it is shown that it is not H, the store of heat, that remains the same in adiabatic changes, but H/T, the ratio of the store of heat to the temperature at which it entered. We call this ratio the *entropy*, and an adiabatic line which conditions thermal isolation and therefore equality of entropy is called an isentropic. If a new quantity of heat h is added at a temperature T the entropy is increased by h/T. If it is taken away again at a lower temperature T' the entropy is reduced by h/T'.

In the technical language of thermodynamics the mechanical work for an elementary cycle of changes is $\delta p.\ \delta v$, and the element of heat $\delta T.\ \delta\phi$. The conversion of heat into some other form of energy by working is expressed by the equation

$$\delta T.\ \delta\phi = \delta p.\ \delta v$$

when heat is measured in dynamical units.

It is useful in meteorology to consider these aspects of the science of heat although they may seem to be far away from ordinary experience because, from certain aspects, the problem of dynamical meteorology seems to be more closely associated with these strange ideas than those which we regard as common. For example, it may seem natural to suppose that if we could succeed in completely churning the atmosphere up to, say, 10 kilometres (6 miles) we should have got it uniform in temperature or isothermal throughout. That seems reasonable, because if we want to get a bath of liquid uniform in temperature throughout we stir it up; but it is not true. In the case of the atmosphere there is the difference in pressure to deal with, and, in consequence of that, complete mixing up would result, not in equality, but in a difference of temperature of about 100°C. between top and bottom, supposing the whole atmosphere dry. The resulting state would not, in fact, be isothermal; the temperature at any point would depend upon its level and there would be a temperature difference of 1°C. for every hundred metres. But it would be perfectly isentropic. The entropy would be the same everywhere throughout the whole mass. And its state would be very peculiar, for if you increased the entropy of any part of it by warming it slightly the warmed portion would go right to the top of the isentropic mass. It would find itself a little warmer, and therefore a little lighter specifically than its environment, all the way up. In this respect we may contrast the properties of an isentropic and an isothermal atmosphere. In an isentropic atmosphere each unit mass has the same entropy at all levels, but the temperatures are lower in the upper levels. In an isothermal atmosphere the temperature is the same at all levels, but the entropy is greater at the higher levels.

An isothermal atmosphere represents great stability as regards vertical movements, any portion which is carried upward mechanically becomes colder than its surroundings and must sink again to its own place, but an isentropic atmosphere is in the curious state of neutral equilibrium which is called "labile." So long as it is not warmed or cooled it is immaterial to a particular specimen where it finds itself, but if it is warmed, ever so little, it must go to the top, or if cooled, ever so little, to the bottom.

In the actual atmosphere above the level of ten kilometres (more or less) the state is isothermal; below that level, in consequence of convection, it tends towards the isentropic state, but stops short of reaching it by a variable amount in different levels. The condition is completely defined at any level by the statement of its entropy and its temperature, together with its composition which depends on the amount of water vapour contained in it.

Speaking in general terms the entropy increases, but only slightly, as we go upward from the surface through the TROPOSPHERE until the STRATOSPHERE is reached, and from the boundary upwards the entropy increases rapidly.

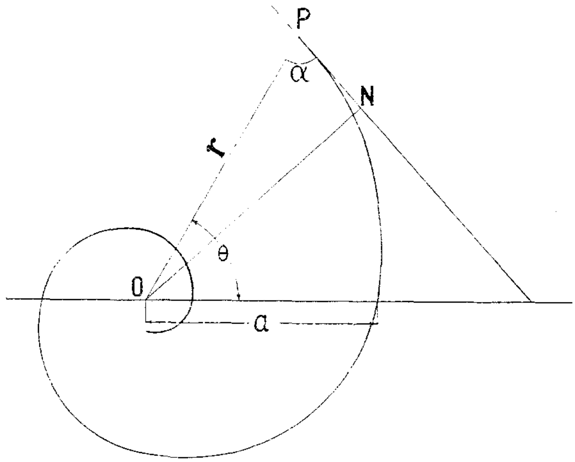
If the atmosphere were free from the complications arising from the condensation of water vapour the definition of the state of a sample of air at any time by its temperature and entropy would be comparatively simple. High entropy and high level go together; stability depends upon the air with the largest stock of entropy having found its level. In so far as the atmosphere approaches the isentropic state, results due to CONVECTION may be expected, but in so far as it approaches the isothermal state, and stability supervenes, convection becomes unlikely.

Equation of Time.—See TIME.

Equatorial Air.—Air originating in low latitudes. It is warm and damp, and often accompanied by low clouds, sea fogs, and drizzle. In the British Isles, and in Europe generally, it is much less common than POLAR AIR. It is sometimes described as "tropical air." (See DEPRESSION.)

Equatorial Current.—A current of air originating in low latitudes, south of 30°N. in many cases. Genuine equatorial currents are most frequent in winter, especially with straight south-west isobars. Sometimes they curve round an anticyclone and arrive from west or north-west. Many southerly currents are not of equatorial origin.

Equiangular Spiral.—A spiral is the locus of the extremity of a line (or radius vector) which varies in length as it revolves about a fixed point.



The equiangular spiral is such that as the vector angle increases arithmetically the radius vector increases geometrically. Another definition is that the tangent makes a constant angle α with the radius vector. The equation in polar co-ordinates is $r = ae^{\theta \cot \alpha}$.

Equinox.—The time of the year when the astronomical day and night are equal, each lasting twelve hours. At the equinox the sun is "on the equator" or is "crossing the line." It is on the horizon in the morning exactly in the east, and exactly in the west in the evening all over the world. Sunrise occurs at the same time all along a meridian. The sun is visible by refraction for a little longer than the duration of the astronomical day.

There are two equinoxes. The spring or vernal equinox about the 21st March, and the autumnal equinox about the 22nd September.

Equivalent Constant Wind.—A particular type of average wind of great importance in BALLISTICS. It may be defined as that wind, constant in speed and direction, which would produce the same displacement of a shell in flight as the actual varying winds which the shell meets during its flight.

Erg.—The absolute unit of work in the C.G.S. system. (See HEAT.)

Error.—In any observation other than the counting of discrete units, such as the number of balls in a basket, the repetition of the observation does not usually yield precisely the same result. This is particularly the case when an instrument is used to yield a measurement to the greatest possible number of significant figures. Successive measurements will then frequently give varying values for the last significant figure. It follows that no single observation can be regarded as strictly correct. The difference between the observed value and the true value is called the "error" of the observation.

In the discussion of errors of observation it is usually assumed that the observations have been carried out with the greatest possible care. Just as an observer may make a mistake in counting the number of balls in a basket, so he may commit a mistake of 5° in reading a thermometer. Such a mistake should be classified as a "blunder" and not as an "error." But even when all possible care has been taken to avoid blunders there still remain errors which cause individual observations in a series to differ from one another and from the true value of the quantity to be measured. These residual errors are due to the peculiarities of the observer, of the instrument, or of the external conditions.

The observer may have individual peculiarities, particularly in measuring positions of moving bodies, or estimating the instantaneous magnitude of a changing length. A good observer tends always to make the same error in observing, whereas an inexperienced observer is more erratic, both as to the magnitude and sign of his error. The personal error or "personal equation" of an observer can in some cases be estimated by comparison with a standard observer, or by means of specially designed laboratory experiments.

The instrument may have errors of construction or of graduation. These can generally be eliminated by comparison with a standard instrument. They may be constant errors, always of the same sign and magnitude, as in the case of a barometer whose scale has been displaced vertically from its correct position; or they may be systematic, bearing a fixed relation to one or more of the conditions of observation. For example, if a thermometer be constructed by graduating a degree scale upon a glass tube at equal intervals, any inequalities in the bore of the tube will lead to systematic errors which can be eliminated by comparison with a standard instrument.

Changing external conditions may also lead to errors in observation. By external conditions we mean such of the conditions of observation as are beyond the observer's control, as for example the vibration of a theodolite by the wind. It is seldom possible to make a correction for such conditions. All that can be done is to select such times of observation as shall be as little as possible subject to uncontrollable external conditions, when such selection is possible.

To obtain accurate observations with an instrument we therefore require to know its constant or systematic error. If the observer has a personal error, an effort should be made to estimate it, and allow for it. When these constant or systematic errors have all been allowed for as far as possible, it will generally be found that the individual observations in a series still differ from one another. The residual error which causes this difference is called the "accidental" error of the observation. The word "accidental" is here used in a special sense, to denote the sum total of all the errors whose source is unknown. They may be due for example to changes in the observer, as when an observer, becoming tired, makes errors of varying magnitude and sign in different observations; or to unsuspected temperature changes in the instrument; or to irregular effects of wind upon the instrument or upon the object observed. They may also be due partly to failure to realise the nature of some of the factors affecting the quantity measured, or even to defects in the theory on which the reduction of the observations is based. The endeavour of the observer should be to take account of all changing conditions as far as possible, and so to remove as much of the errors of observation as he can into the class of constant or systematic error.

Some judgment is, however, necessary in the application of these principles in meteorology. In climatological observations, for example, it is a waste of time to measure the temperature to ·01°C., since the fluctuating changes of temperature at a given place from one minute to the next generally exceed this value. Reading to ·1°C. is, however, readily possible.

See also PROBABILITY, PROBABLE ERROR, NORMAL LAW.

Evaporation.—The process of conversion of water or ice into aqueous vapour. The atmosphere is very rarely completely saturated, so that evaporation is nearly always going on, and in general the greater the difference between the amount of water vapour which the air holds and the amount which would saturate it at the existing temperature, the more rapid is the rate, but other factors such as the nature of the water surface from which evaporation is taking place, and wind, influence the rate.

Some figures for the average depth of water evaporated in various places are given below.

Evaporation from the Surface of Water

	30-year average. London, Camden Square.		1914 Great Britain, mean of 14 stations.		South Africa, Bulawayo. 20° 2′ S., 28° 58′ E.		Egypt, Wadi Halfa. 21° 55′ N., 31° 20′ E.		Australia, Cue, W.A. 27° 27′ S., 117° 52′ E.		Tasmania, Hobart. 42° 53′ S. 147° 20′E.	
	in.	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.
January..	·11	2·8	·10	2·5	8·94	227	11·10	282	21·46	545	5·87	149
February	·26	6·6	·45	11·4	7·40	188	12·64	321	17·13	435	4·21	107
March ..	·66	16·8	·78	19·8	8·74	222	17·96	456	16·78	426	3·03	77
April ..	1·55	39·4	2·13	54·1	8·90	226	21·85	555	11·22	285	1·97	50
May ..	2·38	60·5	2·54	64·5	9·02	229	25·52	648	7·48	190	1·22	31
June ..	2·90	73·7	3·23	82·0	7·99	203	25·28	642	4·84	123	0·67	17
July ..	3·07	78·0	3·07	78·0	8·07	205	23·82	605	5·35	136	0·83	21
August ..	2·36	59·9	2·38	60·5	12·84	326	22·84	580	6·26	159	1·30	33
September	1·37	34·8	2·03	51·6	14·73	374	22·92	582	9·13	232	1·77	45
October ..	·62	15·8	·87	22·1	14·96	380	20·08	510	13·39	340	3·07	78
November	·24	6·1	·41	10·4	10·79	274	15·12	384	18·00	457	4·02	102
December	·10	2·5	·26	6·6	9·84	250	10·75	273	22·37	568	4·88	124
Year ..	15·62	396·9	18·25	463·5	122·22	3104	229·88	5838	153·41	3896	32·84	834

Evaporimeter.—An instrument for determining the rate of evaporation of water into the atmosphere. The best form consists of a metal tank 6 ft. square and 2 ft. deep containing water, the changes of level of which are indicated by means of a gauge operated by a small float. Allowance must, of course, be made for rainfall. To obtain consistent results the tank must be well exposed and the water level should be maintained between 2 and 4 in. below the rim, the latter being about 1½ in. above ground level.

Expansion.—The increase in the size of a sample of material, which may be due to heat or to the release of mechanical strain, or the absorption of moisture or some other physical or chemical change.

The size may be taken as the length or volume, sometimes as the area. In the science of heat the fractional increase of length or volume for one degree of temperature is called the coefficient of thermal expansion. Thus, the coefficient of "linear" expansion with heat of the brass used for barometer scales is 0·0000102 per degree Fahrenheit, which means that for 1°F. the length of the scale increases by 102 ten-millionth parts of its length at the standard temperature (62°F.). The coefficient of "cubical" expansion of mercury is ·0001010, which means that the volume of a quantity of mercury increases by 1·01 ten-thousandth of its bulk at the standard temperature (32°F.) for 1°F. The corresponding expansions and coefficients for 1° C. or 1°A. are larger in the ratio of 18 to 10.

Expansion of volume alters the density of a substance, and changes of density are therefore numerically related to expansion.

The expansion of a gas may be caused either by reduction of pressure or by increase of temperature. So in order to see the effect of temperature alone we must keep the pressure constant. In these circumstances the coefficient of expansion is ·00366 for 1°A. referred to 273°A. as standard, or ·002 for 1°F. referred to 41°F. as standard.

Exposure.—In meteorology, the method of presentation of an instrument to that element which it is destined to measure or record, or the situation of the station with regard to the phenomenon or phenomena there to be observed. If meteorological observations are to be of full value attention must be paid to the manner of the exposure of the instruments. Details are to be found in the "Meteorological Observer's Handbook." Uniformity of exposure is of the greatest importance, and for that reason the pattern of the thermometer screen has been standardised in most countries, while in these Islands a standard height of one foot above ground for the rain-gauge has been fixed. It is important, too, that the sites of the thermometer screen and rain-gauge should not be unduly shut in ; on the other hand, a very open exposure, as on a bare moor, is undesirable for a rain-gauge, as is also a position on a slope, a roof, or near a steep bank. In these cases the catch is reduced by the effect of wind eddies due to the obstruction of the gauge itself. A SUNSHINE RECORDER demands an entirely unobstructed horizon near sunrise and sunset at all seasons of the year. The question of the exposure of ANEMOMETERS is one of great difficulty. The effect of the ground on a uniform current of air blowing above it is to reduce the velocity, the amount of reduction increasing as the ground is approached, and, at the same time, to introduce unsteadiness into the motion which is manifested by the creation of eddies in the air. The motion is then said to be turbulent (see TURBULENCE). A recording tube anemometer erected in a turbulent wind shows a large number of gusts and lulls corresponding with various parts of the eddy-motion. Hence the extent of the gustiness of the wind as recorded by the anemometer (see GUST) is a fair index of the excellence of the exposure. The ideal exposure for an anemometer is at the top of a pole 30 or 40 ft. high, erected on a flat treeless plain. Trees and buildings introduce much turbulence into air motion.

Exsiccation.—Drying by the draining away or driving away of moisture. The term implies some change, frequently the result of human agency, which decreases the quantity of moisture available without any appreciable change in the average rainfall. It is used in contrast with DESICCATION, which implies an actual drying up due to a change of climate. Examples of exsiccation are the washing away of the soil due to the cutting down of forests, with the consequent conversion of a fertile region into the semblance of a desert, the advance of sand dunes across cultivated ground, and the draining of swampy ground.

Extremes.—The highest and lowest values of meteorological elements. Standard climatological tables give the highest and lowest temperatures recorded at an observing station in the day, month and year. The mean daily maximum temperature is the average of the maxima for each day, similarly for the mean daily minimum. The monthly maximum and minimum temperatures are the highest and lowest temperatures recorded during the month. The highest and lowest temperatures during the whole period of the observations are called the absolute extremes.

The absolute extremes are :—For the British Isles : highest, 311·1°A. (100·5°F.) at Tonbridge, July 22nd, 1868 ; lowest, 242·4°A. (− 23°F.) at Blackadder, December 4th, 1879. For the surface of the globe : highest, 330·7°A. (136°F.) at Azizia (Uzzizia), Tripoli, September 13th, 1922 ; lowest, 203·2°A. (− 93·6°F.), at Verkhoïansk, Siberia, January 3rd, 1885. In the upper air : lowest, 182·1°A. (− 131·6°F.) at a height of 16½ Km. over Batavia, Java.

The extreme annual or seasonal totals of rainfall are important in agricultural countries and maximum values of rainfall in a short period are of interest to engineers. The extreme annual total in the British Isles is 247 in. at Llyn Llydaw, Snowdon, in 1909.

The maximum wind velocities in gusts, as shown by pressure-tube anemometers are also important to engineers. The extreme GUST recorded for the British Isles is 111 mi./hr. at Scilly on December 6th, 1929. The highest hourly wind velocity is 78 mi./hr. (34·9 m./sec.) at Fleetwood on December 22nd, 1894.

Eye of Storm.—The central calm area of a tropical cyclone. The most noticeable feature of this area is the sudden drop in wind from hurricane force to light unsteady breezes or even to a complete calm, with more or less cloudless sky and absence of rain. The interior margin of the storm appears to be symmetrical around the calm centre. Over the ocean the sea in the eye of the storm is usually very high and turbulent.

Eye of Wind.—A nautical expression indicating the direction from which the wind blows.

Fahrenheit, Gabriel Daniel.—The improver of the thermometer and barometer, born 1686 at Dantzig. He used mercury instead of spirit for thermometers and marked the freezing point of water at 32°, and the boiling point of water at 212°.

The Fahrenheit scale is still extensively used in English-speaking countries. The size of the degree is convenient and the range of the scale, 0°F. to 100°F., is a serviceable one for the climates of the temperate zone, where temperatures below 0°F. at the earth's surface are of rare occurrence.

Fall.—" The fall of the leaf," a term in common use in America for autumn.

Falling Time, of Barometer.—When a mercurial barometer is raised quickly from the horizontal or an inclined position to the vertical, the mercury which at first fills the tube will take a certain time to get to its position of equilibrium. The rate at which it does so is a measure of the sensitiveness and forms a convenient method of testing the latter. In marine barometers, the sensitiveness must be reduced, by constricting the tube, to minimise " PUMPING," and it is specified that the falling time between 50 and 18 millibars above the true height must lie between 4 and 5 minutes. The falling time, so measured, is equal to the " lagging time," that is, to the time between an actual change of pressure and its indication by the barometer.

False Cirrus.—A term used to denote the cirrus formed on the tops of CUMULO-NIMBUS, which eventually often becomes detached. The reason for the term " false " is not obvious, and the name is not recognised in the International Classification. (See CLOUDS.)

Fata Morgana.—A complicated form of MIRAGE in which multiple images of an object are produced ; these images are frequently elongated. It is produced by several layers of air of different diffractive indices.

Fiducial Temperature.—The temperature at which the readings of a barometer graduated in millibars need no correction in a particular latitude. The maker of a millibar barometer aims at making it read accurately throughout the scale at a certain temperature in lat. 45°. The temperature now adopted is 285°A. This temperature, appropriate for lat. 45°, is called the STANDARD TEMPERATURE of the barometer. Owing to the variation of gravity with latitude a mercury column of given length causes a pressure which is not invariable over the earth's surface but is dependent upon the latitude. A barometer which reads correctly at 285°A. in lat. 45° does not, therefore, read correctly at that temperature in another latitude. A temperature can, however, be found for each latitude at which the readings will be correct. This is termed the fiducial temperature. As an example, a barometer with standard temperature 285°A. will have a fiducial temperature in lat. 51° of 288°A.

Floe.—An area of ice other than fast ice whose limits are within sight. Floes up to 2 ft. in thickness may for convenience of description be termed " light floes " ; floes thicker than this, " heavy floes." Fast ice is sea ice remaining in the position of growth and is only met along coasts where it is attached to the shore or over shoals where it may be held in position by islands or stranded icebergs.

Flow-off.—The flow-off from any CATCHMENT AREA is the quantity of surface water which flows out of the area in a given time. The measurement is made at the place where the stream which carries the surface water emerges from the area.

Fog.—Fog is defined as obscurity in the surface layers of the atmosphere caused by particles of condensed moisture or of smoke held in suspension in the air. It is usual to limit the term " fog " to a condition of atmospheric obscurity in which objects at a distance of one kilometre are not visible. When visibility exceeds this limit, but is less than two kilometres, the obscuration is called " mist " or " haze " according to whether it is produced by condensed water particles or by foreign solid matter such as dust or smoke.

If the accumulation of dust or smoke in the atmosphere is so great as to reduce visibility below one kilometre, a pure dust fog or smoke fog occurs. Smoke fogs are characteristic of large towns and industrial areas where there is a continuous output of smoke and other impurities from factory chimneys, etc. The worst type of fog in such areas occurs when conditions are also favourable for condensation and a mixture of the two kinds of fog produces considerable obscurity.

Dust fogs are associated with the desert regions of the globe. They occur, for example, off the west coast of Africa during the season of the HARMATTAN which carries clouds of dust from the Sahara.

The following scale of fog intensity is used in meteorological work :—

Symbol	Description	Limit of visibility. Objects not visible at a distance of
8f	Dense fog	25 metres.
7f	,, ,,	50 ,,
6f	Thick fog	100 ,,
5f	,, ,,	200 ,,
4f	Fog	500 ,,
3f	Moderate fog	1,000 ,,
m or z	Mist or haze	2,000 ,,

Condensation of water vapour in the surface layers of the atmosphere is brought about most frequently by the direct cooling of the air below its dew-point. The cooling can occur either by lowering of the temperature of the surface of the ground, which is subsequently communicated to the air above it, or by the drift of air over a surface which is colder than itself. In both cases an inversion of the temperature lapse-rate is formed in the lower layers of air, and condensation is produced by the turbulent mixing of the air within these layers (see TURBULENCE). For the effective formation of fog, the wind must be light, in order to allow the air in contact with the ground to become sufficiently cooled.

Fogs over land occur chiefly in autumn and winter. They are formed most frequently on the calm, clear nights which are associated with anticyclonic conditions. They reach their maximum intensity, normally in the early morning, between one and two hours after sunrise, and usually disperse before midday. In winter, however, such fogs occasionally cover a wide area and persist for some days. Fogs may also be formed by the passage of warm air over cold ground or by the mixing of two currents of air of different temperatures. A peculiarity of the London area is the formation of fog, due to condensation together with an accumulation of smoke, in a layer of air above the surface. Such fogs, which are usually of brief duration, may cause darkness in the middle of the day equal to that of night.

Fogs at sea, unlike land fogs, are characteristic of spring and summer, and are usually formed by the passage of a current of air from a large land mass, or from tropical or sub-tropical regions, over the relatively cold sea.

High-level country experiences fog at all seasons due to drifting low cloud which envelops the high ground. High ground near the sea suffers the most in this respect.

The height to which an ordinary fog extends varies considerably. It is usually less than 1,000 ft. and frequently less than 500 ft. Sea fogs are sometimes so shallow that the mast-heads of ships protrude above them. In certain conditions a fog has no clearly defined upper boundary but merges into cloud which may extend to a considerable height.

The following table shows the percentage frequencies of fog and mist at different seasons at stations in the British Isles. The figures are based on observations at 7h., 13h. and 18h. G.M.T. during six years, the frequencies at each of these three hours being averaged to give the frequencies of whole days of fog.

Station	Height above M.S.L. in feet	Number of days per 100							
		Visibilities less than 1,000m.				Visibilities less than 2,000m.			
		Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
Valentia	30	0·1	0·3	0·1	0·0	0·1	0·5	0·4	0·2
Malin Head ..	51	0·6	0·6	0·6	0·4	0·8	1·2	1·0	1·0
Stornoway	30	0·5	0·1	0·9	0·1	1·1	1·4	1·5	0·6
Wick	81	1·6	3·2	0·5	0·2	2·2	3·7	0·9	0·4
Donaghadee ..	40	0·9	1·3	0·8	0·8	1·8	2·5	1·8	1·6
Mount Batten (Plymouth)	82	0·7	1·3	1·5	0·7	1·0	2·4	2·5	2·0
Portland Bill ..	32	1·8	1·8	0·9	0·8	2·5	2·8	1·6	1·7
Holyhead	26	1·2	2·1	0·7	0·6	2·0	3·6	1·8	2·0
Lerwick	54	1·4	3·2	2·9	0·4	1·9	4·0	3·4	0·8
Leuchars	40	1·9	0·8	1·5	1·0	3·2	1·4	2·7	3·4
Falmouth	200	2·1	2·7	2·2	0·7	3·1	3·4	3·0	1·6
Dungeness ..	20	1·2	1·3	2·4	3·5	2·1	1·9	4·0	5·5
Calshot (Southampton)	10	1·2	0·4	2·4	3·1	2·6	1·2	4·7	5·5
Inchkeith	190	2·4	2·1	2·8	2·1	3·8	2·9	3·5	4·4
Gorleston	14	1·6	1·2	2·9	5·9	1·9	1·5	5·0	8·6
Roches Point ..	22	1·9	2·6	1·8	1·5	3·8	4·4	4·5	4·9
Felixstowe	15	0·8	0·5	2·3	5·2	2·1	1·3	5·0	9·9
Scilly	165	3·0	4·9	4·5	2·0	3·7	5·7	5·6	3·0
Clacton	54	0·7	0·4	2·9	5·4	2·2	0·9	6·4	9·8
Aberdeen	46	2·2	1·6	2·0	1·7	5·3	3·1	4·9	6·4
Andover	295	2·5	0·9	3·3	6·5	3·7	1·7	5·9	9·4
Pembroke	150	4·6	4·8	2·7	4·1	5·6	6·0	3·6	5·2
Spurn Head ..	29	1·9	2·3	4·1	7·1	3·6	3·3	6·1	11·3
Cranwell	236	1·8	1·6	5·1	9·1	2·7	2·1	7·9	13·6
Shoeburyness ..	11	1·1	0·4	6·2	8·3	2·7	0·8	10·1	13·5
Ross on Wye ..	223	1·7	1·2	7·6	5·1	3·7	2·2	13·5	10·0
Birr Castle	173	1·6	1·0	5·4	5·1	5·8	2·7	9·2	14·2
Lympne	350	2·7	2·1	4·6	10·0	5·0	3·6	8·6	16·2
Tynemouth ..	67	3·3	4·2	5·0	6·2	6·3	5·9	9·7	12·0
Farnborough ..	230	3·2	0·7	8·1	7·3	5·5	1·3	14·3	12·6
Biggin Hill ..	597	3·5	1·4	6·8	10·6	7·9	3·2	12·2	17·3
Croydon	244	2·7	0·7	7·2	7·3	7·1	2·0	16·5	17·6
Liverpool	189	4·8	1·0	7·3	5·6	14·5	4·0	15·2	14·5
Sealand (Chester) ..	16	2·8	0·8	10·0	8·3	10·0	3·5	20·4	17·9
Kew..	18	3·5	0·8	11·4	11·3	8·6	2·2	20·3	21·3
Renfrew	36	2·9	0·7	10·5	9·2	11·3	4·5	18·8	20·4
Birmingham ..	535	5·1	1·8	10·1	12·9	12·9	4·9	19·4	24·1
Beachy Head ..	525	10·1	9·5	8·2	17·1	15·1	13·4	18·2	24·6

Fog bow.—A white rainbow of about 40° radius seen opposite the sun in fog. Its outer margin has a reddish and its inner a bluish tinge but the middle of the band is quite white. A supernumerary bow is sometimes seen inside the first and with the colours reversed. The bows are produced in the same way as the ordinary rainbow but owing to the smallness of the drops, the diameter of which is about 0·05 mm., the colours overlap and the bow appears white.

Föhn.—A warm, dry wind which blows down the slopes on the leeward side of a ridge of mountains. The name originated on the Alps where the föhn is very prevalent, especially on the northern slopes; the wind also occurs on the eastern side of the Rocky Mountains where it is known as the CHINOOK. Owing to its warmth and dryness it melts the snow very quickly and causes a considerable rise in temperature. It is frequently accompanied by lenticular clouds.

The föhn occurs in the Alps mostly with a southerly wind. The air when coming against the ridge of mountains ascends and dynamic cooling takes place with condensation and precipitation. The temperature of the air falls at the adiabatic rate for wet air, that is at about 1°A. for every 200 m. of ascent. When the air descends the slopes on the other side of the mountain, having lost its moisture it is dynamically warmed at the "dry adiabatic" rate of 1°A. for every 100 m. and reaches the valleys as a warm, dry wind.

The föhn is likely to occur wherever cyclonic systems pass over mountainous regions, for example it frequently occurs on the coast of Greenland where it has a considerable influence on the winter climate.

Foot-pound-second system.—A system of units based upon the foot, the pound and the second as fundamental units. Seldom used in meteorology or the pure sciences, but forms the basis of the units used by engineers. On this system the unit of force is the "poundal," which is the force required to give a mass of 1 pound an acceleration of 1 foot per second per second. The unit of work, the "foot-pound," is the work done in raising a weight of 1 pound through a vertical distance of 1 foot against gravity.

The foot-pound-second system is the counterpart of the C.G.S. system, in which the fundamental units are the centimetre, gram and second.

Forecast.—The first use in this country of synoptic charts for forecasting the weather anticipated in the near future was made by Admiral Fitzroy in 1860 and it was he who invented the special meaning of the term "forecast" to avoid the somewhat unfortunate connotations attaching to such terms as "prognostic" and "prophecy."

In practice, a forecast as issued, for 12, 24 or 36 hours, includes:—

(1) A statement of the anticipated direction and force of the surface wind and the changes therein which are expected during the period of the forecast.

(2) A statement of the anticipated state of the sky (as regards clouds), precipitation (rain, hail, snow or sleet) and temperature, whether it is likely to be greater than, equal to or less than, the normal for the time of year, or higher or lower than at the time of making the forecast.

(3) A note as to the probability of such occurrences as night frost, fog or thunder.

Forecasts issued for special purposes contain special matter, additional to that already specified. For aviation, for example, the anticipated winds at selected or demanded heights are included together with a statement concerning the visibility and any anticipated changes in it. Again, for seamen, statements may be included concerning visibility and the state of the sea.

To derive the forecasts, the forecaster depends upon a close study of the current synoptic charts, especially with regard to anticipated changes in the distribution of pressure, and with constant appeal to physics and to precedent.

The period covered by the forecasts issued by the Meteorological Office does not exceed, as a rule, 24 to 36 hours, but usually a statement under the heading FURTHER OUTLOOK is added, giving the conditions likely to be experienced in the 24 hours or more following the period covered by the actual forecast. Much work has been done in the endeavour to find means to forecast the coming of weather changes at a greater distance ahead but up to the present little success of a practical nature has been achieved.

Fortin Barometer.—A portable form of mercurial BAROMETER in which the zero of the scale is fixed by a pointer, inside the cistern. By making the cistern partly of leather and providing an adjusting screw, the level of mercury in the cistern can be brought up to the scale zero before each reading is taken.

Fourier Series.—A representation of any periodic function of an independent variable in terms of sines and cosines of multiples of that variable is called a Fourier Series. It was first developed by Fourier in his treatise " Théorie de la Chaleur " (Paris, 1822). In symbols,

$$f(x) = A_0 + A_1 \sin x + A_2 \sin 2x + \quad . \; . \; . \; .$$
$$+ B_1 \cos x + B_2 \cos 2x + \quad . \; . \; . \; .$$

See HARMONIC ANALYSIS.

Fracto.—An adjective used in cloud nomenclature to denote a ragged broken structure (fracto-CUMULUS, fracto-STRATUS, fracto-NIMBUS).

Frazil Ice.—Ice which forms in spicules or small plates in rapidly flowing rivers, the movement of the water preventing the ice crystals from forming a solid sheet of ice. The formation has been best observed in the rivers of Canada, and the name is a French-Canadian word, from a French word for cinders, the frazil crystals being supposed to resemble forge-cinders.

Freeze, Freezing.—With reference to the weather, " freezing " is used when the temperature of the air is below the freezing point of water. In America freezing conditions sufficiently persistent to produce what we should call " a FROST " are usually described as " a freeze."

Frequency.—The number of times that a particular phenomenon of weather has happened in the course of a given period of time, generally a number of years. Here, for example, is a summary of the spells of wind from the easterly quarter, according to the direction of the isobars, over south-east England and northern France in nine years. Taking January, for instance, the nine years supply a total of 279 days, of which 58 were days of E. wind. These consisted of one sequence of eight consecutive days of E. wind, one sequence of six days, three sequences of four, two sequences of three and seven sequences of two days, with finally twelve isolated days of E. wind.

Frequency Table.—Number of Spells of Wind of Specified Duration from NE., E. or SE., during the nine years 1904–1912 *inclusive. England, South-East, and Northern France*

Duration of Spell	January	February	March	April	May	June	July	August	September	October	November	December
Days	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
1	12	7	13	15	15	19	13	13	11	12	13	11
2	7	3	3	3	10	7	6	5	8	4	4	2
3	2	5	4	3	3	3	4	—	3	7	1	2
4	3	—	3	1	1	1	4	2	6	1	2	—
5	—	1	—	2	4	—	—	—	1	1	1	—
6	1	—	—	2	1	2	—	2	—	—	1	1
7	—	—	1	1	—	1	—	—	—	—	—	1
8	1	—	—	1	—	—	—	—	1	2	—	1
9	—	—	—	—	—	—	—	—	—	1	—	—
10	—	—	—	—	—	—	—	—	—	—	1	—
11	—	1	—	—	—	—	—	—	—	—	—	—
12	—	—	—	—	—	—	—	1	—	—	—	—
13	—	—	1	—	—	—	—	—	—	—	—	—
Total number of days of E. wind.	58	44	63	71	74	65	53	55	76	75	53	42
Total number of days of observations.	279	255	279	270	279	270	279	279	270	279	270	279

In this case the number of years over which the observations extend is given, quite an arbitrary number, and thus the numbers for frequency of occurrence have to be considered with reference to the number of years selected. It is, however, usual to reduce frequency figures to a yearly average.

In view of the awkwardness of having to bear in mind the possible number of occurrences, while considering the actual or average number, it is convenient to use the percentage frequency instead of the actual frequency. This plan is often adopted for giving the results of observations at sea, which are made six times a day, or every four hours.

It is often convenient to represent the results of observation by means of a *frequency curve*. An example is shown giving the distribution of frequencies of deviations from normal of monthly mean pressures at Edinburgh for the period 1770–1869. (Fig. 17.)

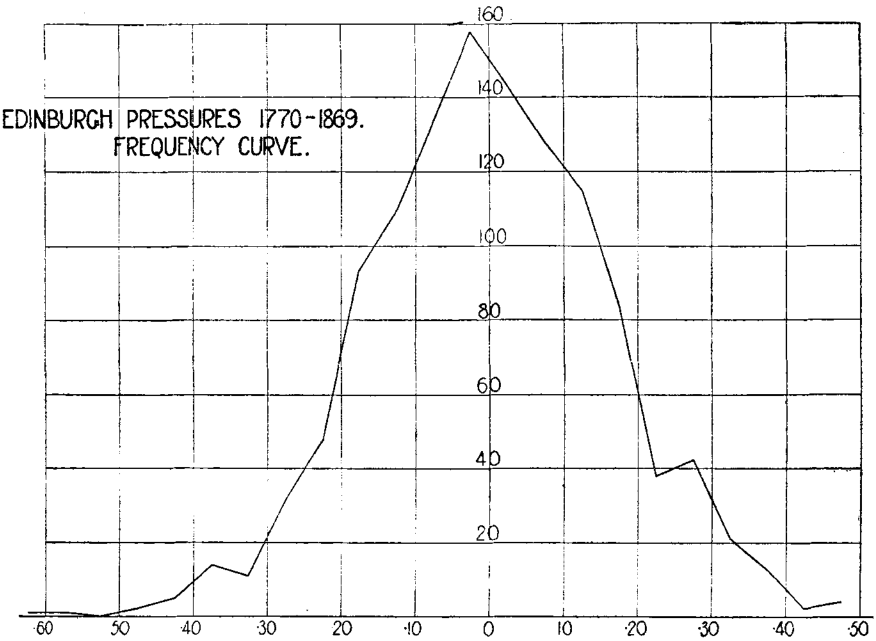


FIG. 17.

Friction.—A word used somewhat vaguely in meteorological writings in dealing with the effect of the surface of the sea or of the land, with its obstacles in the form of irregularity of surface, hills, buildings, or trees upon the flow of air in the lower layers of the atmosphere. The effect of the irregularities of surface is to produce TURBULENCE in the lowest layer which gradually spreads upwards, if the wind goes on blowing, and consists of irregular eddies approaching to regularity in the case of a cliff eddy which can be noticed when a strong wind blows directly on to a cliff and produces an eddy with a horizontal axis. An account of the eddy caused by the eastern face of the rock of Gibraltar is given in the *Journal of the Aeronautical Society*, **18**, 1914, p. 184.

The general effect of this so-called friction is to reduce the flow of air past an anemometer so that the recorded wind velocity is below that which would be experienced if the anemometer were high enough to be out of the reach of the surface effect. Numerical values for this effect are of great practical importance, because they are concerned with the change of velocity in the immediate neighbourhood of the ground. But it is not easy to obtain them, because every exposure near land or sea is more or less affected, and, therefore, no proper standard of reference can be obtained by direct observation. Recourse is, therefore, had to the computation of the wind from the distribution of pressure, the so-called "geostrophic" or GRADIENT WIND.

From the comparison of a long series of geostrophic and observed winds we conclude that over the open sea, or on an exposed spit of flat sand like Spurn Head, the wind loses one third of its velocity from "friction," and at other well-exposed stations the loss is, on the average, as much as 60 per cent, but for any particular anemometer it is different for winds from different quarters because the exposure seaward or landward is different. Information on this point for a number of Meteorological Office stations is given in a memoir by Mr. J. Fairgrieve (*Geophysical Memoirs*, Vol. 1, p. 189).

The consequence of this effect can sometimes be seen in weather maps. On one occasion when the whole of the British Isles was covered with parallel isobars running nearly west and east, all the stations on the western side gave the wind as force 8 (42 mi./hr.) while those on the eastern side gave force 5 (21 mi./hr.), so that the velocity was reduced by one half in consequence of the "friction" of the land. If the velocity at the exposed western stations be taken at two thirds the velocity of the wind free from friction, we get the following interesting result which is probably correct enough for practical use :—One third of the velocity is lost by the sea friction on the western side, and one third more by the land friction of the country between west and east.

Front.—The term introduced by the Norwegian meteorologists to denote the line of separation between cold and warm masses of air. The more important fronts are due primarily to the large-scale horizontal movements, which bring masses of air of widely different origin into juxtaposition. The actual boundary is sometimes diffuse, and only becomes sharp when there is pronounced CONVERGENCE. Sharp fronts are often made diffuse by SUBSIDENCE in the cold air, provided that there is little precipitation, the cold air behind the front descending and being warmed by compression so that it becomes difficult to distinguish it from the warm air which it is displacing. From the line of the front on the ground, a SURFACE OF DISCONTINUITY or frontal surface slopes upward over the cold air. The contrast of temperature and therefore of density affects the pressure and wind distribution, and it can be shown that a front must in general lie along a trough of low pressure (though a rounded trough is not necessarily a front). It may, however, be parallel to the isobars, in which case the steeper pressure gradient is on the side of the higher pressure. In consequence surface friction normally causes some convergence and rainfall along a front, but large amounts of rain can only occur when there is convergence extending up to some thousands of feet, which results in the warm current rising *en masse* up the sloping frontal surface. (See also DEPRESSION, POLAR FRONT, COLD FRONT, WARM FRONT.)

Frost.—Frost occurs when the temperature of the air is below the freezing point of water. It may be transient and local, as is usual in the case of frosts due to the cooling of comparatively mild air of oceanic origin at night under a clear sky, or it may continue night and day over a large area. When persistent frost occurs over a large proportion of the British Isles, it is always initiated by the arrival of dry cold air from the Continent or the Arctic Regions. A persistent anticyclone to the north-west, north or north-east of the British Isles in the winter half of the year may cause such an influx of cold dry air, generally with northerly or easterly winds. If these bring heavy snow, the spell of frost is apt to be severe, because snow absorbs only a small proportion of the solar radiation that falls upon it, while emitting radiation of longer wave-lengths very readily ; and because its thermal conductivity is so low compared with that of the ground that the normal winter flow of heat from the deep earth to the surface is checked. It is with snow-covered ground that temperatures below zero Fahrenheit are liable to occur even in the south of England. The exceptional frosts of February, 1895, were preceded by heavy snow. The expression " degrees of frost " denotes the number of degrees that the temperature falls below the freezing point.

Funnel Cloud.—The cloud formed at the core of a WATERSPOUT or TORNADO, sometimes extending right down to the earth's surface, attributed to the reduction of pressure at the centre of the vortex.

Further Outlook.—A statement in brief and general terms appended to a detailed forecast and giving the conditions likely to be experienced in the 24 hours or more following the period covered by the actual forecast.

Gale.—As ordinarily understood a gale simply means a high wind. For technical purpose however it is necessary to have a more definite specification and it is now the practice in the London Meteorological Office to limit the term gale to winds of force 8 or above on the BEAUFORT SCALE, although Admiral Beaufort himself described force 7 as a moderate gale. As the result of international agreement it has been decided that the equivalent velocity of force 8 on the Beaufort scale extends from 15·3 to 18·2 metres per second for an anemometer exposed at a height of 6 metres over a level surface, this corresponds to velocities between 17·2 and 20·7 metres per second for an exposure 10 metres above the ground, which is the normal exposure of the anemometers used at British stations. Great difficulty is encountered in comparing the frequency with which gales occur at different places. If the observations to be compared are all made by estimates according to the Beaufort scale, the comparison is made difficult because of the different exposure to the wind at the place of observation. Observations made within a sheltered harbour will obviously give fewer gales than observations made on a nearby headland,. Similar difficulties as regards the exposure occur with records obtained by anemometers; but in addition there are difficulties due to the varying height of the anemometers above the ground and also due to the method of reading the anemometer trace. The velocity equivalent of 17·2 metres a second was determined from records each extending over an hour during which the velocity was frequently above this value and also frequently below. Thus it is not correct to report a gale whenever an anemometer trace reaches 17·2 metres per second. From this it is clear that it is essential to state exactly how statistics of frequency of gales have been obtained, and to take into account when discussing the statistics the " exposure " at the observing stations.

The table headed " Gales on or near the coasts of the British Isles " that is appended to this article is based on as homogeneous a set of statistics as it is possible to obtain. All the observations are " Beaufort estimates," which were made on lightships and lighthouses in exposed situations. The table covers the 40 years 1876–1915 and gives (*a*) the average monthly frequency of gales recorded on various sections of the coasts, and (*b*) the odds against the occurrence of a gale on these various sections on any day in the various months, the odds in each case being " odds against one." The table shows that the north-west coast of Ireland is the most subject to gales and the east coast of England the least subject.

Gale Warning.—The Meteorological Office issues notice of the probability of gales on or near the coasts of the British Isles by telegram to ports and fishing stations recommended by responsible local authorities, and the fact that one of these notices has been received at any station is made known by hoisting a cone, three feet high and three feet wide at base, and painted black.

Two cones are used (*a*) the south cone (point downwards) and (*b*) the north cone (point upwards). For the significance of these cones reference should be made to the instructions issued to all gale-warning stations.

Gales on or near the Coasts of the British Isles, 1876–1915

Coasts	Jan.		Feb.		Mar.		April		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.		Year	
	Mean No.	Odds	Mean No.	Odds	Mean No.	Odds	Mean No.	Odds	Mean No.	Odds	Mean No.	Odds	Mean No.	Odds	Mean No.	Odds	Mean No.	Odds	Mean No.	Odds	Mean No.	Odds	Mean No.	Odds	Mean No.	Odds
Scotland :—																										
North-east	5·4	5	3·9	6	3·7	7	1·9	15	1·1	27	0·4	74	0·3	102	0·7	43	1·7	17	3·4	8	4·7	5	5·3	5	32·4	10
East	3·5	8	2·5	10	2·9	10	1·1	26	0·7	43	0·4	74	0·4	77	0·5	61	1·4	20	2·6	11	3·4	8	2·9	10	22·3	15
North-west	5·0	5	3·9	6	3·0	9	1·5	19	1·0	30	0·4	74	0·5	61	0·7	43	2·0	14	2·8	10	4·6	6	5·0	5	30·3	11
West	4·1	7	3·4	7	2·5	11	1·3	22	0·7	43	0·4	74	0·3	102	0·9	33	1·7	17	2·9	10	4·0	7	4·2	6	26·3	13
Ireland :—																										
North-west	6·5	4	4·6	5	4·1	6	2·3	12	1·2	25	0·8	37	1·0	30	1·3	23	2·7	10	4·2	6	5·6	4	6·4	4	40·5	8
South-west	5·7	4	4·9	5	3·9	7	2·0	14	1·2	25	0·5	59	0·5	61	1·4	21	1·9	15	3·4	8	4·8	5	5·9	4	36·1	9
Irish Sea	5·0	5	4·2	6	4·3	6	1·9	15	1·0	31	0·7	42	0·7	43	1·3	23	2·0	14	3·6	8	5·0	5	5·6	5	35·3	9
St. George's Channel ..	4·6	6	3·6	7	3·4	8	1·4	20	0·8	38	0·4	74	0·4	77	1·0	30	1·5	19	3·4	8	4·5	6	5·3	5	30·1	11
Bristol Channel ..	5·2	5	4·7	5	3·6	8	2·0	14	0·9	33	0·7	42	0·7	43	1·7	17	2·1	13	4·4	6	5·2	5	6·3	4	37·6	9
England :—																										
South-west	4·4	6	4·2	6	3·5	8	1·6	18	1·1	27	0·4	74	0·5	61	1·3	23	1·3	22	3·5	8	4·7	5	5·6	5	32·0	10
South	3·5	8	3·1	8	2·4	12	1·1	26	0·6	51	0·3	99	0·6	51	1·4	21	1·2	24	3·1	9	4·0	7	4·4	6	25·5	13
South-east	3·0	9	2·4	11	2·1	14	0·9	32	0·5	61	0·2	149	0·4	77	1·0	30	1·0	29	2·8	10	3·7	7	4·1	7	21·9	16
East	2·4	12	2·2	12	1·8	16	1·0	29	0·5	61	0·2	149	0·2	154	0·6	51	0·7	42	2·3	12	3·0	9	3·0	9	17·9	19
North-east	3·7	7	3·0	8	3·1	9	1·2	24	0·7	43	0·4	74	0·4	77	0·5	61	1·3	22	2·7	10	3·1	9	4·0	7	24·0	14

Notes.—The " mean numbers " signify the average number of gales in the month over the given period.
The " odds " represent in each case the " odds against one " against the occurrence of a gale on any one day in the month under consideration.

The issue of a warning indicates that an atmospheric disturbance is moving or developing in such a way as probably to cause a gale in exposed situations or in the open sea in the district to which the warning is sent, i.e. within a distance of 50 to 100 miles of the place where the cone is hoisted. The meaning of the warning is simply " Look out for high winds or gales."

It needs to be noted that, in connexion with the gale warning service, the term " gale " is used for winds of force 8 and above on the BEAUFORT SCALE OF WIND FORCE.

Gas.—The name used for any kind of fluid which has unlimited capacity for expansion under diminishing pressure. It is to be distinguished from a liquid which has only a limited capacity for expansion under reduced pressure.

A liquid may occupy only the lower part of a vessel like a bottle ; it will flow to the bottom of the vessel and leave a " free " surface. But a gas cannot be located in that way ; its volume is determined not by the amount of material but by the size of the vessel which contains it and by the pressure upon its boundaries.

In scientific practice gas means any substance which obeys approximately the gaseous laws ; these laws are two, viz. :—

1. When the temperature is kept constant the pressure of a given mass of gas is inversely proportional to the volume which it occupies, or the density is directly proportional to the pressure.
2. When the volume is kept constant the pressure is proportional to the ABSOLUTE TEMPERATURE, or when the pressure is kept constant the volume is proportional to the absolute temperature.

General Inference.—The term " General Inference " is used in weather forecasting for a description of the general pressure distribution and the changes of pressure in progress together with a statement of the type of weather likely to be experienced through such changes. It usually precedes a series of more detailed forecasts for individual districts and gives the foundations or framework on which these forecasts are formed.

Geophysics.—Physics is a comprehensive name for the branches of science which deal with those natural phenomena which are not biological and not merely descriptive. Geophysics is the name for those parts of physics which are concerned with the earth and its atmosphere. Meteorology, seismology, terrestrial magnetism, atmospheric electricity and hydrology (including the theory of the tides) all rank as geophysical subjects. Geology and geography are concerned largely with matters which do not come within the range of geophysics, but there is no definite limitation.

Geopotential.—Potential energy is the general name given to ENERGY which is available for conversion to kinetic energy. Thus we may talk of the potential energy of a coiled-up spring. In many cases the potential energy is acquired by a change of position in a field of force and in such cases potential is defined as the potential acquired by the appropriate unit of quantity. When dealing with matter in the gravitational field of the earth, potential, or more specifically geopotential is the potential energy of unit mass. The zero of potential is taken as at sea level.

Since the gravitational attraction of the earth is greater near the poles than near the equator more energy is required to raise a body to a given height near the poles and therefore the geopotential increases more rapidly as we ascend in high latitudes than in low. Conversely the height at which a given potential is reached is less in high latitudes than in low. Points with the same geopotential may be said to be at the same level. By using geopotential rather than height for specifying the position of parts of the atmosphere, the consideration of the air movements is simplified, and for this reason the practice of publishing the results of balloon soundings in terms of geopotential has been advocated and indeed adopted by the international organization.

The natural unit of geopotential is the potential acquired when a mass is raised through the unit distance in a field of force of unit strength. Thus, in the C.G.S. system the unit would be 1cm. × 1cm./sec.^{2} The unit advocated by Bjerknes is 10^5 times greater and is known as the "dynamic metre"; but as this term is objectionable, for it confounds geopotential with height, the name "leo" (from Galileo) has been suggested as a substitute.

Geostrophic.—See GRADIENT WIND.

Glacier Breeze.—A cold breeze, blowing down the course of a glacier, which owes its origin to the cooling of the air in contact with the ice. (See KATABATIC.)

Glaisher Stand.—A form of stand devised by James Glaisher for the exposure of thermometers. The stand consists of a vertical portion, partially roofed, on which the thermometers are mounted, with a doubly roofed sloping rear portion designed to prevent the front portion becoming heated from the rear. The whole is capable of rotation about a vertical axis so that direct sunshine may be prevented from affecting the thermometers at all times. The stand has been superseded at nearly all important stations by the STEVENSON SCREEN.

Glazed Frost.—When rain falls with the air temperature below the freezing point a layer of smooth ice, which may attain considerable thickness, is formed upon all objects exposed to it. This is known as glazed frost. The accumulation of ice is frequently sufficient to bring down telegraph wires. In these Islands the phenomenon is one of comparative rarity. It occurred on the morning of December 21, 1927, in London, and in many other parts of England, and caused several thousand street accidents. Glazed frost also occurs when a warm, damp wind supervenes upon severe cold, the moisture condensing on still freezing surfaces and thus producing a coating of ice, similar in appearance to glazed frost.

A phenomenon similar to glazed frost may also result if sleet, formed by the passage of snow through an upper stratum of air above the freezing-point, occurs during frost. Instances of this occurred in London during the winter of 1916–17, and road traffic, in some cases even rail locomotion, was rendered difficult or impossible.

Glory.—The system of coloured rings surrounding the shadow of the observer's head on a bank of cloud or mist. A typical series of colours in a well developed glory is the following:—A whitish yellow field bounded by dull red; bluish green, reddish violet; blue, green, red; green, red.

When light passes through circular holes in an opaque screen colours are produced by DIFFRACTION. If little mirrors all facing the sun could be substituted for the droplets in a cloud the light from each mirror would behave as if it came through a hole from the reflection of the sun and similar diffraction colours would occur. The action of the drops is probably analagous. The mathematical theory developed by Ray is on these lines. Earlier writers had supposed that the phenomena were produced by the diffraction, by particles comparatively near the surface, of light reflected from deeper portions of the fog or cloud.

A glory may be surrounded by a FOG BOW.

Gold Slide.—When a mercurial barometer is used at sea level in lat. 45° the correction to be applied to its readings in order to reduce them to standard conditions is directly proportional to the difference between its STANDARD TEMPERATURE and the actual temperature. To simplify the application of this correction, it is clearly possible to graduate the attached thermometer directly in millibars, the zero corresponding with the standard temperature. If the height of the barometer cistern is changed by an amount not exceeding 100 ft. the consequent correction is merely equivalent (to a first approximation) to a change in the zero of the correction scale. The same statement applies to a change of latitude.

In the Gold slide, devised by Lieut.-Col. E. Gold, this principle is applied in a practical form for use on marine barometers. The "ATTACHED THERMOMETER" is mounted in a brass stock and the "barometer correction scale" of millibars is mounted on a vertical slide actuated by rack and pinion. Scales are provided whereby the necessary adjustments for index error, height and latitude are readily made and the total correction is read off on the sliding scale opposite the end of the thermometric column, thus avoiding calculation or reference to tables.

Gradient.—The word gradient is used in surveying and in common practice to indicate the slope of a hill, that is the change in height per unit horizontal distance. The word has been adopted in meteorology to indicate the change in certain elements, for example pressure and temperature, per unit horizontal distance and its use has further been extended to the change of elements in the vertical though this use seems hardly justified. Thus, when temperature gradient is referred to it is generally the change of temperature with height in the atmosphere which is meant and not the change along the earth's surface between one place and another. More recently the term LAPSE-rate has been used to replace gradient in the vertical direction ; thus, if the temperature falls at the rate of 5° per 1,000 ft. height in the atmosphere this is referred to as a lapse rate of 5° per 1,000 ft.

Of the several connexions in which the word gradient is used in meteorology that in which it indicates the rate of change of pressure along the earth's surface is the most important, pressure gradient being one of the fundamental quantities with which the meteorologist has to deal. This is mainly due to the fact that the wind at a short distance above the earth's surface is so closely related to the pressure gradient that in many cases a better estimate can be formed of the general wind from the run of the isobars than by any other means. The pressure gradient is the change of pressure per unit distance measured perpendicular to the isobars, that is in the direction in which pressure changes most rapidly. Instead of measuring the pressure difference in a given distance such as 100 miles, it is in practice found more convenient to measure the distance between two consecutive isobars and deduce the gradient by dividing the pressure difference between the two isobars by this distance. The measurement of pressure gradient is a simple matter when the isobars are straight or only slightly curved, are parallel to one another, and are uniformly spaced. When the pressure distribution is irregular and the isobars sinuous, the measurement of the pressure gradient becomes more difficult and it is necessary to study the individual pressure readings in addition to the run of the isobars to determine the gradient in any region.

Gradient Wind.—The flow of air which is necessary to balance the pressure-gradient. The direction of the gradient wind is along the isobars, and the velocity is so adjusted that there is equilibrium between the force pressing the air inwards, towards the low pressure, and the centrifugal action to which the moving air is subject in consequence of its motion.

In the case of the atmosphere the centrifugal action may be due to two separate causes ; the first is the tendency of moving air to deviate from a GREAT CIRCLE in consequence of the rotation of the earth ; the deviation is towards the right of the air as it moves in the northern hemisphere, and towards the left in the southern. The second is the centrifugal force of rotation in a circle round a central point according to the well-known formula for any spinning body. In this case we regard the air as spinning round an axis through the centre of curvature of its path. This part of the centrifugal action is due to the curvature of the path on the earth's surface. Both components of the centrifugal action are in the line of the pressure gradient : the part due to the rotation of the earth is always tending to the right in the northern hemisphere, the part due to the curvature of the path goes against the gradient from low to high when the curvature is cyclonic, and with the gradient when it is anticyclonic, so that in the one case we have the gradient balancing the sum of the components due to the earth's rotation and the spin, and in the other case the gradient and the spin-component balance the action due to the earth's rotation.

The formal reasoning which leads up to this result is given at the end of this article. The two components have been termed by Sir Napier Shaw—that due to the rotation of the earth the *geostrophic* component and that due to the curvature of the path, the *cyclostrophic* component.

Consider the relative magnitude of these components under different conditions. It will be noticed that the geostrophic component depends upon latitude, the cyclostrophic component does not, so, other things being equal, their relative importance will depend upon the latitude ; so we will take three cases, one near the equator at latitude 10° within the equatorial belt of low pressure, one near the pole latitude 80° of undetermined meteorological character, and one, half-way, between, in latitude 45°, a region of highs and lows travelling eastward.

Using V to denote the wind velocity, when the radius of the path is 120 nautical miles the cyclostrophic component is equal to the geostrophic—

in latitude 10° when V is 5·6 metres per second ;
in latitude 45° when V is 22·9 metres per second ;
in latitude 80° when V is 31·9 metres per second.

It will be seen that in the equatorial region the cyclostrophic component is dominant as soon as the wind reaches a very moderate velocity.

EQUATION FOR GEOSTROPHIC WIND.

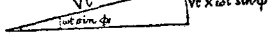
The Relation between the Earth's Rotation and the Pressure Distribution for Great-Circle-Motion of Air.

The rotation ω of the earth about the polar axis can be resolved into $\omega \sin \phi$ about the vertical at the place where latitude is ϕ and $\omega \cos \phi$ about a line through the earth's centre parallel to the tangent line.

The latter produces no effect in deviating an air current any more than the polar rotation does on a current at the equator.

The former corresponds with the rotation of the earth's surface counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere under the moving air with an angular velocity $\omega \sin \phi$. We therefore regard the surface over which the wind is moving as a flat disc rotating with an angular velocity $\omega \sin \phi$.

By the end of an interval t the air will have travelled Vt, where V is the wind velocity, and the earth underneath its new position will be at a distance $Vt \times \omega t \sin \phi$, measured along a small circle,



from its position at the beginning of the time t.

Taking it to be at right angles to the path, in the limit when t is small, the distance the air will appear to have become displaced to the right over the earth is $V \omega t^2 \sin \phi$.

This displacement on the "$\frac{1}{2} gt^2$" law (since initially there was no transverse velocity) is what would be produced by a transverse acceleration

$$2 \omega V \sin \phi.$$

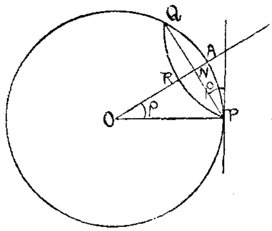
∴ the effect of the earth's rotation is equivalent to an acceleration $2 \omega V \sin \phi$, at right angles to the path directed to the right in the northern hemisphere, and to the left in the southern hemisphere.

In order to keep the air on the great circle, a force corresponding with an equal but oppositely directed acceleration is necessary. This force is supplied by the pressure distribution.

EQUATION FOR CYCLOSTROPHIC WIND.

Force necessary to balance the Acceleration of Air moving uniformly in a small circle, assuming the Earth is not Rotating.

Let A be the pole of circle PRQ. Join PQ, cutting the radius OA in N. Acceleration of particle moving uniformly along the small circle with velocity V is $\frac{V^2}{PN}$ along $PN = \frac{V^2}{R \sin \rho}$ where R = radius of earth; and ρ is the angular radius of the small circle representing the path.



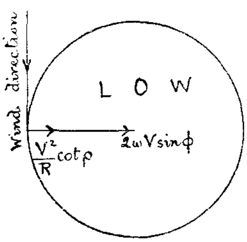
The horizontal component of this acceleration, that is, the component along the tangent at P, is $\frac{V^2 \cos \rho}{R \sin \rho} = \frac{V^2}{R} \cot \rho$.

GENERAL EQUATION CONNECTING PRESSURE—GRADIENT, EARTH'S ROTATION, CURVATURE OF PATH OF AIR AND WIND VELOCITY.

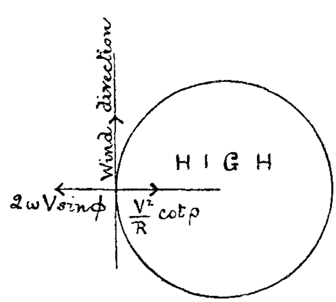
I. *Cyclonic Motion.*—The force required to keep the air moving on a great circle in spite of the rotation of the earth must be such as to give an acceleration $2\omega V \sin \phi$ directed over the path to the left in the northern hemisphere. It must also compensate an acceleration due to the curvature of the path, $V^2 \cot \rho / R$, by a force directed towards the low pressure side of the isobar.

For steady motion these two combined are equivalent to the acceleration due to the gradient of pressure, i.e. $\frac{\gamma}{D}$ where D is the density of the air, and γ the pressure gradient, directed towards the low pressure side.

$$\therefore \frac{\gamma}{D} = 2\,\omega\, V \sin \phi + \frac{V^2}{R} \cot \rho.$$



II. *Anticyclonic Motion.*—In this case $2\,\omega\, V \sin \phi$ and $\frac{\gamma}{D}$ are directed outwards from the region of high pressure, and the equation becomes $\frac{\gamma}{D} = 2\,\omega\, V \sin \phi - \frac{V^2}{R} \cot \rho$.



Gram.—The unit of mass in the C.G.S. system. It is one-thousandth part of the standard kilogram which was originally supposed to represent the weight of a cubic decimetre of pure water at 4°C.; but subsequent research has shown that the relationship was not exact. A gram = 15·4 grains, or rather more than $\frac{1}{30}$ ounce.

Gram-Calorie.—See CALORIE.

Grass Temperature.—A conventional term applied to the reading of a minimum spirit thermometer enclosed in an outer glass jacket and freely exposed at night just above the surface of short grass. Although the grass minimum thermometer does not indicate the temperature of the air at its own level nor the temperature of the grass blades but rather its own temperature, i.e. that of a bulb filled with spirit losing heat by RADIATION and receiving heat by radiation from the clouds, the atmosphere, the ground and surrounding objects and by contact with the air, it does indicate the circumstances in which these temperatures are high or low.

Graupel.—The German word for SOFT HAIL.

Gravity.—The attraction between material bodies. The law of universal gravitation is that every mass attracts every other mass with a force which varies directly as the product of the attracting masses and inversely as the square of the distance between them. It is convenient to regard the attracted body as of unit mass. The law then implies that the force exerted is independent of the temperature or velocity of the attracting body. Both these conclusions have been attacked of late years, but it is not questioned that they are sufficiently exact for meteorological purposes.

It is easily shown mathematically that a sphere whose density varies only with the distance from the centre attracts an external body exactly as if the whole mass were collected at the centre, and that a similarly constituted spherical shell—i.e. a mass bounded by two concentric spherical surfaces—while attracting an external body as if its mass were collected at the centre, exerts no attraction at any internal point. Let us apply this to a point in the atmosphere at height h above the ground, regarding the earth as a perfect sphere of radius R, and assuming the density, whether of the earth or the atmosphere, to vary only with the radial distance. The atmosphere outside the spherical surface of radius $R + h$ exerts no attraction, while the earth's mass plus that of the atmosphere $(M + M')$ within the surface of radius $R + h$ attract as if collected at the centre. Thus the attractive force is $G(M + M')/(R + h)^2$, where G is a constant. This becomes $g_0\ (1 + M'/M)\ (1 + h/R)^{-2}$, where $g_0 = GM/R^2$ is the corresponding force at the earth's surface, i.e. wholly within the atmosphere. Counted in kilograms M' is large, but even if we went to the confines of the atmosphere M'/M would be less than one millionth. Thus the attraction of the atmosphere may be neglected, at least for meteorological purposes. The variation with height of the earth's own attraction is much more important. At all heights attained by balloons we may neglect h^2/R^2, and so replace $(1 + h/R)^{-2}$ by $1-2h/R$. But at a height of say 10 miles this represents a reduction of one part in 200 in gravity.

Although the astronomical definition of gravity relates only to the universal attraction between masses, in geophysics the value of the gravitational acceleration g is taken to represent the total vertical acceleration, and therefore to include the centrifugal acceleration.

In reality the earth is not a sphere but approaches to a spheroid whose equatorial radius is 10·7 k. longer than its polar radius. The earth's surface is also irregular in outline, and the density variable, at least near the surface. Thus the formulae actually advanced to show the variation of gravity at different parts of the earth's surface are complicated.

The value of g at mean sea level in lat. ϕ is

$$g = 980{\cdot}617\ (1 - {\cdot}00259 \cos 2\phi) \text{ in C.G.S. units}$$

where 980·617 cm./sec.^{2} is the value of g at mean sea level in lat. 45°.

In the free air therefore, the value of g at height h in lat. ϕ is given by

$$g = 980{\cdot}617\ (1 - {\cdot}00259 \cos 2\phi)\ (1 - \frac{2h}{R})$$

where R is the radius of the earth (R = 6,370,000 metres = 20,900,000 ft). The above formula would also hold at places on mountains if the effects of the mountains were compensated by a change in the mean density of the earth's crust beneath. If there were no such compensation, g would be given by

$$g = 980{\cdot}716\ (1 - {\cdot}00259 \cos 2\phi)\ (1 - \frac{5h}{4R}).$$

This is the formula which is normally used in the reduction of pressure to mean sea level.

It will be seen that g has its mean value in lat. 45°, i.e. where $\cos 2\phi$ vanishes.

This explains why it is usual to reduce gravity to lat. 45°. This means reducing some measure actually made—e.g. of the height of the barometer—to what it would have been if gravity had possessed its mean value. The formula does not, of course, imply that gravity has the same value at every spot in lat. 45°, irrespective of its height above sea level or other local peculiarities.

The determination of g absolutely at any spot with the precision which the formulae suggest is extremely difficult, but relative values of g, or, differences between its values at different places, can be determined with very high precision by means of pendulum observations.

If t and t' be the times of oscillation of a certain pendulum at two stations, the corresponding values g and g' of gravity are connected by the relation $g'/g = (t/t')^2$.

This enables gravity at any station to be determined in terms of gravity at a base station. For accurate work corrections have to be applied to the observed times of swing to allow for departures of temperature and pressure from their standard values, also for chronometer-rate and flexure of the pendulum-stand. When all the known corrections are carefully made a very high degree of accuracy is obtainable. For instance, taking 981·200 as the value of g at Kew Observatory, this being the value accepted for the purposes of the Trigonometrical Survey of India, the last two comparisons instituted between Greenwich and Kew, the one made by the United States Coast and Geodetic Survey, the other by the Trigonometrical Survey of India—using two different sets of half-second pendulums, gave for g at Greenwich the respective values 981·188 and 981·186.

Pendulum and other geodetic observations have led to a theory of *isostasy* which has received strong support of late years, especially in the United States. According to this theory if we start at about 100 Km. below sea level we find between there and the free surface an approximately uniform quantity of matter irrespective of whether the free surface is mountainous or not. A lesser density under lofty mountains and a higher density under deep seas act as compensations.

While the mass of a body is independent of its position, its weight, i.e. the gravitational attraction exerted on it, varies with g and so increases as we pass from the equator towards either pole. Denoting by g_ϕ the value of g in lat. ϕ we obtain from the formula

$$g_{90} = 983{\cdot}19,\ g_0 = 978{\cdot}00.$$

In other words, gravity at the poles exceeds gravity at the equator by 1 part in 189.

Great Circle.—A line on the earth's surface in a plane through the centre of the earth's figure. All meridian lines are great circles, but all lines of latitude, with the exception of the equator, are small circles, as also is the visible horizon and any closed circular isobar. The great circle which passes through two points on the earth's surface is made up of the shortest and the longest track between the two points, the latter being greater than a semicircle. The above definition of a great circle is rigid but the use of the word "circle" is in an approximate sense, owing to the figure of the earth. Small circles parallel to the equator are true circles.

Green Flash.—The "green flash" is a phenomenon which is observed fairly often at sunset, more rarely (because seldom looked for) at sunrise. At sunset the last glimpse of the sun which is seen is a brilliant green. The colour lasts but two or three seconds. The explanation is that the rays from the sun are refracted in their passage through the atmosphere, the blue and green more than the yellow and red so that when the sun is so low that no red light from it can reach the observer, green light from the upper limb can. The blue light is generally absorbed or diffracted by the atmosphere. The phenomenon requires a clear atmosphere; whether unusual refractive power is also necessary has not been settled.

Gregale.—A strong north-easterly wind which blows in the Ionian Sea and neighbouring parts of the central Mediterranean mainly during the winter. It usually lasts two or three days and frequently reaches gale force. These strong north-easterly winds are associated with pressures above normal to the north of them. Pressure to the south, through relatively low, may yet be above normal. It is well known to seamen that the winds generally occur with high barometer. Temperature at the time of occurrence is low over Greece and the Balkans and the wind is cold but not specially dry: some rain usually falls. The name is derived from the word "Greece" and is spelt in some places "Grecale."

Ground Frost.—As injury to the tissues of growing plants is not caused until the temperature has fallen appreciably below the freezing point of water (32°F.) a "ground frost" is regarded as having occurred when the thermometer on the grass has fallen to 30°F. or below. If the thermometer is read to tenths of a degree the limit is 30·4°F.

Ground, State of.—Observations of the state of the ground are now made regularly at a number of stations in this country, in connexion with the operations of aircraft and of agriculture. They discriminate between dry ground, wet ground, muddy ground, frozen ground, dew, hoar frost or snow on ground. Special provision is made for the condition "glazed roads," which occurs when the roads are very slippery owing to the formation of a continuous sheet of ice from frozen rain or melted snow. A new specification for "state of ground" was drawn up by the International Meteorological Conference at Copenhagen, 1929, and will shortly be brought into use.

Gulf Stream.—The Gulf Stream is one of the strongest and most constant ocean currents. Originating in the eastern area of the Gulf of Mexico it flows through the Straits of Florida and up the eastern coasts of the United States. The Gulf Stream does not flow inshore, but generally speaking follows the edge of the continental shelf. It is continued by a weaker and broader current, often called the Gulf Stream, but more accurately the North Atlantic Drift, right across the Atlantic Ocean, leaving the coast of America in about latitude 40°N. and reaching the British Isles in about latitude 50°N. Like all ocean currents it is subject to variability and even to reverse sets. Recent research shows that up the American coast the Gulf Stream is strongest in spring and summer, when it flows with a mean strength of 30 miles per day. The transatlantic current has a mean strength of 3–5 miles per day. In the autumn the Bahama current flowing to the eastward of the Bahamas joins the Gulf Stream in about latitude 30°N., at other seasons it is partial and interrupted. It is popularly supposed that the temperate climate of the British Isles is due to the warmth conveyed by the Gulf Stream, but the real state of affairs is that our climate is due to the prevailing westerly and south-westerly winds, which also cause the extension of the Gulf Stream across the Atlantic. For a discussion of the effects of the Gulf Stream on the weather of western Europe see *London, Meteorological Office, Geophysical Memoirs*, No. 34, and *Meteorological Magazine*, **63**, 1928, p. 61.

Gust.—The word was used originally for any transient blast of wind, but is now limited to the comparatively rapid fluctuations in the strength of the wind, which are characteristic of winds near the surface of the earth and are mainly due to the turbulence or eddy motion arising from the friction offered by the ground to the flow of the current of air.

An investigation regarding the nature of gusts, as indicated by a tube-anemograph, was carried out by the Advisory Committee for Aeronautics and the results are contained in several reports on wind striucture published in the annual reports of the Committee. The number and extent of the fluctuations are very irregular; the range between gusts and lulls is dependent on the mean velocity of the wind and the exposure of the anemometer. Other factors also play their part, and winds from certain quarters tend to be more gusty than those from others. Expressing the fluctuations as a percentage of the mean velocity the following results were obtained for various anemometers (*Report of the Advisory Committee for Aeronautics*, 1909–10, pp. 103–4).

Anemometer	Range of fluctuation as a percentage of the mean velocity
Southport (Marshside)	30
Scilly (St. Mary's)	50
Shoeburyness, ENE. wind	30
,, W. wind	80
Holyhead (Salt Island)	50
Falmouth (Pendennis) S. wind	25
,, ,, W. wind	50
Aberdeen	100
Alnwick	80
Kew	100

In this table a fluctuation of 100 per cent. means that a wind with a mean velocity of, say, 30 miles per hour fluctuates over a range of 30 miles per hour, between about 15 miles an hour and 45 miles an hour, in consequence of the gustiness.

Gusts are to be distinguished from squalls. A squall is a blast of wind, occurring suddenly, lasting for some minutes, and dying away as suddenly. Gusts are the result of mechanical interference with the steady flow of air, whereas squalls are attributable to meteorological causes.

The strongest gusts recorded on anemometers of the Meteorological Office in recent years are :—

		m/sec.	mi./hr.
1917	Scilly	42·9	96
1918	Quilty	38·4	86
1919	Southport	38·4	86
1921	Larkhill	34·9	78
1922	Pendennis	46·0	103
1923	Valentia	42·5	95
1924	Lerwick	40·2	90
1925	Southport	39·3	88
1926	Edinburgh	37·6	84
1927	Fleetwood	37·6	84
1927	Dunfanaghy	48·7	109
1927	Tiree	48·3	108
1929	Scilly	49·6	111

A gust at Quilty in 1920 was reported as greater than 112 miles per hour, at which point the record left the chart, but this is now regarded as of doubtful authenticity.

Haar.—A local name in eastern Scotland for a wet sea fog.

Hail.—The term properly denotes the hard pellets of ice of various shapes and sizes and more or less transparent, which fall from cumulo-nimbus clouds and are often associated with thunderstorms. A variety known as SOFT HAIL is small, white, opaque and soft, resembling little snow pellets.

Hailstones may attain a great size, stones as large as golf balls have been observed in Europe and the recorded weights range up to a kilogramme (over 2 lb.).

An important characteristic of a cumulo-nimbus cloud is the rapid ascent into it of a moist current of air, which is quickly cooled by reason of the reduced pressure which it encounters aloft. As the process continues cloud particles, and finally raindrops, are formed, but if the ascensional velocity of the air exceeds 8 m./sec. all the condensed water is retained in the cloud (see RAIN-DROPS). At a level not usually exceeding 4 Km. in this country the temperature has already fallen below freezing point. There is much evidence for believing that, at least in many cases, ice crystals are not immediately formed as soon as the temperature falls below freezing point, but that water-drops are still produced. These are in the super-cooled condition, and they are carried upwards into the higher part of the cloud. Near the top of this cloud, however, ice crystals will appear and these will grow into pellets of soft hail by a process of condensation direct from vapour to ice. When the weight of a pellet is sufficient to overcome the resistance of the upward air current it will commence to fall. Let us consider the journey downwards of a pellet which has reached or is formed at the top of the cloud (8 Km., say). It has to encounter a stretch of supercooled waterdrops and saturated air much exceeding 8 km. in length, because the air it meets is being carried upwards at a speed of, say, 8 m./sec. Wegener computes that the stretch of air encountered may be as long as 14 Km. The pellet is continuously passing into air warmer than itself and the temperature difference between the pellet and its surroundings increases continuously until the ground is reached, when in extreme cases the difference has been observed to be as much as 15°C. The air surrounding the hailstone, as the pellet has now become, is saturated with respect to the surface of the supercooled water drops which are floating in it, so that it is super-saturated with respect to ice at its own temperature and still more super-saturated with respect to the hailstone which as explained is at a still lower temperature. Consequently all the water drops held in suspension in the air, which the hailstone encounters on its way down, freeze on the stone immediately it strikes them. Wegener computes that the fall of a pellet from 8 km. to the ground under the conditions described is sufficient to account for the production of the largest hailstones. It may be noted that if the ascensional current fails or is considerably reduced in velocity, the suspended water in the cloud is no longer supported, and it falls with the result commonly described as a cloud-burst.

Halo Phenomena.—The term halo, which might be applied to any circle of light round a luminous body, is restricted by meteorologists to a circle produced by refraction through ice crystals; in contrast to coronae which are produced by diffraction. All the optical phenomena produced by reflection and refraction of light by ice crystals are sometimes grouped together as halo phenomena.

The most common halo is a luminous ring of 22° radius surrounding the sun or moon, the space within the ring appearing less bright than that just outside. The ring, if faint, is white; if more strongly developed the inner edge is a pure red, outside which yellow may be detected. The halo of 22° is very common. In England it can be seen by an assiduous observer about one day in three.*

* At the Radcliffe Observatory, Oxford, there were in 1925 150 days on which solar halos (complete or broken) were observed; lunar halos were registered on 40 nights in the same year.

The angle of 22° is the angle of minimum deviation for light passing through a prism of ice (index of refraction 1·31) with faces inclined at 60°. Thus the occurrence of the halo of 22° radius indicates the presence of ice crystals with faces inclined at 60°. Alternate faces of a hexagonal prism are inclined at this angle, and as hexagonal prisms are frequently found amongst ice crystals the halo is probably due to the refraction of light through such prisms.

A halo of 46° is to be seen occasionally, though seldom complete. This halo requires crystals with faces at right angles.

The halo of 22° is sometimes within a circumscribed nearly elliptical halo the points of contact being at the highest and lowest points. The complete circumscribed halo is only seen when the elevation of the sun is 40° or more. With lower elevations separate tangent arcs are seen. These phenomena are explained by the presence of prismatic ice crystals floating with their axes horizontal.

Another group of phenomena requires prismatic crystals with their axes vertical. In this group are parhelia, or MOCK SUNS (patches of light at the same elevation as the sun) and the circumzenithal arc (a horizontal circle rather more than 46° above the sun).

In weather lore halos are often spoken of as presaging storms. In modern meteorology the cirro-stratus cloud in which halos are likely to be observed is regarded as a feature of a WARM FRONT. Halos are too common, however, to be good signs of exceptional weather.

Harmattan.—A very dry wind which is prevalent in western Africa during the dry season (November to March). During these months (the winter of the northern hemisphere) the air over the desert of Sahara cools rapidly, owing to its clearness and lack of moisture, so that it tends to flow outwards to the coast, especially south-westwards to the Gulf of Guinea, and replace the lighter air there. Being here both dry and relatively cool, it forms a welcome relief from the steady damp heat of the tropics, and from its health-giving powers it is known locally as *The Doctor*, in spite of the fact that it carries with it from the desert great quantities of impalpable dust, which penetrates into houses by every crack. This dust is often carried in sufficient quantity to form a thick haze, which impedes navigation on the rivers.

Harmonic Analysis.—There are many meteorological phenomena which recur with some approach to regularity day by day. If the changes of such a variable as temperature are represented by a curve, then the portions corresponding to successive days bear a strong likeness to one another. If for the actual record for each day the record for the average day were substituted, the variation for a long period would be represented by a curve in which the part corresponding with each day was like its fellows. The simplest curve possessing this property of continuous repetition is a curve of sines. As an example the variation of temperature at Kew Observatory, Richmond, in July, may be cited. The sequence of change throughout the average day is shown in the lower part of Fig. 18. The representative curve is not unlike a curve of sines, but it is not quite symmetrical. The rise which commences at sunrise and lasts until after 15 h. is more steady than the drop which is rapid in the evening and slow after midnight. A good approximation to the temperature on the average day is given, however, by the expression $289{\cdot}9 + 3{\cdot}7 \sin (15t + 224\frac{1}{2}^\circ)$ where t is the time in hours reckoned from midnight. It will be seen that the lowest value is reached at the time given by $15t + 224\frac{1}{2}^\circ = 270^\circ$, i.e. at 3 h. 6 m. and the maximum comes 12 hours later at 15 h. 6 m. The substitution of a sine-curve for the curve based on the observations would make the minimum too early by an hour, but would not affect the maximum so much.

The curve showing the diurnal variation of temperature in March (in the upper part of the figure) is not so near to a sine curve as that for July.

The rise in temperature from minimum to maximum takes little more than six hours. The best sine curve for representing the variation is given by the formula

$$\theta = 278{\cdot}74 + 2{\cdot}47 \sin(15t + 222^\circ)$$

and is shown by the broken line in the figure. It will be seen that the agreement is by no means close. To obtain a more accurate expression for the temperature, an additional sine term with a period of 12 hours may be introduced. The best formula containing such a term is

$$\theta = 278{\cdot}74 + 2{\cdot}47 \sin(15t + 222^\circ) + 0{\cdot}63 \sin(30t + 39^\circ)$$

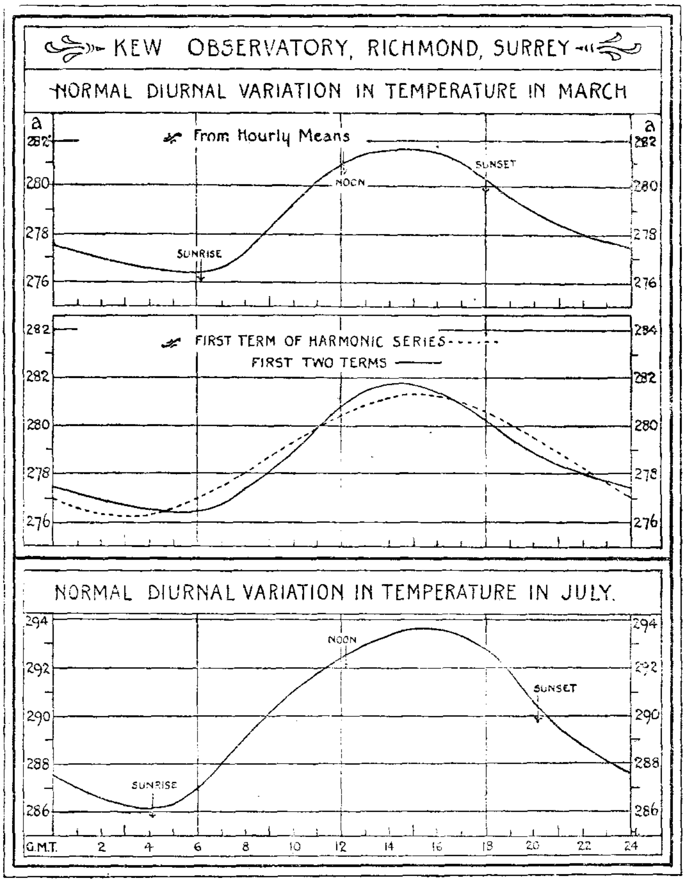


FIG. 18.

The new term $0{\cdot}63 \sin(30t+39^\circ)$ is positive in the early morning and in the early afternoon, so that it delays the drop to the minimum and makes the maximum earlier. In the upper part of Fig. 18, the continuous curve which corresponds with the proposed formula crosses the simple sine curve at intervals of six hours. The resemblance to the curve based on the observations is greatly improved. A closer resemblance would be obtained if additional terms

$$0{\cdot}08 \sin(45t+330^\circ) + 0{\cdot}12 \sin(60t + 190^\circ)$$

were included in the formula.

The harmonic representation of a diurnal inequality may be expressed in either of the alternative forms—

$$a_1 \cos (15^\circ \times t) + a_2 \cos (30^\circ \times t) + a_3 \cos (45^\circ \times t) + a_4 \cos (60^\circ \times t) + \ldots$$
$$+ b_1 \sin (15^\circ \times t) + b_2 \sin (30^\circ \times t) + b_3 \sin (45^\circ \times t) + b_4 \sin (60^\circ \times t) + \ldots,$$
$$P_1 \sin (15^\circ \times t + A_1) + P_2 \sin (30^\circ \times t + A_2) + P_3 \sin (45^\circ \times t + A_3) + P_4 \sin (60^\circ \times t + A_4) + \ldots,$$

where t denotes the time in hours counting from some fixed hour, usually midnight. The latter is the form which has been adopted in the previous part of this note, as it best exhibits the physical significance of the results, but the first form is that employed for the actual numerical calculation of the harmonic coefficients. We first calculate the a, b coefficients and then derive the P, A coefficients from the relations

$$\tan A_n = a_n/b_n\ ;\ P_n = a_n/\sin A_n = b_n/\cos A_n\ ;$$
$$P_n^2 = a_n^2 + b_n^2$$

where n may be 1, 2, 3, 4, etc.

Details of the methods adopted for practical computation of the coefficients will be found in the "Computer's Handbook."

The process of finding the trigonometric series to give the best representation of a periodic function is known as harmonic analysis. The reverse process, determining the value of the function at any time when the components are known, is harmonic synthesis. Both processes can be carried out by suitable machines, and also by arithmetical computation from given data. The latter process is the more usual except in the case of the prediction of tides.

In any term $P \sin (nt + A)$ the coefficient P which determines the range is called the amplitude, $nt + A$ is called the phase angle, A being the phase angle for midnight. It may be mentioned that the alternative form $P \cos n\,(t - t_0)$ where t_0 is the time of the maximum, has certain advantages; it was adopted by General Strachey for the discussion of harmonic analysis of temperature in the British Isles.

By comparison of the amplitudes and phase angles for different places and different seasons, climates may be classified. For example, the amplitude of the whole-day term for temperature in July at Falmouth is 2·1°A., and the phase angle for local apparent midnight is 250°. In comparison with Kew, the amplitude is small and the maximum occurs early. This difference in phase is typical of the difference in conditions on the coast and inland. It may be stated, however, that as regards temperature, harmonic analysis has not yielded information which can not be obtained more readily from the curves showing the daily variation. With pressure more important results have been discovered.

For temperature the first or all-day term in the expansion in trigonometric series is by far the most important. With pressure the second term is comparable in size with the first, and at most stations there are two maxima and two minima in the course of 24 hours. The first term is found to depend on the situation of the station, whether near the coast or inland, in a valley or on a mountain-side, whereas the second or twelve-hour term depends principally on the latitude. The daily changes represented by the first term are clearly understood, they are the effects of local heating of the air. No adequate explanation of the surge of pressure which is represented by the second and higher terms has been put forward.

The daily variation of pressure at Cairo in July is represented graphically by Fig. 19

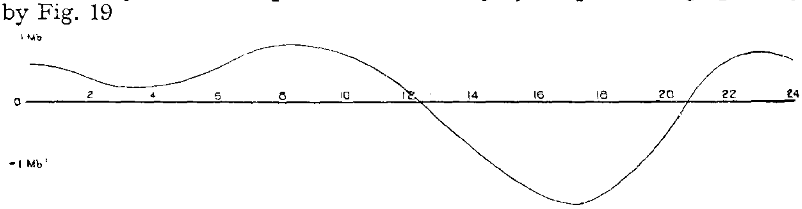


FIG. 19.—Daily variation of the Barometer at Cairo (Abbassia Observatory) in July.

The departure of the pressure from the mean for the day is given in millibars by the expression

$$\cdot 92 \sin (15t + 17^\circ) + \cdot 66 \sin (30t + 140^\circ)$$
$$+ \cdot 12 \sin (45t + 348^\circ) + \cdot 05 \sin (60t + 250^\circ).$$

The first term represents an oscillation with the maximum and minimum at about 5h. and 17h. respectively. It indicates that as the air is warmed in the daytime it expands and overflows from the Nile valley over the surrounding high ground and over the neighbouring seas.

The second term represents an oscillation with maxima at 10h. 20m. and 22h. 20m. These hours are almost the same all over the globe. The amplitude depends on the latitude and to a certain extent on the time of year. The mean value for the year at Cairo is 0·8 mb. It is about 1·3 mb. at the equator, 0·5 in latitude 45°, 0·35 in London and 0·1 mb. in latitude 60°.

The third term is interesting as it changes its phase by 180° at the equinoxes. The first maximum occurs at 2h. in summer, the first minimum at the same hour in winter.

It has been mentioned that the all-day term depends largely on local conditions. An interesting contrast is offered by the British observatories. At Richmond, Surrey, the amplitude of this term in July is about 0·3mb., and it has about the same value at Cahirciveen, but the phases are opposite : at Richmond the maximum occurs at 5h., whereas at Cahirciveen it is the minimum which occurs in the morning (at 7h.).

Harmonic analysis may be extended to the investigation of changes which are caused by forces having different periods. The classical instance is that of the tides. The tides being caused by the attraction of the sun and the moon show as periods the solar and also the lunar day. The process by which the heights and the times of tides are foretold in practice depends on harmonic analysis and synthesis.

Haze.—See FOG.

Heat.—The name used for the immediate cause of the sensation of warmth, a primary sensation which is easily recognised and needs no explanation. As used in relation to the weather, heat and cold are familiar words for opposite extremes of temperature of the air. What the American writers call a heat wave is a spell of hot weather in which the maximum temperatures reach 90° or 100° F. (above 305°A.), and a cold wave is a spell of the opposite character during which temperatures in the neighbourhood of the Fahrenheit zero, or 32 degrees of frost, may be experienced. In continental climates, during the passage of severe cyclonic depressions, the transitions from heat to cold are sometimes extremely abrupt and far-reaching ; a difference of temperature of 50° F. in a few hours is not unknown. We have visitations of similar character in this country, but they are less intense. A few days in succession with a temperature over 80° F. would suffice for a heat wave, and a few days with 10° of frost would certainly be called a cold wave. One of the most noticeable features of our climate is the succession of cold spells which interrupt the genial weather of late spring and early summer. They are not very intense, but a drop in the mean temperature of the day from 55° F. to 45° F., which roughly defines them, produces a very distinct impression.

As used in connexion with the study of the atmosphere heat has another sense which must not be overlooked. It denotes the physical quantity, the reception of which makes things warmer, and its departure makes them colder. If you wish to make water hot, you supply heat to it from a fire or a gas-burner or, in modern days, by an electric heater, a very convenient contrivance for getting heat exactly where you want it. On the other hand, if you want water to become cooler, you leave it where its heat can escape, by CONDUCTION, aided by CONVECTION or by RADIATION. You can also warm water by adding some hot water to it, or cool it by adding cold water to it. Either process suggests the idea of having the same quantity of heat to deal with altogether, but distributing it, or diluting it, by mixing.

The idea of having a definite quantity of heat to deal with, and passing it from one body to another is so easily appreciated and so generally applicable, that the older philosophers used to talk confidently of heat as a substance which they called Caloric, and which might be transferred from one body to another without losing its identity. They measured heat, as we do still, by noting by how much it would raise the temperature of a measured quantity of water. For students of physics the unit of heat is still a *gram-calorie*, the heat which will raise a gram of water through one degree centigrade. To raise m grams from t_1°C to t_2°C, m $(t_2$-$t_1)$ gram-calories are required. The amount can be recovered, if none has been lost meanwhile, by cooling the water. If we wish to be very precise, a small correction is required on account of the variation in what is called the capacity for heat of water at different temperatures, but that need not detain us.

For students of engineering the unit, called the British Thermal Unit, is a pound-Fahrenheit unit instead of the gram-centigrade unit, and the heat required to raise m pounds of water from t_1°F to t_2°F is m $(t_2$-$t_1)$ B.Th.U.

It is in many ways a misfortune that students of physics and engineering do not use the same unit. It is no doubt a good mental exercise to learn to use either indiscriminately without confusion, but it takes time.

From measurements of heat we get the idea that with different substances the same change of temperature requires different quantities of heat; the substances have different capacities for heat. We define *capacity for heat* as the heat required to raise a unit of the substance (1 gram or 1 lb.) through 1 degree.

It is a remarkable fact that of all common substances water has the greatest capacity for heat. It takes one unit to raise the temperature of a unit mass of water one degree, it takes less than a unit, sometimes only a small fraction of a unit, to raise the temperature of the same amount of another substance through one degree. We give the name *specific heat* to the ratio of the capacity for heat of any substance to the capacity for heat of water. Numerically, specific heat is the same as the capacity for heat in thermal units.

The specific heat of water is 1, the specific heat of any other common substance is less than 1. The specific heat of copper is only 1/11. So the heat which will raise the temperature of a pound of copper 1° will only raise the temperature of a pound of water 1/11°, or the heat which will raise the temperature of a mass of water 1° will raise the temperature of the same mass of copper 11°.

This peculiar property of water makes it very useful for storing heat and carrying it about. From that point of view it is the best of all substances for cooling the condenser of an engine, for distributing heat at a moderate temperature in a circulating system, and for many other economic purposes.

In meteorology its influence is very wide. Large masses of water, of which the ocean is a magnificent example, are huge store houses which take up immense quantities of heat from the air when it is warm and give it out again when the air is cold, with very little change in its own temperature, so that a large lake, and still more the ocean, has a great influence in reducing the extremes of temperature of summer and winter, and of day and night, in the countries which border it.

There is another remarkable storage of heat in which water takes a predominant share that is dealt with in physical science under the name of *latent heat*.

Water at 288°A. (59° F.) cannot be evaporated into water vapour unless every gram of it is supplied with 589 calories of heat, which produce no effect at all upon the temperature. The water is at 288°A. to start with, and the water vapour is at exactly the same temperature and yet 589 calories of heat have gone. They are *latent* in the water vapour but produce no effect on the thermometer. You can get them back again easily enough if you condense the vapour back again into water, but you must manage somehow to take away the heat while the condensation is taking place. The separation of the "waters that are above the firmament from the waters that are below the firmament," or in modern language, the evaporation of water from the sea or a lake or the wet earth and its condensation in the form of clouds and rain, implies the transference of enormous quantities of heat from the surface to the upper air, the dynamical effect of which belongs to another chapter of the romantic story of heat which deserves more than the few words which we can afford for it. Readers can find an interesting account in Tyndall's *Heat a Mode of Motion*.

The idea of heat as an indestructible substance, caloric, which could be transferred from one body to another without loss, became untenable when it was found that when air was allowed to expand in a cylinder it cooled spontaneously to an extent that corresponded exactly, so far as could be ascertained, with the means then available, with the amount of mechanical work that the cylinder was allowed to do. It was the last step in the process of reasoning by which men had come to the conclusion that, when *mechanical work* was devoted to churning water or some other frictional process, heat was actually produced, not brought from some other substance but created by the frictional process.

It took many years for men to reconcile themselves to so novel an idea, and a good deal of ingenuity was devoted to trying to evade it, but it has now become the foundation stone of physical science. Heat is not an unalterable indestructible substance but a form of *energy*. It can do mechanical work in a steam-engine or a gas-engine or an oil-engine, but for every foot-pound* of work that is done a corresponding amount of heat must disappear, and in place of it a corresponding amount of some other form of energy is produced. A good deal of heat, besides, may be wasted in the process so far as practical purposes are concerned. In a steam-engine, of the whole amount of heat used, only one tenth may be transformed, the rest wasted, as we have said ; but it is still there raising the temperature of the water of the condenser or performing some other unproductive but necessary duty.

There is, therefore, a numerical equivalent between heat and other forms of energy.

We give the relation :—

1 B.Th.U. is equivalent to 777 foot-pounds of energy.

1 gram-calorie = 42,640 gram-centimetres.

= 41,830,000 ergs.

We have led up to this statement in order to point out how extraordinarily powerful heat can be in producing mechanical energy.

If, in the operations of nature, one single cubic metre of air gets its temperature reduced by 1° C. in such a way that the heat is converted into work by being made to move air, the equivalent of energy would be a cubic metre of air moving with a velocity of nearly 45 m./sec. (101 mi./hr.).

So familiar have we become with heat as a form of energy that we measure the heat of sunlight in joules† and the intensity of sunshine in watts per square centimetre, i.e. the number of joules falling on one square centimetre per second.

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* A *foot-pound* of work is the work done in lifting one pound through a distance of one foot.

A *gram-centimetre* is the work done lifting one gram through one centimetre.

An *erg* is the absolute unit of work on the C.G.S. system ; 1 gram-centimetre = 981 ergs.

† A *joule* is a more convenient unit than the small unit, the erg ; one joule = ten million ergs (10^7 ergs) and one calorie = 4·18 joules.

The *watt* is a unit of power, that is, rate of doing work ; a power of one watt does one joule of work per second.

The specific heat of air.—The foregoing statement is necessary to lead up to a matter of fundamental importance in the physics of the atmosphere, namely the heat that is required or used to alter the temperature of air in the processes of weather; in technical language this is the capacity for heat of air or the specific heat of air.

We have explained that when air is allowed to do work on its environment, in expanding, heat disappears, or more strictly is transformed. So the amount of heat required to warm air through a certain number of degrees depends upon how much expansion is allowed during the process. The most economical way of warming air from the thermal point of view is to prevent its expanding altogether; it then has "constant volume" and its specific heat is 0·1715 calories per gram per degree at 273°A. It is remarkable, but true, that if you have a bottle full of air, it will take more heat to raise the temperature of each gram of it by a degree if you take the stopper out while the warming is going on, than if you keep it tight. The difference between warming a bottle of air with the stopper in and with it out, simple as it may seem, has got in it the whole principle of heat as a form of energy. The effect of leaving the stopper out is that the pressure of the air inside the bottle is the atmospheric pressure for the time being and is therefore practically constant throughout the brief operation. The specific heat of air at constant pressure is 0·2417 gram-calories or 1·010 joules per gram per degree. The specific heat of air at constant volume is 0·72 joules per gram per degree. The difference of the two represents the heat equivalent of the work used in expanding unit mass of the gas against atmospheric pressure.

Helm Wind.—A violent cold easterly wind blowing down the western slope of the Crossfell Range, Cumberland. It may occur at all seasons of the year but mostly when the general direction of the wind is E. or NE. although occasionally when it is N. or SE. When the Helm is blowing, a heavy bank of cloud (the Helm Cloud) rests along the Crossfell Range, and at a distance of three or four miles from the foot of the Fell, a slender, nearly stationary roll of whirling cloud (the Helm Bar) appears in mid-air and parallel with the Helm Cloud. The cold wind blows strongly down the steep fell sides until it comes nearly under the Bar when it suddenly ceases. To the west of this calm at the surface, a westerly wind may be experienced for a short distance. The space between the Helm Cloud and Bar is usually quite clear although the rest of the sky may be cloudy.

High.—Sometimes used to indicate an area of high barometric pressure for which the technical term ANTICYCLONE was coined by Sir Francis Galton. The central region of an anticyclone on a weather chart is frequently indicated by the word "high."

Hoar-Frost.—A deposit of ice formed upon grass and other objects in the same way as DEW by the cooling of exposed objects through the radiation of their heat to the clear sky.

Horizon.—The "sensible or visible horizon" which is visible from a ship at sea, the line where sea and sky apparently join, is a circle surrounding the observer a little below the plane of the horizon in consequence of the level of the earth's surface being curved and not flat. The depth of the "sensible horizon" below the "rational horizon" or horizontal plane is approximately the same as the elevation of the point from which the "sensible horizon" is viewed. Apart from any influence of the atmosphere the distance of the visible horizon for an elevation of 100 feet (30 metres) is about 12 miles. The actual distance is about 2 miles greater on account of refraction. It varies as the square root of the height, so that it would require a height of 400 feet to give a horizon 24 miles off. A level canopy of clouds 10,000 feet high is visible from a point on the earth's surface for a distance of about 125 miles, or the visible canopy has a width of 250 miles.

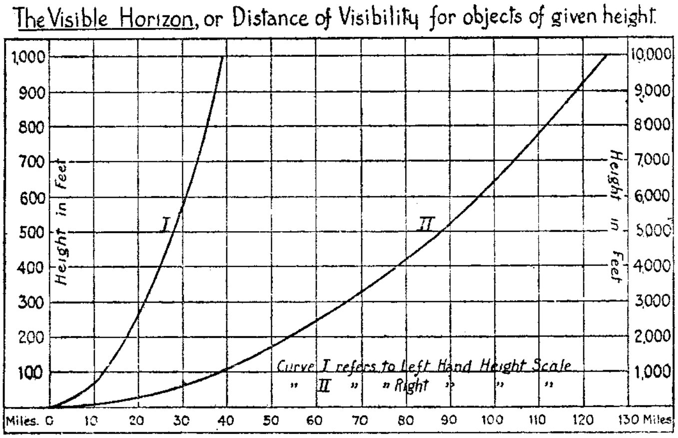

FIG. 20.—Diagram showing the relation between the height of an observation point in feet and the distance of the visible horizon in miles (*neglecting refraction*), or the height in feet of a cloud or other distant object and the distance in miles at which it is visible on the horizon.

Horizontal.—In the plane of the horizon. In dynamics and physics a horizontal line is one at right angles to the direction of the force of gravity, which is vertical and is identified by the plumb line.

Horse Latitudes.—The belts of calms, light winds and fine, clear weather between the TRADE-WIND belts and the prevailing westerly winds of higher latitudes. The belts move north and south after the sun in a similar way to the DOLDRUMS. The name arose from the old practice of throwing overboard horses which were being transported to America or the West Indies when the ship's passage was unduly prolonged.

Humidity.—When used without any qualifying adjective this term usually refers to the RELATIVE HUMIDITY.

Hurricane.—" A name (of Spanish or Portuguese origin) given primarily to the violent wind storms of the West Indies which are CYCLONES of diameter of from 50 to 1,000 miles, wherein the air moves with a velocity of from 80 to 130 miles an hour round a central calm space which, with the whole system, advances in a straight or curved track ; hence any storm or tempest in which the wind blows with terrific violence." (New English Dictionary). Shakespeare uses the word "hurricano" for a water-spout.

The force of the wind which is experienced in cyclones is equalled, if not surpassed, in the TORNADOES which occur in the south-eastern parts of the United States, but the area affected by a tornado is generally a narrow strip a few miles at most in width.

In the BEAUFORT SCALE OF WIND FORCE the name hurricane is given to a wind of force 12, and its velocity equivalent is put at a mean velocity exceeding 34 mi./sec. or 75 mi./hr., but from the remarks under GUSTINESS it will be understood that at ordinary exposures a wind with a mean velocity of 75 mi./hr. will include gusts of considerably higher velocity, reaching 100 mi./hr. or more. Hurricane winds in this sense are occasionally experienced in this country.

Hydrometer.—An instrument for measuring the density of liquids. In marine meteorology hydrometers are used for determining the density of sea water.

Hydrometeor.—A generic term for weather phenomena such as rain, cloud, fog, etc., which mostly depend upon modifications in the condition of the aqueous vapour in the atmosphere.

Hydrosphere.—The name given to the layer of water of irregular shape and depth lying on the earth's surface, between the geosphere, or the solid earth below, and the ATMOSPHERE, the gaseous envelope above.

Hyetograph.—A pattern of self-recording RAINGAUGE in which the recording pen is actuated by a series of stops attached to a vertical float rod.

Hygrodeik.—A dry and wet bulb PSYCHROMETER mounted on a frame, graduated and furnished with an index for determining quickly the relative humidity, dew-point, etc., by a graphical method.

Hygrograph.—An instrument for recording continuously the humidity of the atmosphere. (See HYGROMETER.)

Hygrometer.—An instrument for determining the humidity of the air. The dew-point hygrometer developed by Daniell, Regnault and others aims at determining the dew-point by artificially cooling, until dew is deposited, a polished surface, whose temperature can be measured. Since dew-point hygrometers depend only on the measurements of a temperature and involve no assumption as to the properties of the materials or the laws of evaporation from a wet surface, they may be classed as "absolute" instruments. To the same class belong chemical hygrometers in which the quantity of moisture in a given mass of air is determined by direct weighing. Unfortunately, neither dew-point nor chemical hygrometers are suitable for routine use in meteorology and it is, therefore, necessary to use methods depending on (*a*) the change of length of hairs with varying relative humidity, or (*b*) the lowering of temperature due to evaporation.

In the hair hygrometer, of which Lambrecht's polymeter and Richard's hair hygrograph are applications, use is made of the fact that human hair expands with increasing relative humidity. Hair hygrometers are incapable of high precision, but they possess the advantage that they operate equally well above or below the freezing point. Wet and dry bulb hygrometers (or "psychrometers") are ordinarily used for routine observations. They depend on the accurate determination of the depression of the wet bulb reading below the dry bulb and give sufficient precision for ordinary needs. Their accuracy is considerably increased if arrangements are made, as in the Assmann PSYCHROMETER, for "aspirating" the air at a known speed.

Hygroscope.—An instrument for showing whether the air is dry or damp, usually by the change in appearance or dimensions of some substance. Hygroscopes are frequently sold in the form of weather predictors, e.g. "weather houses" in which the appearance of the "old man" or the "old woman" is determined by the twisting and untwisting of a piece of catgut in response to changes of humidity.

Hypsometer.—Literally, an instrument for measuring height (Gr. *Hupsos*). The term is, however, applied exclusively to an instrument in which water is boiled under conditions which make it permissible to assume that the temperature within the vessel is, accurately, the boiling point of water. The boiling point of water depends on the atmospheric pressure in accordance with the following table :—

Boiling point	Pressure	
	Millimetres of mercury at 0° C., sea level, latitude 45°	Millibars
°A.	mm.	mb.
374	787·67	1050·12
373	760·00	1013·23
372	733·16	977·45
371	707·13	942·74
370	681·88	909·08
369	657·40	876·44
368	633·66	844·79
367	610·64	814·10
366	588·33	784·36
365	566·71	755·54
364	545·77	727·62

Consequently, a measurement taken by means of a thermometer placed in the hypsometer serves to determine the pressure. If the measurement is made on a mountain and the pressure has been determined at some lower level, the height of the station can be calculated. Everything depends upon the accuracy of the thermometers. To obtain the height to within ten feet it must be possible to measure temperature to within one-hundredth of a degree. This requires very accurate thermometers combined with skilful manipulation. Nevertheless, the compactness of a hypsometer gives the instrument an advantage over the fragile and cumbersome mercurial barometer in journeys of exploration.

If the atmospheric pressure is known from the reading of a good barometer, a hypsometer may be used to determine the error, at the boiling point, of a thermometer, provided, of course, that the boiling point lies within the range of the thermometer.

Ice.—Owing to the large amount of heat absorbed in melting (80 CALORIES for one gramme melted) a mass of ice represents a powerful reservoir of cold. Masses of ice or snow can attain to such dimensions in nature that the heat absorbed during melting is of climatological importance. An excellent example is furnished by the icebergs observed by Antarctic explorers. The largest of these appear to be portions of the great Ice Barrier that have broken away during the summer months. They are generally several hundred feet thick and may exceed 20 miles in length The amount of heat required to melt one 20 miles long, 5 miles broad and 600 feet thick would be sufficient to raise the temperature of the air over the whole British Isles from the ground up to a height of 1 kilometre (3,281 feet) by over 40° C.

When ice forms upon a pond during frosty weather the cooled water at the surface is continually replaced by warmer water from below until the whole mass has fallen to 277°A. (39° F.), which is the temperature at which water has its greatest density. The surface can then cool undisturbed until the freezing point is reached and ice begins to form. The formation of ice in rivers is a more complicated question ; in cold countries three kinds of ice are produced (1) sheet ice which forms on the surface of the water first of all near the banks extending gradually towards the centre (2) FRAZIL ICE and (3) ground ice, both of which form in the rapidly-moving stream in the centre of the river in very cold weather. Ground ice (or anchor ice) forms at the bottom adhering to rocks and other substances in the river bed. It often rises to the surface dragging with it masses of rock ; it can be very destructive to river structures.

When the sea freezes the crystals formed contain no salt but cannot easily be separated from the brine which is mixed up with them, consequently the water obtained by melting genuine sea ice is salt. When, however, this ice forms hummocks under the action of pressure the brine drains out and leaves pure ice. Newly-formed sea ice has a surprising degree of flexibility due to the fact that the crystals are separated by layers of brine or salt, and even when it is several inches thick the surface can be moved up and down unbroken by a swell. As the thickness increases this can no longer happen, and the sheet is broken up into pieces, which grind together and soon form the beautiful "pancake ice" familiar to polar explorers.

Some beautiful illustrations of ice forms have been given by Wright and Priestley in their book on the British Antarctic Expedition.*

The properties of ice depend very largely on its mode of formation. Wright and Priestley* quote a number of values of the DENSITY ; the density of icicles at 0° C. was found by Nichols to be ·918, while two samples of pond ice gave ·91644 and ·918 (Nichols). Values of the density of ice made from boiled water range from ·916 to ·9177. ICEBERGS, owing to the amount of included air, may have a much lower density. The COEFFICIENT of linear expansion of ice at −10° to 0° C. lies between ·000050 and ·000054 ; its specific heat at 0° C. is about ·5.

* C. S. Wright and R. E. Priestley: "British (Terra Nova) Antarctic Expedition, 1910–13. Glaciology." London, 1922.

The great ice masses of the Arctic Ocean and the Greenland Seas exercise an appreciable influence on the weather of north-west Europe.* The most important effect for the British Isles is the tendency for much ice in spring and early summer to be followed by stormy weather in late autumn and winter.

Ice Age.—A geological period in which great glaciers and ice sheets cover large parts of the continents, reaching the sea in places and lowering the temperature of the oceans. The latest began early in the Quaternary Period, when the ice covered much of Europe and North America; the present ice sheets of Greenland and the Antarctic are relics of this Ice Age. Other great Ice Ages occurred in the Permo-Carboniferous, when the ice sheets developed principally within the present tropics, in South America, Africa, India and Australia; and in the earliest known geological period, the Archaean.

Iceberg.—A mass of land ice broken from a glacier or a barrier and floating in the sea. The glacier bergs are greenish in colour, irregular in shape and may be broken by crevasses. The bergs which are broken off from an ice barrier are white, rectangular in shape and often very large; they are usually described as "tabular" and are characteristic of the Antarctic. Another type of berg which is not a true iceberg is composed, at least above sea level, of névé or compacted snow, these bergs have much the appearance of tabular bergs, but float with a greater proportion above the sea surface than true icebergs.

With favourable winds and currents icebergs drift into latitudes of 40–50°. According to H. T. Barnes the break-up occurs in the following way: the surface of the berg is running with water all day, at night the melting stops and surface freezing takes place; at sunrise again, before surface melting starts, the heat of the returning day causes unequal expansion which results in considerable cracking. Barnes's experiments show that iceberg ice is as pure as distilled water, containing only 4 parts of solid per million. Icebergs also contain a considerable quantity of air, in one specimen examined Barnes found 15·1 per cent and in another 7·4 per cent.

Iceblink.—The whitish glare in the sky over ice which is too far away to be visible.

Ice Saints.—St. Mamertius on May 11, St. Pancras on May 12 and St. Gervais on May 13 are known on the Continent as the "cold Saints' Days." It is said in France that these three days do not pass without a frost. From observations at selected stations in Scotland from 1857–66 Buchan found a cold period from May 9–14. For further information see *Meteorological Magazine*, **57**, 1922, p. 177 and **63**, 1928, p. 93.

Ice sheet.—A large area of land ice, with a dome-shaped, almost level surface, which almost completely covers the land on which it rests, so that precipitation of snow takes place directly on the surface of the ice. The best known and largest ice sheets at present existing are those of the Antarctic and Greenland.

Increment.—The small amount by which a variable is increased, or the increase in a function as the independent variable is increased.

Index.—The pointer or other feature in an instrument whose position with regard to the scale determines the reading. The term is also sometimes applied to the fixed mark which constitutes the zero, e.g. in the term "index-error." (See ERROR.)

Index correction.—The quantity which (with proper sign) has to be added to an instrumental reading to correct for index error (see ERROR). It is of the same magnitude as the index error, but of the opposite sign.

* C. E. P. Brooks and Winifred A. Quennell: *London, Meteorological Office, Geophysical Memoirs*, No. 41.

Index error. (See ERROR.)

Indian Summer.—A warm, calm spell of weather occurring in autumn, especially in October and November. The earliest record of the use of the term is at the end of the eighteenth century, in America, and it was introduced into this country at the beginning of the nineteenth century. There is no statistical evidence to show that such a warm spell does tend to recur each year.

Insolation.—A term applied to the solar radiation received by terrestrial or planetary objects (Willis Moore).

The amount of solar radiation which reaches any particular part of the earth's surface in any one day depends upon (1) the SOLAR CONSTANT, (2) the area of the intercepting surface and its inclination to the sun's rays, (3) the transparency of the atmosphere, (4) the position of the earth in its orbit. The following table compiled from Angot* assumes the atmosphere to be perfectly transparent.

Calculated Insolation reaching the Earth.

Latitude	January	February	March	April	May	June	July	August	September	October	November	December	Year
N.													
90°	0·0	0·0	1·9	17·5	31·5	36·4	32·9	21·1	4·6	0·0	0·0	0·0	145·4
80°	0·0	0·1	5·0	17·5	30·5	35·8	32·4	20·9	7·4	0·6	0·0	0·0	150·2
60°	3·0	7·4	14·8	23·2	30·2	33·2	31·1	24·9	16·7	9·0	3·8	1·9	199·2
40°	12·5	17·0	23·1	28·6	32·4	33·8	32·8	29·4	24·3	18·4	13·4	11·1	276·8
20°	22·0	25·1	28·6	30·9	31·8	32·0	31·8	30·9	28·9	25·8	22·5	20·9	331·2
Equator ..	29·4	30·4	30·6	29·6	28·0	27·1	27·6	28·6	30·1	30·2	29·5	28·9	350·3
S.													
20°	33·8	32·2	29·0	24·9	21·2	19·6	20·5	23·7	27·7	31·1	33·3	34·1	331·2
40°	34·8	30·4	23·9	17·4	12·5	10·4	11·6	15·8	21·9	28·5	33·6	36·0	276·8
60°	33·0	25·3	16·0	8·1	3·3	1·7	2·7	6·5	13·6	22·6	31·1	35·3	199·2
80°	34·2	20·5	6·3	0·3	0·0	0·0	0·0	0·0	3·8	16·0	31·0	38·1	150·2
90°	34·7	20·7	3·2	0·0	0·0	0·0	0·0	0·0	1·0	15·6	31·5	38·7	145·4

* "La distribution de la chaleur à la surface du globe." *Ann. bur. cent. météor., Paris*, 1883.

The unit is the amount of energy that would be received on unit area at the equator in one day, at the equinox, with the sun at mean distance, if the atmosphere were completely transparent. It is 458·4 times the solar constant, or in gramme calories per minute per square centimetre 885, taking the solar constant to be 1·93.

Instability.—Any system can remain in equilibrium when the forces acting upon it balance each other. If further, when the system is disturbed from its equilibrium position and then left to itself, it returns to its original state, it is said to be in stable equilibrium. If when disturbed and left to itself it stays in the disturbed position it is said to be in indifferent equilibrium. If when disturbed and left to itself, it goes still further from its original state, it is said to be in unstable equilibrium. Stability and instability thus have to be defined in terms of the effects of small disturbances. A pencil standing on end is stable, since it is not upset by small disturbances, though it falls down when disturbed through a not very large finite angle.

In meteorology we are mainly concerned with the vertical stability of air masses, and the customary treatment of the question lays down the condition of stability as the possession of a LAPSE rate not exceeding the ADIABATIC. The phenomena of CONVECTION are associated with the growth of the lapse rate to a value exceeding the adiabatic, but in practice it is not unusual to find lapse rates exceeding 10 or even 20 times the adiabatic. It thus appears that the phenomena are likely to be more complicated than the assumptions usually made in discussing this topic.

The discussion above refers to statical equilibrium. When a system in motion is slightly disturbed, if the result is to produce small oscillations superimposed on the original motion, the system is dynamically stable. If the result is to cause an increasing departure from the original motion, the system is said to be dynamically unstable.

Instability Showers.—SHOWERS due to vertical instability. Such instability is caused by a warming of the lower layers of air or by a cooling of the upper layers or by a combination of the two causes. Nearly all heavy showers are of this type, but the term is most frequently used for showers in POLAR CURRENTS passing over warmer sea or land. Over the sea they may develop at any season, but more especially in autumn and winter, while after the current has crossed a considerable land area they are most frequent on spring and summer days, and are rare in mid-winter. (See also CONVECTIONAL RAIN.)

Interpolation.—When a varying quantity has been observed at certain intervals of time, or of some other independent variable, the evaluation of values appropriate to intermediate stages of the independent variable is called interpolation. When a curve can be drawn to represent the observations with reasonable accuracy, the values for intermediate values of the independent variable can be read off from the curve. Numerous formulae have also been developed for the same purpose. These might be used for example in deducing the intermediate values of a function from values tabulated for definite intervals. On account of its utility in such cases, interpolation has been described as " reading between the lines of a mathematical table."

Inversion.—An abbreviation for " inversion of temperature-gradient " (see GRADIENT). The temperature of the air generally gets lower with increasing height but occasionally the reverse is the case, and when the temperature increases with height there is said to be an " inversion."

There is an inversion at the top of a fog layer, and generally at the top of other clouds of the stratus type. Inversions are shown in the diagram of variation of temperature with height in the upper air, Fig. 24, by the slope of the lines upwards towards the right instead of towards the left, which is the usual slope. In the TROPOSPHERE inversions do not generally extend over any great range of height; the fall of temperature recovers its march until the lower boundary of the STRATOSPHERE is reached. At that layer there is generally a slight inversion beyond which the region is isothermal, so far as height is concerned. For that reason the lower boundary of the stratosphere is often called the " upper inversion ". In some soundings with ballons-sondes from Batavia the inversion has been found to extend upwards for several kilometres from the commencement of the stratosphere.

Near the ground, say the lowest hundred metres, an inversion occurs on every clear night. During anticyclonic weather in winter this surface inversion may grow until it extends to a considerable height and it may then persist for several days. The dense fogs which characterise some cities in winter usually originate from such an inversion. Alternatively, the accumulation of smoke overhead may produce almost complete darkness at midday in a city if the inversion is sufficient to prevent the smoke from dispersing. Fogs on land nearly always imply the existence of an inversion.

An inversion invariably means thermal stability of the atmosphere and the absence of turbulence.

The term " counter-lapse " has been suggested as an alternative to inversion.

Ions.—The name selected by Faraday for the component parts into which a chemical molcule is resolved in a solution. Of the two components one carries a positive charge the other an equal negative charge. The laws of electrolysis indicate that these charges are of the same magnitude for ions of all substances. Electric force causes the free ions charged with positive electricity to move in one direction whilst those charged with negative electricity move in the opposite direction. These movements constitute the electric current through the solution.

Similarly a gas may conduct electricity by virtue of the presence of free ions. The ions may be produced by combustion or by the action of radio-active substances (like radium) or by ultra-violet light. The conduction of electricity through the atmosphere is now attributed to the free ions which exist in it. (See ATMOSPHERIC ELECTRICITY.)

It is supposed that all matter is built up of units which have positive or negative charges. The positively charged units are called protons, the negatively charged ones electrons. In neutral matter the positive and negative charges just balance, according to this hypothesis. A negative ion is matter to which an extra electron is attached, a positive ion is matter which has lost an electron. The ionic charge is identical with the charge of an electron. Its value as determined by Millikan is $15 \cdot 9 \times 10^{-20}$ coulomb.

Iridescence or Irisation.—Words formed from the name of Iris, the rainbow goddess, to indicate rainbow-like colours. In its more technical usage iridescence refers to tinted patches generally of a delicate red or green, sometimes blue and yellow, occasionally seen on high clouds. A brilliant iridescent cloud of considerable area is " one of the most beautiful of sky phenomena." The boundaries of the tints are not circles with the sun as centre but tend to follow the outlines of the cloud. The iridescence is probably due to diffraction by small waterdrops and the colours seen are determined partly by distance from the sun, partly by the size of the drops, whereas in the production of the corona the variations between the drops are of little importance and the same tint is to be seen at the same distance from the sun in any direction. The drops responsible for iridescence are very small and probably super-cooled well below the freezing point. Just as a HALO is evidence for the presence of ice crystals so iridescence is evidence for the presence of super-cooled waterdrops.

Isallobars.—Isallobars are lines drawn upon a chart through places at which equal changes of pressure have occurred in some period of time. They are formed by plotting the changes in barometric pressure which have taken place between two sets of observations. Lines of equal change, or isallobars, are drawn to enclose regions of rising and of falling pressure. At the Meteorological Office, the isallobaric chart is drawn each day from the observations taken at 7 a.m. G.M.T. and the isallobars represent the differences in pressure in half millibars between the readings of the barometer at 4 a.m. and 7 a.m. The barometer is not actually read at 4 a.m. but the rise or fall of pressure can be obtained with sufficient accuracy from a barograph trace.

Generally the areas of rise or fall in an isallobaric chart are regular in form. Dr. Nils Ekholm,* by whom this method of plotting the pressure differences was introduced, claimed that when successive charts of isallobars were drawn the movements of the various groups of isallobars were on the whole more regular than those of the isobaric groups. E. G. Bilham,† however, points out, when the pressure distribution is accurately known at the beginning and end of a time interval, that

> " in the case of small depressions uncomplicated by other systems the isallobars are merely a sort of composite picture of the two sets of isobars and no additional information is imparted by them. . . . When the distribution is complex, however, the isallobaric chart is of value since it performs the function of separating the active from the quiescent features of the pressure distribution."

* " Wetterkarten der Luftdruckschwankungen." *Met. Zs.*, 1904, pp. 345–57.

† " Isallobars of moving circular depressions." *Geogr. Ann.*, 1921, H.4, p. 356.

Isanomaly.—This word is a combination of the prefix ISO and the word ANOMALY, and is used of lines joining all points on a map or chart having equal anomalies, or differences from normal, of a particular meteorological element.

Isentropic.—Without change of ENTROPY, generally equivalent in meaning to ADIABATIC.

Iso.—A prefix meaning equal, extensively used in meteorological work, in conjunction with another word, to denote lines drawn on a map or chart to display the geographical distribution of any element, each line being drawn through the points at which the element has the same value. The words having this prefix are generally self-evident in meaning and can be interpreted without any difficulty.

In 1889 the tentative use of the word *isogram* was suggested by Sir Francis Galton as a generic term for all lines of this type. The name *isopleth* is literally applicable for this purpose and is so used by many writers. The use of isogram, however, seems advisable, in order to avoid confusion, as isopleth is often used with a more specific meaning, viz., a line showing the variation of an element with regard to two co-ordinates, such as the time of year (month) and the time of day (hour).

Some of the more important examples of the use of iso are set out below.

Isobars :—Lines on a chart joining places of equal barometric pressure.
Isotherms :—Lines showing equal temperatures.
Isohyets :—Lines showing equal amounts of rainfall.
Isohels :—Lines showing equal duration of sunshine.
Isonephs :—Lines showing equal amounts of cloudiness.

Isobars.—The distribution of atmospheric pressure is indicated on a weather map by means of isobars—these being lines of equal pressure or lines along which the pressure is constant.

The atmospheric pressure at any given place is readily obtained by means of a mercury barometer, but in order that the barometric readings from different places may be comparable one with another it is necessary that they be reduced to a common standard. Corrections are therefore applied to reduce the readings to mean sea level (see REDUCTION TO SEA LEVEL). On the charts used at the Meteorological Office in connexion with weather forecasting, it is customary to plot the barometric readings to the nearest tenth of a millibar and to draw the isobars for every two millibars, the isobars being those of even number, i.e. 1,000 mb., 1,002 mb., 1,004 mb., etc. It seldom happens that an exact even millibar reading occurs at any station at one of the fixed observation times and in consequence it is necessary to find the position of the even millibar readings by means of interpolation. When there is a close network of stations and the pressure variations from place to place are not too great, this is quite a simple matter, if it be assumed that the barometer falls uniformly between two stations. By repeating this process a series of positions for any given value is obtained and by drawing a curve connecting these points the isobar for this value is formed. Isobars even in complicated pressure systems can be drawn readily after some practice.

It will be seen that when travelling along an isobar pressure remains continually higher on one side of the isobar than on the other, and that an isobar must come back again to the place from whence it starts if a large enough area be considered. This may be simply stated by saying that an isobar must form a closed curve.

After the pressure readings have been plotted on a map and the isobars drawn, it will be seen that the isobars are analogous to contour lines, the areas of high pressure corresponding with the hills and those of low pressure with the valleys.

Examples of different systems of isobars will be found in the illustrations which accompany the articles on ANTICYCLONE, COL, DEPRESSION, SECONDARY, V-SHAPED DEPRESSION and WEDGE.

Isobars over the world for the months of January and July are shown on pp. 16 and 17.

Isomeric Values.—The values obtained when the average monthly rainfall amounts for any station are expressed as percentages of the annual average. When the percentage values for a number of stations for any month are plotted on an outline map an isomeric chart is obtained for the month, and the lines drawn on such a chart to represent the distribution of the values are termed "isomers" or lines of equal proportion. Isomeric charts of the British Isles showing the proportion of the annual average rainfall falling in each month of the year were published in *Q. J. R. Meteor. Soc.* **41**, 1915, pp. 1–44 and *British Rainfall*, 1914, pp. 25–44.

Isopycnic.—Relating to field of mass. Term for surfaces of equal density. See BAROCLINIC. Isopycnic charts of the globe for different heights in the atmosphere are given in *Q. J. R. Meteor. Soc.*, **50**, 1924, pp. 37–41.

Isosteric.—Relating to field of mass. Term for surfaces of equal specific volume. (See BAROCLINIC.)

Isotherm.—A line joining places along which the temperature of the air or of the sea is the same. When the places are at different altitudes a correction may be necessary on account of the general upward decrease of temperature (see REDUCTION TO SEA LEVEL). The first isotherms were constructed by A. von Humboldt in 1817. Isotherms of mean daily maximum and mean daily minimum temperature are given in "The Book of Normals of Meteorological Elements for the British Isles," Section III. Isotherms for the globe for each month and the year are contained in the "Manual of Meteorology," Vol. 2, by Sir Napier Shaw (Cambridge University Press, 1928).

Isothermal—of equal TEMPERATURE. An isothermal line is a line of equal temperature, and, therefore, is the same as isotherm.

Isothermal is frequently used in meteorological writings on the upper air for the so-called "isothermal layer" by which is meant the layer indicated in the records of all sounding balloons, of sufficient altitude, by the sudden cessation of fall of temperature with height and generally by a slight INVERSION (see also GRADIENT) followed by practical uniformity of temperature.

The layer is not really isothermal, since it has a horizontal temperature gradient. The word STRATOSPHERE was therefore coined by M. Teisserenc de Bort, who was instrumental in discovering this region, while he gave the name of TROPOSPHERE to the region below. These names have now been generally adopted.

Joule.—The unit of energy associated with the practical system of ELECTRICAL UNITS.

1 joule = 1 watt-second = the energy converted to heat when a current of one ampere flows through a resistance of one ohm for one second.

The joule is approximately the energy required to lift one kilogramme through 10 centimetres; it is equal to 10^7 ergs.

The 20° calorie, the heat required to raise the temperature of one gramme of water by 1° C. from $19\frac{1}{2}$° C. to $20\frac{1}{2}$° C. is equivalent to 4·18 joules.

Katabatic.—Referring to the downward motion of air due to convection. A local cold wind is called katabatic if it is caused by the gravitation of cold air off high ground; such a wind may have no relation to the distribution of atmospheric pressure. The best known example of a katabatic wind is the BORA.

Kew Pattern Barometer.—A portable marine BAROMETER designed by P. Adie in 1854 for the Kew Committee of the British Association. The scale is graduated to take account of changes in the level in the steel cistern so that it is only necessary to read the top of the mercury column. The tube is constricted to minimise PUMPING when the barometer is used at sea. Similar barometers, known as " station " barometers, but without the constriction, were subsequently adopted for use on land, and are regularly employed at most British and Colonial meteorological stations.

Khamsin.—A S. wind blowing over Egypt in front of depressions passing eastward along the Mediterranean, while the pressure is high to the east of the Nile in Middle Egypt. As this wind blows from the interior of the continent it is hot and dry.

Kilo.—A prefix meaning 1,000, arbitrarily representing Greek " khilioi," e.g., kilometre, one thousand metres.

Kilowatt-hour.—The unit by which electrical energy is sold. This unit has sometimes been referred to as a Board of Trade Unit but that name is not to be recommended as confusion may arise with the " British Thermal Unit " the heat required to raise the temperature of a pound of water by 1° F.

1 kilowatt-hour $= 3 \cdot 6 \times 10^{13}$ ergs.
$= 8 \cdot 6 \times 10^{5}$ calories.

Kite.—An appliance which ascends into the air in virtue of the pressure of a relative wind upon an inclined surface. The kite is held captive by means of a cord or wire. It consists of a framework of wood or light metal, covered with fabric, or other suitable material. The general form used for scientific work, is the box kite, invented by Hargrave ; this form consists of a light wooden framework, usually rectangular in cross section, covered with fabric at either end for about one quarter of the length, the middle portion being left free, thus forming rectangular cells. Kites are frequently flown in tandem, and heights of over 20,000 ft. have been reached. A box kite of lozenge shape, was used by W. H. Dines, a special form of meteorograph being designed for the purpose.

There are many forms of kites, from the Malay kite, with the attached tail, to the large man-lifting kites used by Cody and others. Kites were known to the Chinese at a very early date, and were flown upon festive occasions.

High-altitude kite-flying necessitates the use of a thin steel wire.

Kite Balloon.—A captive balloon, elongated in form, and fitted with fins or air ballonets at the rear end. The kite balloon is so rigged, that when moored, it flies with the forward end tilted to the wind, thus, the the underneath of the gas bag acts as a plane surface, tending to lift the balloon in the manner of a kite.

The fins or ballonets are connected with an opening facing the wind, by which they are kept inflated.

The observer's basket is suspended from the gas bag by means of cords. Small kite balloons have been designed for carrying meteorographs. Unless special precautions are taken, the steel cable constitutes a danger to aircraft, as in the case of the kite.

See BALLOON, KITE.

Kuro-Shiwo.—Variously translated " blue salt " stream or " black " stream, a warm water current of a characteristic dark blue colour which flows north-eastward off the eastern coasts of Japan. This current is analogous to the Gulf Stream of the Atlantic, carrying warmth to higher latitudes, and between it and the Japanese coasts flows a cold current from the Bering Sea, analogous to the Labrador current. Part of the current sets north-eastwards towards the Aleutian Isles, and part gradually merges in the general eastward drift of the North Pacific. The strength of the current varies with the wind, increasing in the (summer) season of the south-west monsoon and decreasing in the (winter) season of the north-east monsoon.

Labile.—In unstable equilibrium. In meteorology the term labile is applied to a portion of the atmosphere which has a LAPSE-rate exceeding the ADIABATIC.

Lag.—The delay between a change in the conditions and its indication by an instrument. It is the aim of instrument makers to reduce this interval as much as possible, but a limit is often set by practical considerations such as the need for robust construction. In marine barometers lag is introduced deliberately to minimise "pumping." In Symons's earth thermometers lag is introduced by immersing the bulb in paraffin wax, a poor conductor of heat, so that the reading does not change perceptibly when the thermometer is drawn up for reading into surroundings at a different temperature.

Land and Sea Breezes.—These occur on the coast in fine summer weather. During the day the land is warmed by the sun's radiation more quickly than the sea, the warm air over the land rises and flows out above thus increasing the pressure over the sea; this increase of pressure over the sea causes a flow of air landwards which constitutes the sea breeze. During the night the conditions are reversed, the land cools more quickly than the sea, pressure is higher over the land and a flow of air takes place towards the sea, constituting the land breeze.

The direction of the sea breeze is nearly perpendicular to the coast during the early afternoon, but it tends to veer with the sun and towards sunset may be blowing obliquely inland. The sea breeze may also combine with a general wind to give a wind inclined to the coast. The direction of the land breeze depends mainly on the configuration of the ground. The velocity of these breezes is small and they seldom penetrate beyond about 10–15 miles on either side of the coast line. They are quite shallow and seldom reach beyond a height of 1,000 feet. The regularity and the velocity of the sea breeze are more marked than in the case of the land breeze.

Lapse.—The term lapse is used instead of gradient to denote the decrease of temperature of the atmosphere with height. The lapse-rate is the fall of temperature in unit height, and is taken positive when the temperature decreases with height.

When the temperature at different heights is represented diagrammatically, height being conveniently measured along the vertical coordinate and temperature along the horizontal axis, the condition of the atmosphere is represented by a curve which is sometimes called the "lapse line." Average conditions in the atmosphere are represented by a straight line whose slope corresponds to a lapse rate of about 0·6° C. per 100 metres.

The lapse-rate of temperature is of fundamental importance in determining the vertical stability of the atmosphere (see ADIABATIC, INSTABILITY and ENTROPY). When the lapse-rate is negative the temperature increases with height (see INVERSION). In the TROPOSPHERE this only occurs through limited intervals of height.

Latitude.—The geographical latitude is defined as the angular elevation of the celestial pole above the surface tangential to the spheroid which represents the earth. It is also equal to the angle between the normal to this surface and the plane of the equator. The geographical latitude ϕ at any point differs only slightly from the geocentric latitute ϕ', the latter being the angle between the radius of the earth passing through the point and the plane of the equator. The relation of ϕ and ϕ' is approximately represented by the equation $\phi - \phi' = 68 \cdot 8'' \sin 2\phi$.

Astronomical latitude is defined as the elevation of the celestial pole above the level of a mercury surface, or in other words as the angle between the plumb line and the plane of the equator.

To face page 113.

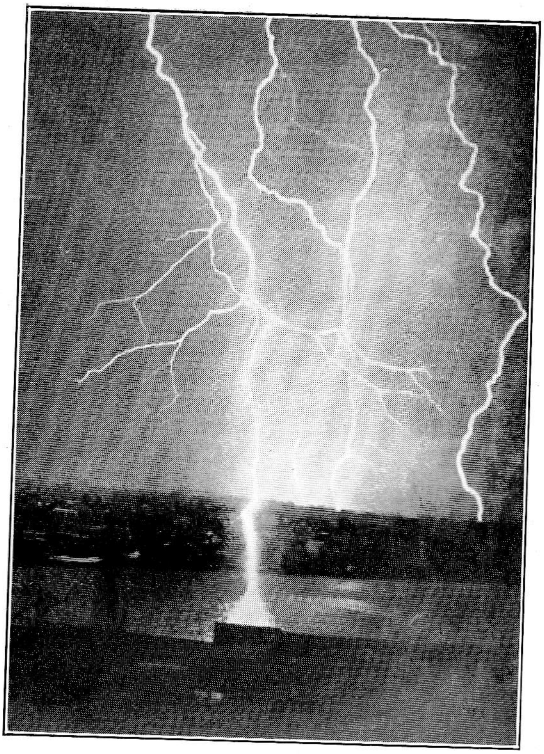

FIG. 21.—Photograph taken at Sydney Harbour, Dec. 1892, of four flashes from the same cloud.

Law of Storms.—A nautical expression denoting the mariners rules for minimising the dangers of tropical cyclones, and especially for avoiding the so-called "dangerous half" of the cyclone. These rules as used at the present time were drawn up by Dr. C. Meldrum and Captain Wales.

Least Squares, Law of.—Pairs of related values, such as autumn rainfall and the subsequent yield of wheat, can be represented by points on a diagram in which one variate forms the abscissa and the other the ordinate. The relation between the two variates can often be expressed by drawing a straight line across the diagram, and the "best-fitting" straight line is defined as that which makes the sum of the squares of the distances from the points to the line a minimum. See CORRELATION.

Lenticular.—In shape like a lens or lentil. The shape is characteristic of a type of cloud most often seen over hills or mountains, formed in a damp layer at the crest of a stationary or slow-moving wave. The cloud is formed by a large mass of clustered cloudlets and is apparently disposed horizontally. It has well defined edges, a pointed end and a broad middle or base. The cloud is usually of smooth appearance, but the cloudlets are often visible, streaming through the cloud. Sometimes the side of the cloud has an appearance not unlike that of stratified rocks. The lenticular clouds are frequently associated with FÖHN. Clouds of rather similar structure are the CAPS on cumulus clouds, and the flat patches sometimes visible near cumulo-nimbus, often appearing dark against a white background.

Leste.—A hot, dry, S. wind occurring in Madeira and northern Africa in front of an advancing depression.

Levanter.—A strong wind from NE. which blows on the east coast of Spain especially from February to May and October to December. In the Straits of Gibraltar the levanter blows from the E. In winter it is often strong and squally, raising a high sea, and it may continue for two or three days; in summer it is of shorter duration and less intensity. The associated pressure distribution generally shows a high pressure over central Europe and a depression over the south-western Mediterranean or African coast.

Leveche.—A hot, dry, SW. wind which occurs in Spain in front of an advancing depression.

Level.—A surface is level, if it is everywhere at right angles to the direction of the force of gravity, which is indicated by the plumb-line. The word is also used to indicate the height of a level surface above a standard such as SEA LEVEL. Tidal and river levels in Great Britain are usually referred to Trinity High Water (T.H.W.), 12·47 feet above ordnance datum.

Lightning.—The flash of a discharge of electricity between two clouds or between a cloud and the earth. A distinction is drawn between "forked" lightning, in which the path of the actual discharge is visible, and "sheet" lightning, in which all that is seen is the flash of illuminated clouds and which is attributed to the light of a discharge of which the actual path is not visible.

Since the introduction of photography many photographs of lightning have been obtained, and in general character they cannot be distinguished from photographs of electric discharges of six inches or more in length which are obtained in a laboratory, but the varieties of form of lightning discharges are very numerous. Frequently a flash shows many branches, especially the upper part of a flash between the clouds and the earth. Among a collection of photographs thrown upon a lantern screen, W. J. S. Lockyer once interpolated a photograph of the River Amazon and its tributaries, taken from a map, and the photograph was accepted without comment as a picture of lightning.

G. C. Simpson* has compared numerous photographs of lightning and

* "On lightning." *London, Proc. R. Soc.*, Series A, **111**, 1926, pp. 56–67

finds that in nearly every case of a branched discharge comparable in shape with a river and its tributaries, the branches spread out downwards, away from the cloud (see Fig. 21). Laboratory experiments and theoretical discussions agree in shewing that in such cases the flow of positive electricity is downwards. The discharge does not all reach the ground, for the majority of the branches of the flash, if not all, terminate in the air. Flashes in which a negative charge goes to earth are likely to be unbranched unless they branch inside the cloud where they can not be seen.

The quantity of electricity which is discharged by a lightning flash has been shewn by C. T. R. Wilson* to be of the order 20 coulombs. In the case of a discharge to earth from a high cloud with the potential 10^9 volts the energy dissipated would be 10^{10} joules or 3,000 kilowatt hours which is equivalent to the energy of 80 projectiles each weighing a ton and moving at 500 metres per second.

A. Matthias, who utilised an oscillograph with a very open time scale, 10 cm. to a second, found at Wannsdorf near Berlin that a single lightning flash usually involved about five partial discharges. The duration of a partial discharge was between ·0005 second and ·01 second. The maximum interval between consecutive partial discharges was 0·37 second. The same observations indicate that the theory that the lightning discharge is oscillatory cannot be upheld.

For an account of the origin of the electrical energy in lightning see ATMOSPHERIC ELECTRICITY (*Electricity on rain*).

Limit-Gauge.—A rainfall measure especially designed to show with precision the readings 0·095 in. and 0·100 in. made with an ordinary 5-in. gauge. This limit is often of importance in connexion with rainfall insurance, since payments are made if the rain exceeds the critical reading of 0·095 in. The gauge is described in *Q. J.R. Meteor. Soc.*, **50,** 1924, pp. 23–25.

Line-Squall.—Squalls may occur simultaneously along a line, sometimes 300 or 400 miles in length, advancing across the country, and to such phenomena the name "line-squall" is applied.

The passage of a line-squall at a ground station in a country like the British Isles is marked by characteristic happenings which include all or some of the following :—

An arch or line of low black cloud of definite straightness.
A sudden or rapid rise of wind velocity.
A sudden or rapid change of wind direction.
A sudden or rapid drop in temperature.
A rapid rise in barometric pressure.
Heavy rain or hail (occasionally snow).
Thunder and lightning.

It is the first and second of these characteristic happenings that, combined, have given the special name. In the upper air the passage of the squall is marked by dense cloud and very violent vertical disturbances.

The fundamental physical fact underlying the phenomena is that suddenly a distinctly colder body of air replaces a warmer current, and this sudden replacement is brought about when the COLD FRONT of a depression passes. The advancing cold current pushes itself wedge-wise under the warmer air and causes that warmer air to rise up an oblique plane ; this ascent is sufficient to produce the cloud and precipitation mentioned, whilst the rise in pressure and the drop in temperature are the results of the following cold air.

In the British Isles the warm current in front of the squall is usually from a southerly or south-westerly point and moist. In some parts of the world it is dry and in these latter cases the squall may pass without rain or even without cloud ; the dryness means that a great ascent has to be carried out before saturation, and hence cloud formation, is attained and sufficient ascent may not occur.

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* *London, Phil. Trans.*, A, **221**, 1920, p. 73.

Line-squalls usually cross the British Isles in an easterly direction. Their speed of advance can be forecast with considerable certainty for in active systems any given part of a cold front advances with a velocity which is approximately equal to the component, perpendicular to the front, of the gradient wind in the cold (polar) air in its rear.

The life of a line-squall is often 24 hours or more.

Liquid.—The name given to a class of fluids. The liquid has this property : that if a limited quantity is poured into a sufficiently large vessel it forms a definite layer at the bottom of the vessel having a clearly defined upper boundary or free surface, which is horizontal when the vessel is at rest.

Litre.—Defined as the volume of a kilogramme of pure air-free water at the temperature of maximum density (3·98° C.), and 760 mm. pressure. 1 litre = 1000·028 c.c. = 1·7598 pints.

Local Time.—Time reckoned from the epoch noon which at any place is the time of transit of either the true sun or mean sun (according as local apparent or local mean time is being used) across the meridian. A sundial and sunshine recorder indicate local apparent time (see TIME).

Longitude.—The intersection of a plane through the axis of rotation of the earth with the earth's surface is called a meridian. The longitude of any place is the angle between the meridian through that place, and a standard meridian. The standard meridian is unually taken to be the meridian of Greenwich.

Looming.—A nautical expression for an indistinct enlarged appearance of any object, particularly during the prevalence of slight fog. The expression is not used for unusual visibility by reason of which distant objects appear nearer.

Low.—Used to denote a region of low pressure, or a DEPRESSION, in the same way as "high" is used for a region of high pressure or anticyclone. On weather charts the central part of a depression is usually indicated by the word "low."

Lunar.—Dependent upon *luna*, the moon ; thus a lunar rainbow is a rainbow formed by the rays of the moon, a lunar cycle a cycle dependent upon the moon's motion. A month is really, from its name, a lunar cycle, but the introduction of a calendar month makes it necessary to draw a distinction between it and the lunar month, which is the period from new moon to new moon. In astronomy it is called the synodic month, and is equal to 29·5306 days. (See CALENDAR.)

Lustrum.—A period of five years, which is commonly used for grouping meteorological statistics which extend over a long period of years.

Mackerel Sky.—A sky covered with CIRRO-CUMULUS or ALTO-CUMULUS clouds arranged in somewhat regular waves and showing blue sky in the gaps.

Maestro.—A north-westerly wind which blows in summer in the Adriatic when pressure is low over the Balkan Peninsular. It is a fresh breeze accompanied by fine weather and light clouds.

Magnetic Storm.—A state of large irregular disturbance or fluctuation, world-wide in extent, of the earth's magnetic field, the normal regular diurnal changes being largely or entirely masked. The duration may vary from a few hours to a few days. Some storms begin abruptly (a "sudden commencement") and apparently simultaneously, at least to within the limits of accuracy of measurement of the autographic records, at all places. The intensity of disturbance is greater in high than in low latitudes ; in middle latitudes the absolute range of variation in a force component of the earth's field amounts to a very few per cent of the normal value of the component. A conspicuous feature of most storms is the depression in the value of horizontal magnetic force after the early stages of the storm. Storms may occur at any time of the year and at any phase of the solar cycle; but the frequency of occurrence of highly disturbed conditions is greater near the equinoxes than near the solstices, and greater in years of sunspot maximum than in years of sunspot minimum. There is a marked tendency for magnetically disturbed conditions to recur at intervals of about 27 days (the solar rotation period), although a large disturbance may not be followed by another, or even by any noteworthy disturbance, 27 days later. Other conditions being favourable, AURORA is usually observed from places in comparatively low latitudes on occasions of magnetic storms. On such occasions large and irregularly varying earth currents cause interference with telegraphic communication. Definite effects in radio-wave propagation have been observed during magnetic disturbances. (See also TERRESTRIAL MAGNETISM.)

Mammato-Cumulus.—Clouds with rounded protuberances on their under surfaces, sometimes called "festooned clouds" or "pocky clouds." (Fig. 13.) Well developed examples are usually associated with thunderstorms. The same cloud structure is occasionally seen at the base of ALTO-STRATUS or of dense CIRRUS, and it is fairly frequent under the lateral extension of an ANVIL. It also occasionally develops in heavy strato-cumulus, though usually only to a feeble degree.

Manometer.—An instrument for measuring differences of pressure. Ordinarily the weight of a column of liquid is balanced against the pressure to be measured. The mercurial BAROMETER is, therefore, a form of manometer.

Mares' Tails.—The popular name for tufted CIRRUS clouds.

Maximum.—The highest value reached by any element in a given period. For example, the highest temperature recorded during the 24 hours is the maximum temperature for that period. (See EXTREMES.)

Mean.—The mean value of a set of numerical quantities is the average value determined by adding them together and dividing the result by the number of quantities. In some cases there may be an ambiguity unless the context makes it clear as to how the numerical quantities are classified. For example, the mean temperature of the atmosphere extending above a certain place might indicate the arithmetical mean of the temperatures taken at equal intervals of height or at equal intervals of pressure going upwards. (See also NORMAL, AVERAGE.)

Mean Square Error.—The square root of the mean of the squares of the deviations from the mean value. If n observations yield measurements $x_1, x_2, \ldots x_n$, the mean square error is usually taken to be

$$\sqrt{\frac{\Sigma (x_r - \bar{x})^2}{n - 1}}$$

the factor $n - 1$, one less than the number of observations, occurring in the denominator instead of n in order to take account of the uncertainty of the mean value $\bar{x}$. The mean square error is a measure of the closeness with which the observations are clustered about the mean. It is usually denoted by μ.

Megadyne.—One million dynes. A pressure of a megadyne per square centimetre is equal to one bar or 1,000 millibars. (See DYNE.)

Meniscus.—The curved upper surface of liquid in a tube. If the tube is of narrow bore the curvature is pronounced, and in estimating the height of the liquid column, allowance must be made for it. In the case of water, the meniscus, when viewed horizontally against the light, appears as a dark belt. The upper edge represents the highest point to which the water is drawn up against the glass, and the lower edge the lower part of the surface out in the middle of the tube. When the tube is broad like the measuring glass of a rain-gauge, the bottom edge should be used in reading; but in narrow tubes the mid-point would be more suitable. Mercury has a convex upper surface and in the case of the barometer the index is adjusted to the top of the meniscus.

Mercator's Projection.—See PROJECTION.

Mercury.—Mercury is a metallic element of great value in the construction of meteorological instruments. In the mercurial barometer its great density enables the length of the instrument to be made moderate, while the low pressure of its vapour at ordinary temperatures makes possible a nearly perfect vacuum in the space above the top of the barometric column. In the mercury thermometer there is no risk of condensation in the upper end of the stem, as in the case of the spirit thermometer.

Specific gravity = 13·5955 at 273°A.
Specific heat = 0·0335 at 273°A.
Freezing point = 234·2°A.
Coefficient of expansion = ·0001818 per °C.

Meteor.—A meteor or shooting star is a fragment of solid material entering the upper regions of the atmosphere from outer space and visible by its own luminosity. The luminosity is attributed to incandescence due to the compression of the air in front of the meteor. A large meteor may have a luminous trail that persists for half an hour or longer. The majority of meteors are exceedingly small, comparable with grains of sand, but large bodies—meteorites, aerolites or siderites—fall to the ground occasionally. There is no generally accepted theory of the origin of meteors.

Accurate determinations of the track of the meteor by reference to the constellations by observers in different parts of the country may enable the height of the track to be determined. Usually a meteor becomes luminous between 150 and 100 Km. above ground and disappears at about 80 Km. It is remarkable that very few disappear at heights between 70 and 50 Km. Most of those which get below 70 Km. get below 50 Km.

According to the theory of meteors worked out by Lindemann and Dobson* the density of the air and therefore its temperature can be estimated from the records of the velocity of meteors, their brilliance and their points of appearance and disappearance. The theory indicates that at 60 km. and perhaps lower the atmosphere is at a high temperature, at least as high as that near the ground. (See AUDIBILITY; OZONE.)

The appearance of a large meteor is followed occasionally by sounds usually known as "detonations." The sounds are probably due to the waves created by the meteor making its way through the air, not to the explosive breaking up of the meteor. The sounds can be heard occasionally at a distance of 50 miles from any part of the visible path of the meteor. In some cases a zone of silence and an outer zone of audibility have been found.

To explain the breaking up of a meteor it has been suggested that the air pressure acting on a surface which is probably quite irregular causes the meteor to spin. The meteor is not strong enough to withstand the centrifugal force generated by very rapid rotation and therefore breaks into fragments.

Meteorograph.—A self-recording instrument which gives an automatic record of two or more of the ordinary meteorological elements. Of late the term has been more generally applied to the instruments that are attached to kites or small balloons and sent up to ascertain the pressure, temperature and humidity of the upper atmosphere. (See BAROTHERMOGRAPH.)

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* "A theory of meteors and the density and temperature of the outer atmosphere to which it leads" *London, Proc. R. Soc.*, Series A, **102**, 1922, pp. 411–37.

Meteorology.—The science of the atmosphere; from the Greek μετεωρος, lofty or elevated (τα μετεωρα, atmospheric phenomena) and λογος, discourse. Modern meteorology includes the study of the physical processes which occur in the atmosphere, and of the connected processes of the lithosphere and hydrosphere.

Metre.—The unit of length in the METRIC SYSTEM. It was intended to be equal to one forty-millionth of the Paris meridian, but errors entered into the calculation and it must now be considered as an arbitrary length. It is the distance, at the melting point of ice, between two lines engraved upon a platinum iridium bar kept in Paris.

1 metre = 10 decimetres = 100 centimetres = 1,000 millimetres.

The Order in Council of 1898 defines the inch as 25·400 millimetres and the metre as 39·37 0113 inches.

Metric System.—Name for the C.G.S. system, derived from the word METRE. The units of length, mass and time are the centimetre, gram, and second respectively.

Micro.—A prefix meaning small from the Greek μικρος, for example microbarograph, microseism. Micro is sometimes used in the sense of one millionth, for example microfarad.

Microbarograph.—An instrument designed for recording small and rapid variations of atmospheric pressure. It consists of an air-tight reservoir of ample size containing air, and the difference of the external atmospheric pressure and the internal pressure in the reservoir is made to leave a record on a drum driven by clockwork. The reservoir is well protected from changes of temperature by a thick covering of felt or other non-conducting material, and it is also provided with a small leak, the magnitude of which can be adjusted. If the external pressure changes slowly the leak allows the internal pressure to follow it closely, but as the leak is small, the internal pressure cannot adjust itself rapidly to any sudden changes in the external pressure, and consequently a record of such changes is obtained.

Microseisms.—Seismographs are designed to record the tremors which pass through the ground from distant earthquakes but these instruments reveal also the fact that the ground is nearly always oscillating. The continuous oscillations are known as microseisms. The amplitude of microseismic disturbances is conveniently expressed in terms of the unit denoted by μ; this unit is the millionth part of a metre. In the British Isles the average amplitude of the microseismic oscillations recorded by a seismograph varies from about $0{\cdot}3\,\mu$ in July to about $2{\cdot}6\,\mu$ in January. The average period is about 6 seconds. The oscillations are always fluctuating however. During one half minute the amplitude may increase: during the next half minute the oscillations die out as if there were interference between waves from different origins.

Microseisms are most vigorous at times when there are strong winds over shallow seas. The theory put forward by the German seismologist, E. Wiechert, that microseisms are produced by the sea waves beating on steep rocky coasts is supported by observations in Europe but is not accepted by all seismologists. An alternative explanation is that the variations in pressure on the sea bottom set up the microseismic oscillations.

Mile.—The *statute mile* is defined as 1,760 yards or 5,280 ft. The *geographical mile* is the length of an arc of one minute of latitude, and varies with latitude, being equal to $(6076{\cdot}8 - 31{\cdot}1 \cos 2\phi)$ feet or $(1852{\cdot}2 - 9{\cdot}5 \cos 2\phi)$ metres in latitude ϕ. The *nautical mile*, as used in hydrographic surveying, is identical with the geographical mile, but in general practice the nautical mile is taken as 6,080 ft., the approximate value of the geographical mile in lat. 50°.

Milli-.—A prefix meaning one thousandth part of, (Latin *mille* a thousand) as in millimetre, millibar, milligram, etc.

Millibar.—The thousandth part of a BAR, which is the meteorological unit of atmospheric pressure on the C.G.S. system. Since the bar is equal to a pressure of one megadyne per square centimetre, i.e. to 1,000,000 dynes per square centimetre, a millibar is equivalent to 1,000 dynes per square centimetre.* The millibar has been in general use in the Meteorological Office since May 1st, 1914. The principal advantage of using a unit of this type is that a statement of atmospheric pressure as a certain number of millibars is perfectly definite. According to the older practice a separate unit had to be used for *length* in reading the height of the mercury in the barometer, generally the inch or the millimetre, but this length is not a measure of the atmospheric pressure until the density of the mercury, the temperature of the scale and the value of gravity at the place are allowed for. The "millibar" on the other hand can only be used for *pressure*. If a barometer graduated in the C.G.S. system is set up at any place, there is a definite temperature called the FIDUCIAL TEMPERATURE at which the scale reading of the mercury column gives the pressure of the air in millibars; a correction must be applied to the reading when the temperature of the instrument is not the fiducial temperature. (See "Meteorological Observer's Handbook.")

1,000 millibars are equivalent to the pressure of a column of mercury 750·1 millimetres (29·531 inches) high at 0° C. (273°A.) in latitude 45°.

Millimetre.—One thousandth of a METRE.

Minimum.—The lowest value reached by an element in a given period. (See EXTREMES.)

Mirage.—The term mirage is used for certain appearances produced by the refraction of light by the atmosphere; these appearances include the illusion of a sheet of water in the desert as well as cases in which definite distant objects can be seen in duplicate.

Over a heated desert the air very close to the ground is less dense than that above it so that the velocity of light is greatest close to the ground. Rays coming down from the sky at a gentle inclination may be bent up again to the observer, to whom the rays appear to come from a bright water surface. The banks, reeds, etc., are the images of various objects distorted by being viewed through layers of air of varying density so that a dark stone appears as though it were an upright stake. Hills situated a short distance away may appear as detached masses floating on this lake-like surface, their lower portions being invisible under the conditions prevailing. Mirages may often be seen over smooth road surfaces on calm hot days in England, especially over tarred roads.

These are all cases of inferior mirage. "Superior" mirage in which the light rays are bent downwards from a warm stratum of air resting on a colder is seen most frequently in polar regions. The distances involved are greater so that the details can hardly be observed without telescopic aid. With such assistance a distant ship may sometimes be seen in triplicate, one of the images being inverted. As the stratification which produces superior mirage is stable the images are clear and well defined in contrast to the shimmering images of the inferior mirage.

The images produced by superior mirage are not always exactly in the same vertical. The separation is explained by a slight departure of the strata of equal density from horizontal planes. Lateral refraction of this kind is to be distinguished from the phenomenon which can be observed sometimes near a heated wall when objects appear to be reflected in the wall.

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* It should be explained here that a megadyne is a measure of force. The dyne is the unit force of the C.G.S. system of units, and stands for the force which produces unit acceleration in one gram. As the force of gravity is the most familiarly known of all forces, we may say that the force of one dyne differs but little from the weight of a milligram, and a megadyne stands in the same relation to the weight of a kilogram. The precise numerical relation is dependent upon locality, because the weight of a body, that is, the force which gravity exerts on it, depends upon latitude and the distance from the Earth's centre. At sea level, in latitude 45°, the gram weighs 980·6 dynes, the kilogram 0·9806 megadynes.

Mist.—See FOG.

Mistral.—A cold, dry northerly or north-westerly wind which blows along the Mediterranean coast of France. It is a KATABATIC wind similar to the BORA, it is less violent, however, as its path is not so steep. It occurs along the Mediterranean coast as far as Genoa, but is most prevalent between Montpellier and Toulon. It is usually accompanied by clear weather and bright sunshine.

Mock Moon.—See PARASELENAE.

Mock Sun.—See PARHELION.

Mock sun ring or parhelic circle.—The circle passing through the sun parallel to the horizon. The whole of this circle may be bright but colourless. The phenomenon is explained by the presence of ice crystals with vertical facets from which the light is reflected. (See HALO PHENOMENA.)

Monsoon.—The name is derived from an Arabic word for "season," and originally referred to the winds of the Arabian sea, which blow for about six months from the NE., and six months from the SW. It has been extended to include certain other winds which blow with great persistence and regularity in opposite directions at different seasons of the year. The primary cause of these winds is the seasonal difference of temperature between land and sea areas. They are analogous to land and sea breezes, but their period is a year, instead of a day, and they blow over vast areas, instead of over a limited region.

Near the equator the seasonal changes of temperature are in general too small to cause the development of monsoons; in the higher latitudes of the prevailing westerlies and in the polar regions the wind components due to contrast of temperature between land and sea are at most sufficient only to modify slightly the "planetary" wind circulation, so that the regions most favourable to the development of monsoon conditions are in middle latitudes, near the tropics.

The moisture content (determined by the length of sea track pursued) of the landward-blowing winds and the topography of the land on to which the moisture-carrying winds blow have great influence on the amount of rainfall associated with the landward monsoon. Owing to a suitable combination of the various factors monsoon conditions reach their greatest development over eastern and southern Asia, in most of which regions a rainy summer monsoon from the SW. is the outstanding feature of the climate. In the countries of its occurrence the term "the monsoon" is popularly used to denote the rains, without reference to the winds.

Monsoon conditions occur also, but to a much less extent in north Australia, parts of western, southern and eastern Africa, and parts of North America and Chile.

Month.—See LUNAR, CALENDAR.

Moon.—The only satellite revolving round the earth. Its *sidereal* period of revolution (i.e. *from star to star*) averages about 27¼ days, but varies as much as three hours from this value on account of the eccentricity of its orbit, and its "perturbations." The *synodic* period of revolution (i.e. the interval from new moon to new moon) has a mean value of about 29·53 days, but varies about 13 hours on account of the eccentricities of the orbits of the moon and the earth.

The brilliance of the moon is due solely to sunlight falling upon it. The fallacy that the moon's rays are injurious to plants arises from the fact that nights of ground frost are clear nights, on which the moon will be visible if suitably placed.

Moon, Phases of.—The appearance of the moon, by custom restricted to the particular phases of *new moon* when nothing is visible, *first quarter* when a semicircle is visible with the bow on the west, *full moon* when a full circle is visible, and *last quarter* when a semicircle is visible with the bow on the east. The changes of phase are due to the changes in relative position of earth, moon and sun. The moon rotates on its axis once in each orbital revolution, and so the same face of the moon is always turned towards the earth. The popular belief in the association of weather changes with the phases of the moon is not confirmed by meteorological investigations, though S. Chapman* has shown that there is a very minute lunar tide in the atmosphere, giving a variation of pressure of only a small fraction of a millibar.

Mountain breeze.—A breeze which blows at night down valleys and mountain slopes. At night the mountain slopes become cooled by radiation, the air in contact with them is also cooled and its consequent increase in density causes it to flow downwards. (See KATABATIC.)

Nadir.—The point of the sky immediately below the observer, i.e. in the vertical produced downward through and beyond the earth's centre. The opposite of ZENITH.

Nephoscope.—An instrument for determining the direction of motion of a cloud and its angular velocity about a point on the ground vertically below it. The types most commonly employed are the Fineman reflecting nephoscope and the Besson comb nephoscope, descriptions of which will be found in the "Meteorological Observer's Handbook." A camera obscura arranged to project a view of the clouds near the zenith on to a graduated board may be used as a nephoscope.

Neutral Point.—See POLARIZATION.

Night Sky, Light of.—The background from which the stars stand out on a clear night is not mere darkness. A certain amount of light is always present though its colour can not be appreciated by the human eye. By the use of very long exposures (up to 200 hours) Lord Rayleigh has photographed the spectrum of the night sky. He finds on a continuous background the green auroral line, 5577 Å, and the dark Fraunhofei lines H and K. These dark lines are regarded by Rayleigh as evidence that there is a certain amount of light from the stars in the continuous spectrum. It may be noted that the spectrum of aurora shows in addition to the characteristic green line certain bands which are observable in electric discharges through nitrogen ; these bands are not present in the spectrum of the normal night sky.

On account of the presence in the night sky of the green auroral line, Rayleigh has introduced the term "non-polar" aurora.

Polar aurora.	*Non-polar aurora.*
Shows the green line 5577 and the negative band spectrum to nitrogen.	Shows the green line 5577 without the negative band spectrum of nitrogen.
Confined for the most part of high latitudes, only descending occasionally to temperate latitudes.	Apparently occurs all over the world, and may be even stronger in low latitudes.
Often shows highly characteristic foims such as arcs, draperies, etc.	Uniform all over the sky.
Changes in form and intensity in the course of a minute or even less.	Often shows no sensible change of intensity for weeks.

A scheme for systematic observations of the night sky at a number of widely distributed stations was organised by Rayleigh in 1925. On the whole there appears to be little difference between the intensity of the light in different parts of the world. The variations do not occur simultaneously in all districts, but there may be long-period variations swamped by local irregular changes.

Observations of the night sky are not possible in summer owing to twilight. In England the sky is comparatively bright from August to

* London, *Q.J.R. Meteor. Soc.*, **44**, 1918, p. 271.

November and fainter through the winter. During the period, 1923–28, there was a progressive increase in the intensity of the light from year to year; this is thought to be connected with the simultaneous increase in the frequency of sunspots.

In 1929 Rayleigh developed a method of measuring the intensity of the light using a photo-electric cell instead of the human eye. With this apparatus he has demonstrated that there is an increase in intensity throughout the evening.

Nimbus (Nb.).—*A dense layer of dark shapeless cloud with ragged edges from which steady rain or snow usually falls. If there are openings in the cloud an upper layer of cirro-stratus or alto-stratus may almost invariably be seen through them.*—If a layer of nimbus separates into ragged cloud, or if small detached clouds are seen drifting underneath a large nimbus (the SCUD of sailors), either may be specified as fracto-nimbus (Fr.-Nb.).

Normal.—The name given to the average over a number of years of any meteorological element such as pressure, temperature, precipitation or duration of sunshine. The name implies that the number of years over which the observations extend is such that the inclusion of a longer period would make no appreciable difference. The shortest period which can be employed for reliable normals depends on the standard deviation. In most tropical countries satisfactory monthly normals can be obtained from ten years' observations (except for rainfall which requires a longer period). In the more variable temperate regions at least 35 years are required.

Normal values of the various climatological elements, especially temperature and rainfall, are necessary for economic purposes and the meteorological services of most countries have published such data for a large number of places. In this country the first section of the "Book of Normals of the Meteorological Elements for the British Isles" was published in 1919, giving monthly and yearly normals for temperature, rainfall and susnhine for the period 1881–1915 for between 100 and 200 stations. Since then five more sections of the book have been published. These include normal district values, maps illustrating Section I, range of variation of temperature and rainfall, frequency tables for hail, thunder, snow, snow lying and ground frost, monthly normals of rainfall for 578 stations and normals of relative humidity.

Normal values are conveniently represented on maps. A collection of climatological maps appeared in 1899 in "Bartholomew's Physical Atlas, Vol. III, Atlas of Meteorology." Monthly and annual charts showing the distribution of nearly all meteorological elements over the whole globe appear in volume II of the "Manual of Meteorology" by Sir Napier Shaw.

Table of normal hourly velocities of the wind in metres per second for every other hour of the day, for each month at Kew Observatory (35 *year normal* 1881–1915).

Hour	2	4	6	8	10	12	14	16	18	20	22	24	Mean*
January ..	3·3	3·3	3·3	3·4	3·7	4·3	4·3	3·8	3·7	3·7	3·6	3·4	3·7
February ..	3·4	3·3	3·4	3·5	4·1	4·9	4·9	4·5	3·9	3·7	3·5	3·4	3·9
March	3·2	3·1	3·2	3·7	4·8	5·2	5·3	5·0	4·0	3·6	3·3	3·2	4·0
April	2·7	2·6	2·8	3·8	4·7	5·2	5·3	5·2	4·4	3·5	3·1	2·7	3·9
May	2·3	2·2	2·6	3·5	4·2	4·7	4·7	4·7	4·1	3·2	2·7	2·4	3·4
June	2·0	1·9	2·5	3·3	3·8	4·2	4·3	4·3	3·9	2·9	2·5	2·2	3·2
July	1·9	1·8	2·2	3·0	3·6	4·0	4·2	4·1	3·6	2·7	2·3	2·0	2·9
August ..	1·9	1·9	2·1	3·1	3·8	4·1	4·3	4·1	3·5	2·7	2·3	2·1	3·0
September ..	1·8	1·9	1·9	2·6	3·6	4·0	4·1	3·8	2·9	2·5	2·2	1·9	2·8
October ..	2·4	2·3	2·4	2·7	3·5	4·2	4·1	3·5	2·8	2·7	2·5	2·4	3·0
November ..	3·0	3·1	3·0	3·0	3·5	4·3	4·3	3·6	3·3	3·3	3·1	3·0	3·4
December ..	3·5	3·5	3·5	3·6	3·8	4·4	4·3	3·8	3·7	3·7	3·6	3·6	3·7
Year ..	2·6	2·6	2·8	3·3	3·9	4·5	4·5	4·2	3·7	3·2	2·9	2·7	3·4

* Mean of 24 hourly values.

Table giving normal pressure, temperature, humidity, rainfall and sunshine for Kew Observatory (lat. 51° 28′ *N., long.* 0° 19′ *W., height of barometer* 34 *ft.)* 35 *year normals* 1881–1915 *(humidity,* 30 *years* 1886–1915 *only).*

	Pressure*	Temperature			Humidity*	Rainfall		Bright sunshine per day
		Max.	Min.	Mean*				
	mb.	°F.	°F.	°F.	%	in.	mm.	hr.
January ..	1017·6	43·1	34·6	39·1	84·5	1·76	45	1·39
February ..	1016·0	45·0	35·1	40·0	81·6	1·54	39	2·13
March ..	1013·4	48·7	36·0	42·1	79·3	1·69	43	3·39
April	1014·4	55·0	39·5	46·9	74·7	1·45	37	5·23
May	1015·9	61·7	45·0	53·2	73·4	1·72	44	6·48
June	1016·7	67·6	50·8	58·9	72·8	2·15	55	6·57
July	1015·8	71·0	54·3	62·3	73·0	2·17	55	6·48
August ..	1015·3	69·7	53·5	61·2	75·8	2·24	57	6·03
September ..	1017·4	64·9	49·3	56·8	79·2	1·87	48	4·83
October ..	1014·0	56·2	43·5	49·7	84·6	2·70	69	2·97
November ..	1014·6	49·1	38·8	44·2	85·9	2·22	56	1·73
December ..	1013·7	44·7	35·9	40·7	85·9	2·29	58	1·19
Year	1015·4	56·4	43·0	49·6	79·2	23·80	606	4·04

* Means of 24 hourly values.

Normal Law (of Errors).—When the error to which an observation is subject may be regarded as made up of a large number of small independent errors, each as likely to be positive as negative, it can be shown that the probability that one observation should yield a result having an error between x and $x + dx$ is

$$\frac{h}{\sqrt{\pi}} e^{-h^2 x^2} dx.$$

where h is a parameter. If a large number n of observations be made we should therefore expect a number

$$\frac{n\,h}{\sqrt{\pi}} e^{-h^2 x^2} dx.$$

to lie between the limits x and $x + dx$. The observations are then said to satisfy the "normal law of errors," of which the last sentence is a complete statement. It will be noted that the FREQUENCY is the same for $+ x$ as for $- x$, so that the frequency curve is symmetrical about the axis of y. Many proofs of the normal law are to be found in text books on "least squares," but no proof is altogether satisfactory. Further it must be noted that distributions of observations are frequently met, especially in biological and allied sciences, which are not symmetrical.

The parameter h is related to the MEAN SQUARE ERROR μ by the relation $h\mu = \cdot 7071$. It is related to the PROBABLE ERROR r by the relation $hr = \cdot 477$.

Norte, Norther.—A dry, cold, N. wind over the Gulf of Mexico. Similar winds at Valparaiso and Table Bay have the same name.

Observer.—In meteorology, a person who undertakes, in co-operation with others at a réseau of stations, to make regular and simultaneous records of the weather upon an organised plan. Good observing requires punctuality and accuracy, and therefore skill in reading and setting instruments, and intelligence in noting occurrences which are worth recording, though they are not in the prescribed routine. The best observer is one who is personally interested in scientific work on a co-operative basis.

Occlusion.—A newly developed DEPRESSION has in accordance with the Bjerknes theory a WARM SECTOR, that is a roughly V-shaped sector running out from the centre which contains warm or equatorial air, the rest of the depression at the earth's surface being occupied by cold or polar air. The front of the V-shaped sector is the WARM FRONT of the depression while the back of it is the COLD FRONT, these fronts marking the chief regions of cloud and rain in the depression. The warm air is gradually pushed from the earth's surface by the advance of the heavier cold air behind it so that after a time the cold front closes on the warm front. The warm sector is then reduced to a line called the line of occlusion and subsequently is lifted from the surface of the earth. It is still present, however, in the upper layers and the cloud and rain associated with the fronts are therefore to be found along a line of occlusion for some time after the warm air has left the earth's surface. The majority of depressions which reach Europe from the Atlantic are occluded by the time they reach the seaboard, and lines of occlusion are thus much more frequent upon European weather charts than warm and cold fronts.

Ombrometer.—Another name for RAIN-GAUGE.

Optical Phenomena.—The optical phenomena of interest to meteorologists are numerous. They include the BLUE OF THE SKY, SUNRISE AND SUNSET COLOURS, the production of RAINBOWS, CORONAE and HALOS, the fading of daylight and the twinkling of the stars. These matters are very fully dealt with in the great treatise of the Austrian meteorologist Pernter, the second edition of which was prepared by his pupil and collaborator F. M. Exner.* The best account in English is to be found in Humphreys's "Physics of the Air."†

Orientation.—From *Oriens* (Lat.), the rising of the sun—the east. The direction of an object referred to the points of the compass.

Orographic Rain.—Rain caused by the interference of rising land in the path of moisture-laden wind. A horizontal air current striking a mountain slope is deflected upwards, and the consequent dynamical cooling associated with the expansion of the air produces rain if the air contains sufficient aqueous vapour. Mountain ranges at right angles to the direction of the wind offer greater obstruction to the wind and therefore are more likely to produce rain, than mountain ranges which lie in the direction of the wind. In the case of isolated mountain peaks, the wind is often able to go round and the amount of rain produced may be trifling. The prevailing wind of these Islands is from the SW. and as this damp wind passes across the country the aqueous content decreases. A mountain range of a given height along the west coast would therefore produce a greater rainfall than a range of similar height and position relative to the wind in the east. These orographic rains are typically persistent and usually widespread. Their great importance lies in the fact that the main controlling factor, the rising ground, is always operative, and naturally, always in the same place. Thus a station on a hill is not only usually wetter year by year than a neighbouring station in a valley, but the proportion remains fairly constant. Some valleys, if they are surrounded by mountains on all sides, receive nearly as large a rainfall as the surrounding mountains since air is generally rising as it passes over these valleys. (See CONVECTIONAL RAIN, CYCLONIC RAIN.)

Oscillation.—A periodic movement to and fro, or up and down, or a periodic variation of a quantity above and below its mean value. The simplest dynamical illustration is the simple pendulum, which swings first to one side of the vertical then to the other. The term oscillation is used in meteorology in connexion with a wide variety of phenomena, such as the diurnal variation of pressure, the annual variation of temperature, the gusts and lulls of wind, etc.

Overcast Day.—Defined as a day on which the average CLOUDINESS at the hours of observation is more than eight tenths of the sky.‡

* Pernter, J. M. and F. M. Exner: "Meteorologische Optik." Wien and Leipzig, 1922.

† Philadelphia, 1920.

‡ Codex of Resolutions adopted at International Meteorological Meetings, 1872-1907. London, 1909.

Ozone.—An allotropic form of oxygen for which the chemical symbol is O_3. It is produced by passing electrical sparks through oxygen or by the action of cathode or ultra-violet rays. The amount of ozone in the atmosphere is best determined by spectroscopic observations, as ozone absorbs ultra-violet light of certain wave-lengths. By this test it can be shown that there is very little ozone in the atmosphere near the ground. There is however a region in the upper atmosphere where ozone is comparatively plentiful.* The quantity of ozone can be determined by the analysis of sunlight, and by comparison of observations with high and low sun, the height at which the ozone occurs can be estimated. The quantity of ozone is found to be such that if it could be brought down to the ground it would form a layer abour 3 mm. thick. The bottom of the region in which it occurs is about 30 Km. above the ground. The amount shows considerable variations. The zone absorbs ultra-violet light coming from the sun and it is believed that the energy derived from this ultra-violet light maintains a very high temperature in the upper atmosphere. (See METEORS and AUDIBILITY.)

Pack Ice.—Sea ice which has drifted from its original position. It is termed " close pack " if the floes are mainly in contact and " open pack " if the floes for the most part do not touch.

Pallium.—A term occasionally used to denote a uniform grey cloud sheet normally associated with precipitation.

Pampero.—A name given in the Argentine and Uruguay to a severe storm of wind, with rain, thunder and lightning. It is a LINE-SQUALL, with the typical arched cloud along its front. It heralds a cool south-westerly wind in the rear of a DEPRESSION ; there is a great drop of temperature as the storm passes.

Parallax is an apparent change in the position of an object caused by a change in position of the observer. In connexion with the reading of meteorological instruments an *error of parallax* may arise whenever the indicator of the instrument (e.g. end of column of mercury or water, pointer, etc.), and the scale against which the indicator is to be read are at a distance from one another which is comparable with the length of the smallest readable scale division ; for in such a case a movement of the observer's head may cause his line of vision to the indicator to intersect the scale at different points and so give rise to different readings. The error is eliminated by ensuring that the line of vision to the indicator is at right angles to the scale when the reading is made.

Parallax is unfortunately almost universal among meteorological instruments. Thus the distance of the scale of the ordinary Kew-pattern barometer from the top of the mercury meniscus is about half an inch, and as an accuracy of ·001 in. in the scale reading is usually required the error of parallax may in this case be very serious. Barometers are, however, designed to ensure that errors of parallax can be completely eliminated when reading. An error of parallax of $\frac{1}{2}°$ F. may easily be made in reading a thermometer in a Stevenson screen ; to avoid such errors care must be taken to see that imaginary lines drawn towards the observer at right angles to the scale at all points, at which readings may be taken, are not obstructed by part of the screen itself, or by other thermometers placed in the screen. Errors of parallax in reading a rain measure are also important, and are experienced whenever an observer habitually places his eye either above or below the level of the water surface in the rain measure.

Paranthelia.—A mock sun at the same elevation as the sun and in an azimuth greater than 90° from the sun may be called a paranthelion. White paranthelia at 120° from the sun are fairly common. Paranthelia at about 140° from the sun have been recorded on rare occasions.

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* London, *Q.J.R. Meteor. Soc.*, **51**, 1925, p. 367.
London, *Proc. R. Soc.*, **120**, 1928, p. 255.

Paraselenae or mock moons, analogous to mock suns, have been observed occasionally. No measurements are available but it may be presumed that mock moons will be at the same elevation as the moon and that the angular distance will vary like that between sun and mock sun, being 22° when the luminary is on the horizon and 25° when the luminary is at an elevation of 30°.

Parhelion.—An image of the sun, coloured or white. The mock suns seen most frequently are at the same elevation as the sun and coloured with red nearest the sun. When the sun is near the horizon the distance is equal to the radius of the ordinary halo, i.e. 22°. When the sun is higher the distance is greater so that if halo and mock sun are both seen the mock sun is outside the halo. White mock suns are to be seen in the azimuth 120° from the sun. Bright patches seen at the top and bottom of the halo of 22° at the points of contact of the tangent arcs are sometimes referred to as mock suns.

Passing Showers.—Described in Beaufort notation by the letter "p," passing showers are characteristic of the unstable conditions which obtain in "cold" air, i.e. air which is moving towards regions where temperature is higher. (See INSTABILITY SHOWERS, SHOWER.)

Pentad.—A period of five days. Five-day means are frequently used in meteorological work, as five days form an exact sub-division ($\frac{1}{73}$rd) of the ordinary year, an advantage not possessed by the week.

Percolation.—The downward passage of surface water through the soil. Part of the rain which falls on the land surface re-evaporates, part runs off into streams and rivers to the sea, while part percolates through the soil. Measurements of the amount of rain water which percolates through certain depths of soil have been published in the annual volumes of *British Rainfall.* Some of the gauges are described in *British Rainfall,* 1924, p. 128. Usually the gauge consists of a cubic yard of natural earth inserted in a metal container and sunk in the hole formed by removing this earth. The rain water which percolates through is drained off and measured daily at 9h., access to the receiver being obtained by means of a trap door at the side of the gauge. The results are usually published as a depth in hundredths or thousandths of an inch of water.

Periodical.—Recurring at regular intervals, like the position of the bob of a simple pendulum. The most obvious periodical variations in the atmosphere are associated with the alternation of night and day, and the alternation of winter and summer, corresponding respectively with the day and the year. Strictly speaking a variation is not to be called periodical unless the interval between successive maxima and successive minima is constant, and so the sunspot variation should not strictly be described as periodical, since the interval between successive maxima or minima varies from about 8 years to about 16 years.

Periodicity.—A periodical variation. A vast amount of labour has been devoted by meteorologists to the search for periodical variations other than those whose periods are the day or the year, by the use, at some stage or other of the work, of the methods of HARMONIC ANALYSIS. It is thus implied that a periodicity as normally treated, shall be at least approximately of the nature of a harmonic oscillation, capable of being represented by a simple sine curve. A periodicity requires for its complete determination the length of the period, the amplitude (i.e. half the total range) of the variation, and the time of occurrence of the maximum. If a periodicity is to be of value in forecasting, the square of its amplitude must be an appreciable fraction of the square of the STANDARD DEVIATION of the original observations.

Periodogram.—A diagram used in a method devised by Schuster for the investigation of hidden periodicities. In meteorological phenomena, the variations from day to day or from month to month are so irregular that usually the existence of any period other than the yearly one is masked. Schuster's method of finding the lengths and amplitudes of periods which are thus masked by apparently casual variations consists in taking different trial periods T, and evaluating the amplitude R for each trial period. A graph is drawn with R^2 as ordinate and T as abscissa. Usually the diagram thus obtained shows a number of peaks which stand out above the general level of the curve. The values of T corresponding with these peaks are taken to be the most likely periods. There is no special advantage in graphing R^2 and T rather than R and T, since the same peaks stand out in the graph of R and T. If the original n observations formed a random distribution, with standard deviation σ, the expectation (or mean value) of R^2 would be $\frac{4\sigma^2}{n-1}$. Schuster has shown that the probability that any particular value of R^2 should exceed κ times $\frac{4\sigma^2}{n-1}$ is $e^{-\kappa}$. This expression is frequently used to test the reality of periods revealed by the periodogram, but the process requires considerable care.

Persistence.—In meteorology, the tendency for abnormal conditions of the same type to continue over a longer period than usual ; thus we speak of a persistest anticyclone. E. V. Newnham* has shown that the tendency for the persistence of wet or fine weather increases with the length of the period through which similar conditions have already persisted. Thus at Greenwich after one day without rain, the probability that the next day will be rainless is ·57, but after ten successive fine days, the probability has risen to ·80. Similarly after one rain-day, the probability of a rain day is ·59, but after ten successive rain-days it is ·70.

Personal equation.—An expression used to denote the correction which might or should be applied to an observer's readings of an instrument, in consequence of an unconscious tendency on his part to read too high or too low. The tendency is usually nearly constant for any given observer reading a given instrument. A familiar example is that of reading the rain-measure. The observer is directed to hold the measure so that the meniscus is level with the eye, but it is difficult for an observer to judge when this condition is correctly secured. Some observers hold the glass always too high, resulting in readings which are too low, others possess the opposite tendency.

Phenology.—The study of the sequence of seasonal changes in nature. All natural phenomena are included, seed-time, harvest, flowering, ripening, migration, and so on, but often in practice the observations are limited to the times at which certain trees and flowering plants come into leaf and flower each year, and to the dates of the first and last appearances of birds and insects.

A phenological report is published each year by the Royal Meteorological Society, in which the phenological data contributed by observers stationed all over the British Isles are brought into relation with the weather of the year under review.

A " bioclimatic law " has been proposed by Dr. Andrew Hopkins, of the United States Weather Bureau. It was determined from phenological observations made in the eastern United States, and states that a progression or regression (according to season) of plant life occurs there, which is at the rate of four days for each degree in latitude or five degrees of longitude, or for 400 ft. of altitude. The law appears to hold approximately for the British Isles in so far as changes of latitude and altitude are concerned.

Phenomenon.—" That of which the mind or senses takes note." The word is generally used in meteorology, however, to denote either (1) an unusual intensity of some occurrence, e.g. " ugly " sky, high rainfall, low

* The persistence of wet and dry weather. *London, Q.J.R. Meteor. Soc.*, **42**, 1916, p. 153.

temperature, high pressure, gale ; or (2) occurrences which are only occasionally noted, e.g. thunder, halo, fog, glazed frost. The occasional nature of these occurences has no doubt been responsible for the fact that effective means of measuring them have not in some cases been developed.

Phosphorescence.—The phosphorescence of the sea is one of the most remarkable of natural phenomena and various explanations of it have been attempted in the past. One theory held that sea water absorbed sunlight by day and emitted it by night. In 1749–50, however, a small animalcule giving a blue light was discovered by Vianuelli and Guixellani in the Mediterranean and subsequent investigation has shown that animal life is the origin of marine phosphorescence. Light production is due to a great variety of organisms, from microscopic ones up to many forms of deep sea fish, and the peculiarity of the light is that it is generated without heat, a process never yet achieved in the laboratory. Different types of light have been analysed and the colour is also found to vary through white, silver, green blue and lilac to red. The method of production has been shown to be some form of slow oxidisation which is entirely automatic in the lower forms of life but is in some measure under control in the higher forms. Recent research has shown that while phosphorescence may occur anywhere it is most frequent in the warmer tropical seas and in particular in the Arabian Sea, where it exhibits a definite maximum in August. In the North Atlantic ocean some regions show summer maxima, while others have spring maxima. It also appears that phosphorescence is more frequent in coastal regions than in mid-ocean. One remarkable type of phosphorescence is the diffused " milky sea " which may give light enough to read by and to illuminate clouds. This type has often been reported as exerting a calming effect upon the sea surface. More elaborate phenomena occur which have not yet been satisfactorily explained, such as phosphorescent bands and the great rotating phosphorescent wheels.

Photographs, Meteorological.—Whenever unusual meteorological phenomena occur an attempt should be made to photograph them, if possible. Notes accompanying photographs should give the date, time and geographical position of the occurrence of the phenomenon, and the weather conditions prevailing at the time and the relative sizes of the photograph and the original or the focal length of the lens.

For photographing clouds Cave* finds that panchromatic plates and colour screens give the most satisfactory results ; he advises a moderately deep yellow screen for all clouds except cirrus, and for cirrus a red screen. For persons unfamiliar with panchromatic plates and colour screens Clarke† recommends very slow plates and hydroquinone developer.

Pilot Balloon.—A small free rubber balloon, filled with hydrogen or other light gas, for obtaining the direction and velocity of the upper wind. The balloons commonly employed are known as 48, 70 or 90 in., these being the circumferences when fully inflated. They are normally filled with hydrogen to have a known theoretical rate of ascent, based upon the following formula :—

$$V = q \cdot L^{\frac{1}{2}}/(L + W)^{\frac{1}{3}}$$

where V is the upward velocity, W is the weight of the balloon (and any attachment), and L is the free lift. If L and W are expressed in grammes and V in feet per minute, q is about 275. If V is in metres per minute the value of q is 84 (83·8). Assuming a known rate of ascent, the balloon may be observed, for horizontal and vertical motion, by means of a single theodolite, and the direction and velocity of the wind in the different layers computed, using either graphical methods, or the pilot-balloon slide rule. In the case of high altitudes, however, errors may occur owing to the balloon developing minute holes and becoming porous, so that it ceases to rise at the assumed rate, or perhaps commences to fall.

* The forms of clouds. *Q.J.R. Meteor. Soc.*, **43**, 1917, pp. 61–82.
† Instructions for the taking of photographs of clouds. Paris, Commission Internationale des Nuages et Office National Météorologique de France.

A more accurate method, without this liability to error, is the use of two theodolites and a measured base line, thus making it possible to calculate the actual height of the balloon, in addition to the other factors. This method naturally demands the attendance of several observers. A third method is to attach a tail of known length to the balloon, and measure the angle between the end of the tail and the centre of the balloon, by means of a graticule or divided scale in the eye-piece of the theodolite. This method is useful, but occasionally a swinging tail is apt to lead to incorrect values. For use at night an ordinary balloon is employed with a small paper candle lantern attached.

Pitot Tube.—An instrument for determining the velocity of a stream of fluid by measuring the increase of pressure above the "static" or undisturbed pressure, in an open tube facing the stream. The velocity is computed from the relationship $p = \frac{1}{2} \rho v^2$ (where p is pressure, ρ density and v velocity). Suitably mounted, a pitot tube may be used as an ANEMOMETER.

Pleion.—A term introduced by H. Arctowski to signify an area over which some meteorological element, for example temperature, is above normal. Areas where the element are below normal are termed anti-pleions. Arctowski drew his pleions by constructing overlapping twelve-monthly departures from average, and he found a tendency for the pleions and anti-pleions obtained in this way to persist for a considerable time, moving slowly across the country.

Pluviograph.—A self-recording RAIN-GAUGE; the rise of the water in the gauge is recorded by means of a pen attached to a float. Some form of device by which the gauge automatically empties itself when the water reaches a certain height is often employed.

Pluviometer.—A RAIN-GAUGE.

Pocky Clouds.—See MAMMATO-CUMULUS.

Polar Air.—Air originating in Arctic regions. It is usually cold and dry, and has a bracing feeling, but if it crosses a long stretch of warm sea it becomes rather mild and damp near sea level and is then known as "maritime polar air." As a rule polar air is cold up above, but it frequently subsides and is warmed by ADIABATIC compression and thus loses some of its polar characteristics. The term is sometimes used rather loosely to denote relatively cold air. (See DEPRESSION, FRONT, INSTABILITY SHOWERS, SUBSIDENCE.)

Polar Current.—A current of air from polar regions. The majority of well marked polar currents which pass over the British Isles come down between high pressure over Greenland or Iceland and low pressure over Scandinavia. They may also leave the polar basin between Greenland and Newfoundland and cross the Atlantic, or come down over Russia and the Baltic and arrive from the east round anticyclones. Frequently polar currents sweep round a depression and arrive from south-west or even south, about three to five days after leaving high latitudes.

Polar Front.—The line of discontinuity, which is developed in suitable conditions between air originating in polar regions and air from low latitudes, on which the majority of the DEPRESSIONS of temperate latitudes develop. It can sometimes be traced as a continuous wavy line thousands of miles in length, but it is interrupted when polar air breaks through to feed the trade winds, and is often replaced by a very complex series of FRONTS, or by continuous gradients of temperature.

Polarization.—If we make waves in a long rope by shaking one end we can contrive for the motion to be in a vertical plane or in a horizontal plane, or again the motion may be irregular but with a preponderance of vertical movement. Light waves have similar properties, which can be detected by suitable instruments called analysers. In so far as light waves, like wireless waves, are electric, a wave in which the electric force and the direction of propagation are in one plane is said to be polarized perpendicular to that plane. When there is merely a preponderance of electric force in one direction the light is said to be partially polarized.

Light reflected from the surface of water or glass is partially polarized, the polarization being in the plane containing the incident and reflected rays. Light coming from the blue sky is also polarized. This discovery was made by Arago in 1809. More precisely, sky light is in general a mixture of ordinary and plane polarized light. The maximum proportion (usually about two-thirds) of polarized light comes from a region in the solar vertical and about 90° from the sun. Light from this point or region is polarized in the plane containing the sun, the observed point and the observer; or, in terms of the electromagnetic theory, the electric vector in the wave front is at right angles to this plane. In or near to the solar vertical are three neutral points, or small regions, the light from which is unpolarized. They are named after Arago, Babinet, and Brewster, and their approximate positions are respectively, 160° from the sun (i.e. 20° above the anti-solar point), 20° above and 20° below the sun. So-called neutral lines pass through points in which the plane of polarization is inclined at 45° to the vertical and also through the neutral points mentioned. When the sun's altitude exceeds 20° the plane of polarization of light received from regions (excluding the vicinity of neutral points) not within 30° of the sun does not usually differ greatly from the plane containing the sun, observer, and observed point. The degree of polarization and the position of the neutral points depend on the sun's altitude, on the wave length of the light examined, on the degree of turbidity of the atmosphere, and, in consequence of the last factor, on the weather conditions. Factors promoting an increase of the amount of light reflected through the atmosphere (e.g. a layer of snow on the ground) tend to decrease the percentage of polarization. Light from the clear sky at night is only very feebly polarized.

The phenomena of polarization of sky light are to be attributed to the scattering or diffraction of light. It was demonstrated theoretically by Rayleigh (third Baron) that the light scattered, by air molecules or other particles small in comparison with the wave length of light, in a direction perpendicular to the sun's rays should be completely polarized in a plane containing the incident and scattered rays; polarization should be less complete in other directions and non-existent in either direction along the incident rays. Rayleigh (fourth Baron) and others have shown experimentally that polarized light is scattered from a beam of ordinary light traversing dust-free air; polarization is in the sense indicated by theory and is a maximum, about 96 per cent in a direction perpendicular to the primary beam. Although the plane of polarization of the sky light received perpendicularly to the sun's rays is in accordance with experiment and the theory of primary scattering, the degree of polarization is much less complete. Moreover, the occurrence of neutral points and other phenomena remains unaccounted for. A point of the sky is illuminated not only by the sun but also by light from other parts of the sky. According to Soret, Ahlgrimm, and others the light due to secondary scattering or diffraction by the air molecules and small suspended particles is partly unpolarized and partly polarized in the horizontal plane, i.e., perpendicularly to the polarization due to primary scattering. This theory, which is not universally accepted, indicates why there is incomplete polarization even in the skylight received perpendicularly to the sun's rays; and also that the two polarization effects cancel to produce unpolarized light at certain points, the neutral points, on the sun's vertical.

Pole.—The geographical poles lie at the extremities of the axis of rotation of the earth. The magnetic poles are at some considerable distance from the geographical poles. (See TERRESTRIAL MAGNETISM.)

Pollution.—See ATMOSPHERIC POLLUTION.

Polymeter (Lambrecht's).—An instrument combining a thermometer and a direct reading hair hygrometer. The hairs, which hang vertically, operate a pointer which indicates directly the relative humidity and the depression of the dew-point below the air temperature. The thermometer gives the air temperature and the dew-point can thus be readily ascertained from the readings of the two instruments.

Ponente.—A westerly wind which blows in the Mediterranean.

Poorga (Purga).—See BURAN.

Potential as applied to energy indicates the ENERGY which is due to the position of a body. In considering the total amount of energy available, in any case we must consider not only the position but the quantity of working substance that is collected there. If we wish to consider the influence of the position alone we must limit our ideas to a particular amount of the working substance. We naturally choose the unit measure as the amount for this purpose, and the potential energy of unit quantity is called the *potential at the point.* Thus, the electrical potential at any point in the atmosphere is the amount of energy which one unit of electricity possesses in virtue of its position at the point. Similarly, the gravitational potential or GEOPOTENTIAL at any point above the earth's surface is the potential energy of a unit quantity of material, a gram or a pound, placed there.

Potential Temperature.—The temperature which a specimen of air would acquire if it were brought to standard pressure under ADIABATIC conditions. If the absolute temperature and the pressure of the air be T and p respectively and the standard pressure be P, the potential temperature θ is given by the relation

$$\theta = T\left(\frac{P}{p}\right)^{0\cdot 29}$$

Potential temperature is related to the entropy ϕ by the relation—

$$\phi = c_p \log \theta + \text{constant}$$

where c_p is the specific heat at constant pressure.

Precipitation.—A term borrowed from chemistry to denote any one of the results of the conversion of the invisible water vapour to visible water or ice, thus comprising not only rain, hail, snow, sleet, dew, hoar-frost and rime, but cloud, mist and fog. In practice, however, the use of the word is limited to appreciable deposit in either the solid or the liquid form at the earth's surface, the definition of "Day of precipitation" being identical with that of RAIN DAY (*q.v.*). At low levels it is rare for appreciable deposit of water in the rain-gauge to result from precipitation of cloud, mist or fog, but in mountainous districts wet fog and SCOTCH MIST (*q.v.*) are responsible for a considerable quantity of "rainfall." (See RAIN, HAIL, SNOW, etc.)

Pressure.—Pressure is the force per unit area exerted against a surface by the liquid or gas in contact with it and since the force on a unit area of a surface at any particular point in a fluid is independent of the orientation of the unit surface in the fluid, it follows that no specification of direction is necessary in speaking of the pressure at any given point in the fluid. The pressure of the atmosphere which is measured by the barometer, is produced by the weight of the overlying air. The pressure exerted by the wind is very small in comparison with that of the atmosphere; a wind of force 6 on the BEAUFORT SCALE exerts approximately one thousandth part of the pressure of the atmosphere. (See ATMOSPHERIC PRESSURE, MILLIBAR.)

Probability.—If in a large number N of trials, an event occurs n times and fails to occur $N - n$ times, the fraction n/N is called the probability of occurrence of the event. If a coin is tossed, the ratio of heads to the number of trials will approach more and more closely to $\frac{1}{2}$ as the number of trials is increased. Strictly speaking, probability can only be discussed in dealing with a large number of trials. If a coin is tossed 6 times, we cannot assume that the result will be 3 heads and 3 tails, though if we were so placed that we had to adopt some definite figure, we should assume

3 heads and 3 tails as the likeliest distribution. If the probability of occurrence of an event is 1/10, then we could not say that the event should occur 10 times in 100 trials, nor even that it should occur 1,000 times in 10,000 trials, though the figure 1,000 could be accepted as being relatively more reliable than the figure 10 in the first case.

In some cases we can resolve a complex event into a number of simpler events, and it is important in that case to know how to evaluate the probability of the complex event from the separate probabilities of the simpler events. Let the complex case be the simultaneous occurrence of two events A and B, the probability of occurrence of A being a and the probability of occurrence of B being b. Then the probability of the occurrence of both A and B is ab, if, *and only if*, the events A and B are absolutely independent. Unless the events are independent, this simple rule of multiplication of probabilities is invalid. But provided the events are all independent, the rule can be extended to any number of events.

In practice the procedure outlined in the first paragraph has frequently to be inverted. If the probability of an event is p, then in N trials, the event should occur Np times, provided N is large. But in practical questions it is seldom possible to make N indefinitely large, and we have to be satisfied to take the ratio of the frequency of occurrence of the event (Np), to the number of trials N, as the probability, when N is not indefinitely large.

If the probability of the occurrence of an event is p, the probability of its non-occurrence is $1 - p$. In a large number of trials, say N, the event will occur Np times on the average, but for any series of N trials the actual number of occurrences may differ from Np. It is useful to have some guidance as to the extent of the variability to be expected in the result. The PROBABLE ERROR of the result Np is $\cdot 6745\sqrt{Np\,(1 - p)}$ or $\frac{2}{3}\sqrt{Np\,(1 - p)}$ with sufficient accuracy. An example may help to make clear the utility of this relation. The ratio of the number of male children born to the number of female children born is said to be 1·05 : 1. If in a particular community 51,400 out of 100,000 children born were male, could we deduce from this any abnormality in the community? The expected number of male children is $100{,}000 \times \frac{1\cdot 05}{2\cdot 05}$ or 51,220. The probable error is $\cdot 6745\sqrt{\frac{100{,}000 \times 1\cdot 05 \times \cdot 95}{(2\cdot 05)^2}}$ or 104. The deviation from the expected result is 180, and is therefore less than twice the probable error. If, on the other hand, the number had been 51,800 males out of 100,000 births, the deviation would have been about six times the probable error, and we should be justified in regarding this as greater than would be produced by chance, and therefore as indicating some abnormality in the community concerned.

Another example, though admittedly an artificial one, is the following. A coin is tossed 1,000 times, yielding 470 heads and 530 tails. Is the deviation from the expected equality of the number of heads and tails sufficient to indicate that the coin is not truly made? The probable error of the number of heads (500) is $\cdot 6745\sqrt{1{,}000 \times \frac{1}{2} \times \frac{1}{2}}$ or about 10. The deviation is about three times the probable error, and though this is not very likely to occur by chance, we can draw no definite conclusion. But if the coin were tossed 10,000 times, giving 4,700 heads and 5,300 tails, the probable error would be about 34, and the deviation would be more than nine times the probable error, and this is so very unlikely to occur by chance that we could safely infer some defect in the coin.

A common way of expressing probability is to state it in the form of "odds against" or "odds on" the occurrence of the event. If the probability of an event is 1/10, the event fails nine times for each time it succeeds, and this may be expressed by saying that the odds are 9 to 1 against the event. (See also NORMAL LAW.)

Probable Error.—A quantity, usually denoted by r, such that the error of a single observation is as likely to be within as without the limits $\pm r$. In other words there is an even chance that the error of a single observation shall not exceed r. The probable error therefore gives a measure of the closeness with which the observations are clustered about their mean value. If $x_1, x_2, \ldots x_n$ are n observations whose mean value is $\bar{x}$, the probable error r is given by

$$r = 0{\cdot}6745\sqrt{\frac{\Sigma (x - \bar{x})^2}{n - 1}}$$

It is usually sufficiently accurate to replace $n - 1$ by n in the denominator. If the observations are distributed in accordance with the NORMAL LAW OF ERRORS the probability of the occurrence of an error as great as $2r$ is ·177, of an error as great as $3r$, ·043, of an error as great as $4r$, ·007, of an error as great as $5r$, ·001, and of an error as great as $6r$ is about ·00005.

Prognostics.—See WEATHER MAXIM.

Projection.—This term is used in connexion with maps in a sense wider than that of geometrical perspective. It denotes any relationship establishing a correspondence between a domain of the earth's surface and a domain of a plane surface, the map, such that to each point of one corresponds one and only one point of the other. The projection is completely represented by constructing, on the plane surface, a graticule formed by two intersecting systems of lines, corresponding respectively to parallels of latitude and meridians of longitude on the earth. The position on the map of any features on the earth's surface is then determined by reference to this graticule.

The scale of the map is the ratio of the distance between two neighbouring points on the map to the corresponding distance on the earth. A perfect map in which the scale is uniform throughout is not possible. A class of projections termed " orthomorphic " or " conformal " have the property that, at any point, the scale in all directions is the same, though varying from point to point. This is equivalent to the property that the angle of intersection of any two lines on the earth (such as an isobar and a meridian) is preserved unchanged on the map, or the shape of any small area is preserved. Orthomorphic projections are not much used generally, but owing to the above properties, they enter into meteorological practice as base maps for the representation of meteorological elements. They are recommended for this purpose by a resolution of the International Meteorological Committee, London, 1921, which adds the conditions that the meridians should be represented by straight lines and that the variations of scale over the region represented should be as small as possible, having regard to the extent of the region represented.

The " conical orthomorphic projection with two standard parallels " is very suitable, especially for middle latitudes, and is used for the majority of the working charts of the Meteorological Office. The meridians are straight lines converging to the pole and the parallels of latitude are circles centred at the pole. The scale is correct at all points along two chosen parallels and any two meridians converge at an angle which is a fraction of the angle between them on the earth, the fraction depending solely on the choice of standard parallels. The spacing of the other parallels is then uniquely determinate to secure the orthomorphic property. The scale is somewhat too low between the standard parallels and increases rather rapidly outside them.

A special case of the conical orthomorphic projection arises when the meridians converge at their true angle. This is the " zenithal orthomorphic projection " in which the scale is correct on any one chosen parallel. It is suitable for the polar regions.

Another special case is that in which the angle between the meridians is zero. The meridians are equally spaced parallel straight lines and the parallels of latitude are straight lines at right angles to the meridians and spaced so as to secure the orthomorphic property. This is the " cylindrical orthomorphic or Mercator's projection " and is most suitable for the equatorial zone.

Conical and zenithal projections can be made with other than orthomorphic properties, by suitably altering the spacing of the parallels. Preservation of areas may be secured or a compromise between the equal area and orthomorphic properties.

The latter is the case in Clarke's zenithal projection used in the Meteorological Office for weather charts of the northern hemisphere.

There are, in addition, many other projections, each to serve a special purpose. Of these " Mollweide's Equal-Area Projection " is often useful when a world map is required. The whole globe is represented within an ellipse whose major axis is twice the minor axis.

(For further information see " Map Projections," by A. R. Hinks, Camb. Univ. Press. The mathematical properties of orthomorphic projections are to be found under " conformal representation " in books on the theory of functions of a complex variable.)

Psychrometer.—An alternative name for the dry- and wet-bulb hygrometer. Two similar thermometers are employed, one, the " dry " bulb, reading the air temperature, while the other, the " wet " bulb, whose bulb is covered with muslin wetted with pure water, gives the " temperature of evaporation." For a given value of the temperature, the wet bulb reads lower than the dry bulb by an amount depending on the relative humidity and the rate of flow of air over the bulbs. Tables have been compiled for the purpose of ascertaining the relative humidity, dew-point, etc., from the readings of the two thermometers under various conditions.

In the Assmann psychrometer, a definite rate of ventilation is secured by drawing the air over the bulbs by the agency of a fan driven by clockwork. The thermometers are mounted in a plated metal frame designed to secure immunity from errors due to solar radiation. In the sling or " whirling " psychrometer (see SLING THERMOMETER), a similar degree of ventilation is secured by whirling the thermometers which are mounted in a frame resembling a " policeman's rattle." For use on aircraft psychrometers have been designed to utilise the motion of the aeroplane itself for ventilation purposes.

Pumping.—Unsteadiness of the mercury in the barometer caused by fluctuations of the air pressure produced by a gusty wind, or due to the oscillation of a ship.

Purple Light.—Shortly after the sun has set below the western horizon a brighter patch appears on the darkening sky about 25° directly above the position where the sun has disappeared. This patch appears brighter as the sky darkens and takes on a purple tone. The patch expands into a disc and when the sun is about 4° below the horizon it reaches its maximum brilliancy, when it may be so bright that white buildings in the east which are lit up by it, glow with a purple colour which corresponds to the afterglow seen on the peaks of snow-covered mountains. The disc of purple light sinks downwards at twice the rate at which the sun sinks while at the same time its radius expands and its light becomes less intense. It finally sets behind the bright segment of the twilight arch. Occasionally when the first purple light has passed below the horizon, the phenomenon repeats itself with less intensity. The second patch of light appears at a slightly less altitude than the first but otherwise follows the same course.

Pyranometer.—See PYRHELIOMETER.

Pyrgeometer.—See PYRHELIOMETER.

Pyrheliometer.—An instrument for measuring the rate at which radiant heat is received from the sun. In Ångström's form the rate of absorption of heat by a thin strip of blackened platinum, when exposed normally to the sun's rays, is ascertained by measuring the electric current necessary to heat a similar strip to the same temperature. The rate of generation of heat in the strip in the electrical circuit is then equal to the rate of absorption of heat by the strip exposed to the sun. In Abbot's "silver disc" pyrheliometer, the rise of temperature in a silvered disc exposed to the sun's rays is measured directly and the intensity of the radiation is determined therefrom by reference to the calibration data of the instrument. The **Pyranometer,** devised by Abbot and Aldrich, measures outgoing radiation (nocturnal radiation) as well as sky radiation. The nocturnal radiation can also be measured by Ångström's **Pyrgeometer**, in which use is made of the lower radiation from a gilded than from a blackened strip of manganin.

Quasi.—Literally—as if; a prefix which when attached to a noun (or adjective) means seeming(ly) not real(ly), practical(ly), almost. For example, certain phenomena which recur more or less regularly but without the exactness of truly periodic phenomena are termed quasi-periodic.

Radiation.—*Units.*—The intensity of radiation is measured by the energy which crosses a certain area in a given time. In physics the unit adopted is generally one erg per cm.² per second. For meteorological purposes a larger unit is required and one milliwatt per cm.² is found appropriate. The relation between these units is simple. Moreover the latter unit can be brought into relation with the engineers' unit of power, the kilowatt, by adopting the square decametre as unit of area. In most meteorological work the energy is expressed in terms of the gram-calorie (see CALORIE), the energy required to raise the temperature of a gram of water by one degree centigrade. Theoretically this is not a good unit as it can only be made definite by specifying the actual range of temperature. The capacity for heat of water varies from 4·219 joules per gram per degree at 0°C. to 4·173 at 35°C. In meteorology the 15° calorie and the 20° calorie have both been used. The equivalents are 4·184 joules and 4·180 joules respectively. Fortunately the difference is of little practical importance. The relations between the units of radiation are

$$1\,\frac{\text{mw.}}{\text{cm.}^2} = 1\,\frac{\text{Kw.}}{\text{dm.}^2} = 10^4\,\frac{\text{ergs}}{\text{cm.}^2\,\text{sec.}}$$

$$1\,\frac{\text{gm. cal.}}{\text{cm.}^2\,\text{min.}} = 69{\cdot}7\,\frac{\text{mw.}}{\text{cm.}^2}$$

$$1\,\frac{\text{gm. cal.}}{\text{cm.}^2\,\text{day}} = \frac{1}{1440}\,\frac{\text{gm. cal.}}{\text{cm.}^2\,\text{min.}} = {\cdot}0484\,\frac{\text{mw.}}{\text{cm.}^2}$$

These units are suitable for the measurement of the total radiation received by a surface from the sun or from the whole sky. For the measurement of the radiation from a part of the sky W. H. Dines adopted the convenient practice of giving the radiation which would be received on a flat surface from the whole sky if the intensity were uniform. When the intensity is uniform, the radiation per unit of solid angle is equal to $\frac{2}{\pi}\times$ (the radiation received on a flat surface).

Black-body radiation.—The colours attributed to solid objects depend on their appearance when daylight falls on them. A white surface scatters a large proportion of the daylight: a dull black surface absorbs the daylight. Little light is absorbed by a bright metallic surface.

According to the theory of exchanges all solids give out radiant heat. When a solid is hotter than its surroundings it gives out more heat than it absorbs. The radiation from a burnished metal is much less than that from a dull surface at the same temperature and experiment indicates that at moderate temperatures the strongest radiation is given out by a black surface.

When solids are heated so that they become red hot or even white hot there are still differences between the amounts of radiation which they emit. In general the solid which is black at ordinary temperatures continues to give out most radiation at higher temperatures. Experiment suggests that there is an upper limit to the radiation which can be emitted by a surface of specified area at any given temperature. The ideal substance which would at every temperature emit the greatest possible amount of radiant energy is known as a "perfect radiator" or "perfectly black" substance.

It has been demonstrated that the radiation which passes out through the narrow mouth of a cavity in a solid at uniform temperature is equivalent to that from a perfect radiator at that temperature. The radiant energy emitted by an element dS of the surface of a perfect radiator is given by a simple formula, found empirically by Stefan and afterwards demonstrated theoretically by Boltzmann. The formula is

$$\text{total radiation} = \sigma\ T^4\ dS$$

T being the absolute temperature and σ a constant. If T is measured in centigrade degrees from $-273 \cdot 1$°C. the value of σ is

$$5 \cdot 709 \times 10^{-5} \text{ ergs per cm.}^2 \text{ per second.}$$

This is equivalent to $5 \cdot 709 \times 10^{-12}$ watts per cm.^{2} and to 82×10^{-12} gram-calories per cm.^{2} per minute. The same formula serves to give the flux of radiation passing directly or obliquely across an area dS parallel to the radiating surface and a small distance from it.

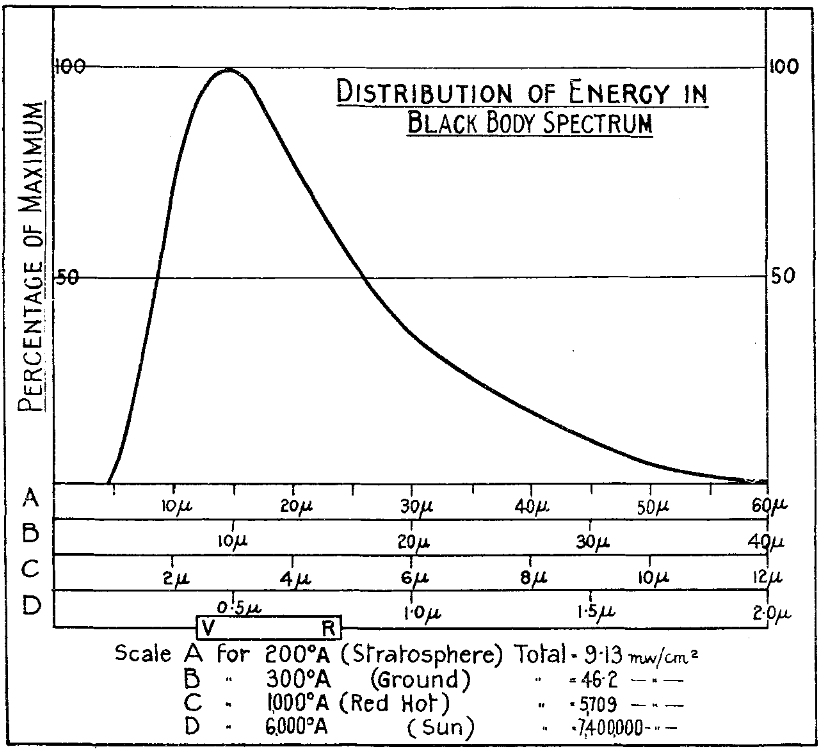

FIG. 22.

The distribution of energy in the spectrum.—The familiar fact that a piece of metal changes colour as it is heated in a furnace is an indication that the distribution of radiant energy in the spectrum is changing. *Wien's displacement law* tells us that the graph shewing the relation of energy to wave-length for a perfect radiator at one temperature will serve to give the relation at any other temperature. The wave-length scale has to be changed in the inverse ratio of the temperatures, whilst the energy scale is changed by the fifth power of this inverse ratio.

Planck's radiation formula.—The laws of Stefan and Wien can be deduced from the classical laws of thermodynamics. The actual distribution of energy in the black-body spectrum can not be deduced from these laws. The specification of this distribution was given by Planck. In doing so he made one of the most important and difficult steps in the advance of science, by propounding the "Quantum Theory."

Planck's distribution law is illustrated in Fig. 22 for a black body at 6,000°A. The distribution of energy is comparable with that in solar radiation. The visible spectrum occupies the range from $0\cdot4\mu$ (violet) to $0\cdot7\mu$ (red) or in Ångstrom units from 4,000Å to 7,000Å.

Radiation and the atmosphere.—The principal gases of the atmosphere, oxygen and nitrogen, are transparent to nearly all the radiation of the solar spectrum and also to the long-wave radiation such as is given out by a body at the temperature of the ground. Carbon-dioxide absorbs long-wave radiation with wave-length in the neighbourhood of 15μ. The most important absorbent in the atmosphere is however water vapour. The water vapour absorbs some of the solar radiation in the visible spectrum (so giving rise to "rain-bands" in the spectroscope) and much of the infra-red radiation. Most long-wave radiation is absorbed by water vapour but there is a short range of wave-lengths between 8μ and 12μ for which the vapour is transparent.

Since gases emit and absorb radiation of the same wave-lengths, the radiation which is returned by the atmosphere to the ground comes mostly from the water vapour and it is found by observation that the strength of the radiation from the sky after dark depends on the amount of water vapour present as well as on its temperature.

Thus the absorbing power of water vapour plays an important part in the meteorology of the lower atmosphere. It is believed to be equally important in the meteorology of the upper atmosphere as it is mostly through the absorption of long-wave radiation that the temperature of the stratosphere is maintained.

The part played by water in the form of clouds in regulating the temperature of the globe has not been fully realized until recently. Clouds have a high reflecting power and it is estimated that the light reflected from the clouds together with light reflected from the sea and from the air accounts for half of the radiation received by the planet from the sun. This half passes out into space as short-wave radiation. The other half is absorbed by the planet; the equivalent energy passes out again eventually as long-wave radiation. The value of this fraction depends on the average amount of cloud over the globe. Simpson* has pointed out that an increase in radiation from the sun would lead to an increase in the amount of cloud and therefore to an increase in the proportion of light and heat reflected. There is almost an automatic control of the temperature of the globe. It is instructive to notice that Venus, which is nearer to the sun than is the earth, is continually mantled in clouds whilst Mars, which is further away, is devoid of cloud. Only the earth enjoys such conditions that the cloud-thermostat can be effective.

Terrestrial radiation.—The cooling of the ground at night is mainly due to the excess of the outward radiation above the radiation which comes down from the sky. The radiation from the ground is practically the same as would be given out by a perfect radiator at the same temperature See *Black-body radiation*. It is convenient to regard it as divided into three parts: (*a*) radiation in wave-lengths between $5\cdot5\mu$ and 7μ and all radiation of longer wave-length than 14μ. To radiation of this sort water vapour is opaque. (*b*) radiation in wave-lengths between $8\frac{1}{2}\mu$ and 11μ. To such radiation water vapour is transparent. (*c*) radiation in intermediate wave-lengths. To this water vapour is semi-transparent.

The radiation of the (*a*) type is caught quite close to the ground. There is always enough water vapour to send back a full measure of this radiation so that the inward and outward flows of radiant energy balance. The

* "Further studies in terrestrial radiation." *London, Mem. R. Meteor. Soc.* **3**. No. 21, 1928.

radiation of the (*b*) type passes (if the air is clear and there are no clouds) right through the atmosphere to outer space. There is no compensating inward radiation. The proportion of (*c*) radiation absorbed by the atmosphere depends on the quantity of water vapour in the atmosphere and the strength of the return radiation is affected in the same way.

According to the observations made by A. Ångström in Algeria and California the ratio of the incoming radiation from the sky to that emitted by a black body at air temperature varies between 62 per cent for a vapour pressure of 4 millibars and 74 per cent for a vapour pressure of 16 millibars.

If the ground were at the same temperature as the air and the vapour pressure 10 millibars the resultant outward flow from the ground would be 32 per cent of black-body radiation. Actually the ground is cooled below air temperature and there is a corresponding reduction in the radiation given out. Thus with the ground 5° C. below air temperature the radiation emitted from the ground is reduced to about 93 per cent of that of a black body at air temperature and the resultant outflow of radiation is reduced from 32 per cent to 25 per cent.

The conditions favourable for cooling of the ground at night are:—

(1) A cloudless sky. When the sky is covered with clouds at moderate heights the radiation from the clouds in types (*b*) and (*c*) is almost equivalent to the radiation of the same types from the ground.

(2) Dry air—so that the return radiation of type (*c*) may be slight.

(3) Absence of wind. The effect of wind is to bring more air into contact with the ground. The air gives heat to the ground and so prevents it from cooling so much. On the other hand the cooling of the lowest layers of the air produces stratification and reduces turbulence so that the wind can continue at considerable heights and glide over the quiet air near the ground. Thus it is equally true that the air is calm because the ground is cold and that the ground is cold because the air is calm.

(4) Low conductivity of the ground. The heat conducted from below tends to keep up the temperature of the surface In this connection it may be noticed that snow being a bad conductor the surface of snow can attain very low temperatures.

The most conspicuous signs of effective terrestrial radiation are the deposit of DEW and HOAR-FROST.

Terrestrial-radiation thermometer.—The "grass minimum thermometer" is sometimes referred to as a "terrestrial-radiation thermometer." Low readings of such a thermometer are a sign that terrestrial radiation has been effective but there is no rule for deriving from the thermometer readings a numerical estimate of the strength of the radiation. The thermometer is placed above the grass so that its temperature is not affected by conduction from the ground. It is to be expected that the thermometer will be a little cooler than the grass blades near by.

Ultra-violet radiation.—When a spectrum is photographed it is found that the limits of the photograph are by no means the same as the visible limits of the spectrum. Probably the red end of the spectrum is cut off in the photograph. On the other hand the photograph extends considerably beyond the violet. The photographic paper is said to have been affected by ultra-violet radiation. The prolongation of the solar spectrum beyond the violet was first noticed by Sir John Herschel in throwing the spectrum on turmeric paper. The prolongation was yellow. Herschel's experiment was an example of how certain substances become "fluorescent" when illuminated by ultra-violet light.

The wave lengths of ultra-violet light are shorter than those of visible light, the limit of which is about $0{\cdot}4\mu$. On the other hand there is no ultra-violet of very short wave length in the light which reaches us from the sun. The solar spectrum is cut off at about $0{\cdot}3\mu$. It is believed that the ultra-violet of shorter wave-length is absorbed by ozone some 30 kilometres or more above the ground.

One of the effects of ultra-violet light is the ionization of gases. It is probable that the high electrical conductivity of the "Heaviside layer" in the upper atmosphere is produced in part by ultra-violet light from the sun.

Rain.—Produced by the condensation of the aqueous vapour in the atmosphere. A definite volume of air is capable of holding a certain definite amount of water in the form of vapour; the amount depends only upon the temperature, being large when the temperature is high, and small when it is low. When the temperature of a mass of air containing water vapour falls sufficiently, a point is reached where the vapour is condensed into fine particles of water, and a cloud is formed. As the cooling continues more water is condensed to form larger drops which fall as rain.

Rain has been classified according to the manner in which the cooling is brought about. The types are OROGRAPHIC, CYCLONIC and CONVECTIONAL and these are discussed under their separate headings. While orographic and cyclonic rains are often very persistent and widespread, convectional rains are typically intense and of short duration. Both orographic and cyclonic rains are rather more frequent in winter, while convectional rains are more common in summer.

The *average annual rainfall* at any station is the mean annual fall over a long period, often of 35 years. The monthly and annual averages at some 570 stations are set out in Section V of the "Book of Normals of Meteorological Elements for the British Isles." Over the British Isles the average annual rainfall varies from 20 in. along the Thames Estuary to over 150 in. in the English Lake District, Snowdonia and parts of the Western Highlands of Scotland. Maps showing the average distribution in the year and the individual months have been included in the "Rainfall Atlas of the British Isles," published by the Royal Meteorological Society in 1926. The general rainfall for each month of the year of the larger divisions and of the British Isles is set out below.

Average Monthly Rainfall, 1881–1915

	England	Wales	England and Wales	Scotland	Ireland	British Isles
	in.	in.	in.	in.	in.	in.
January	2·69	4·72	2·99	4·90	4·07	3·78
February	2·34	3·94	2·57	4·18	3·53	3·26
March	2·47	3·82	2·67	4·05	3·36	3·22
April	1·98	2·96	2·12	2·99	2·75	2·52
May	2·19	2·95	2·30	3·01	2·75	2·61
June	2·33	3·05	2·44	2·83	2·82	2·64
July	2·75	3·60	2·87	3·78	3·37	3·25
August	3·11	4·71	3·35	4·51	4·20	3·88
September	2·37	3·51	2·54	4·00	3·13	3·09
October	3·69	5·63	3·97	4·90	4·08	4·25
November	3·19	5·25	3·49	5·29	4·28	4·19
December	3·56	6·00	3·92	5·88	4·96	4·72
Year	32·67	50·14	35·23	50·32	43·30	41·41

It will be noticed that over the British Isles as a whole December is the wettest month and April the driest. The three months October, November and December receive nearly twice as much rain on the average as the three months April, May and June. There is also a subsidiary maximum in August, making that month the fourth wettest of the year. The seasonal distribution in the various divisions of the British Isles is very similar. In July and August the rainfall is actually greater in the east of England than many earlier months of the year, and in some places those months are the rainiest in the year on account of the frequency of summer thunderstorms. Over the east and south of England generally the rainiest month is October, while for the west and north of Great Britain it is December or January.

Extremes of rainfall can be conveniently considered for the various units of time, e.g. the year, month, day and even for shorter periods. In the case of the month and year, the distribution of the extreme values is largely controlled by the configuration of the land, while for shorter periods the largest values on record occur in the drier regions of central and eastern England, where convectional rains are more common. (*a*) The wettest *year* over the British Isles as a whole was 1872, and the driest year 1887. The wettest and driest years on record have not been the same, however, in all parts of the British Isles, and maps showing the wettest and driest years in all parts of the country have been published (see *Q. J. R.Meteor. Soc.*, **52**, 1926, pp. 237–248). Annual totals exceeding 240 in. were recorded at The Stye, at the head of Borrowdale in Cumberland, in 1872 and 1923, at Ben Nevis Observatory, in Inverness, in 1898, and at Llyn Llydaw on Snowdon in 1909. The rainfall in 1921 in the south-east of England was by far the smallest on record, as little as 10 in. being recorded at Margate. (*b*) The wettest *month* over the British Isles as a whole was December, 1876, and the driest months March 1929, June 1925, and February 1891. The largest actual values at individual stations are set out below :—

Station	County	Month	Amount in.
Snowdon (Llyn Llydaw) ..	Carnarvon ..	October, 1909 ..	56·54
Borrowdale (The Stye)	Cumberland ..	January, 1872 ..	50·05
Ben Nevis Observatory	Inverness ..	December, 1900 ..	58·34

Several stations recorded no rain in February, 1891 ; September, 1894 ; February, 1895 ; July, 1911 ; April, 1912 ; June, 1921 ; June, 1925 ; and March, 1929. The stations with no rain were mainly in south-eastern England. In February, 1891, some 270 stations situated in central and south-east England measured no rain for the month, while in June, 1925, no rain was recorded over an area of 6,410 square miles, or an area equal to about 85 per cent of the total area of Wales.

The distribution of the extreme annual values is very largely controlled by the configuration of the land, the largest values occurring in the mountainous regions and the smallest on the plains. The distribution of the monthly extremes reveals a second factor, viz., that the south-east of England is more liable to periods of little or no rain, while in the north-west rain falls more frequently. Thus, at Eallabus, in Islay, on the west coast of Scotland, rain fell every day from August 12 to November 8, 1923, a period of 89 days, or nearly three months, the average annual rainfall at Eallabus being only about 50 in. a year. This second factor is shown very clearly in monthly and annual maps of the number of days with rain. They indicate that in general there is a steady increase in the number of days with rain from the south-east to north-west, even at stations with the same annual fall. The least number of days recorded in any year was in 1921, when there were less than 100 days of rain over a well marked area in the neighbourhood of the Thames Estuary. In 1923 the north-west of Ireland had more than 300 days with rain and Ballynahinch Castle, in Connemara, recorded 309 rain days in the same year. A map of the average annual number of rain days was published in *British Rainfall*, 1926, p. 264, and maps of the average number in each month in *Q. J. R. Meteor. Soc.*, **54**, 1928, pp. 90–101.

The longest periods on record in these Islands with no rain occurred in 1893, during the famous spring drought, when some 20 stations in the south-east of England, mostly in Kent and Sussex, recorded no rain for a period of 50 days or more. Locally in this district there was a two months' drought from March 17 to May 16. The year 1893 was unprecedented for periods of little or no rain.

The largest falls on record for one day (9h. to 9h.) are set out below :—

County	Station	Amount	Date
		in.	
Somerset ..	Bruton (Sexey's School)	9·56	June 28th, 1917.
,, ..	Cannington (Brymore House) ..	9·40	August 18th, 1924.
,, ..	Bruton (King's School)	8·48	June 28th, 1917.
,, ..	Aisholt (Timbercombe)	8·39	June 28th, 1917.
Glamorgan ..	Rhondda (Pont Lluest Wen) ..	8·31	November 11th, 1929.
Inverness ..	Loch Quoich (Kinlochquoich) ..	8·20	October 11th, 1916.
Cumberland ..	Borrowdale (Seathwaite)	8·03	November 12th, 1897.

The average annual rainfall for the first four stations is 30 to 35 in., while that for the fifth and sixth stations exceeds 100 in. ; so that with the short interval of the day the influence of configuration over the distribution of extreme values has practically disappeared.

The most widespread heavy rain on record occurred in East Anglia on August 25 and 26, 1912, when 1,939 square miles received more than 4 in., corresponding with a volume of rainfall of 154,133 million gallons.

Of the list of heavy falls in short periods, it is only possible to quote a few examples. The fall of 1·25 in. in five minutes reported at Preston in Lancashire, on August 10, 1893, gives the largest rate on record, viz., 15 in. per hour. The largest fall in half an hour is 2·90 in. recorded at Cowbridge in Glamorganshire on July 22, 1880, and in one hour that of 3·63 in. at Maidenhead on July 2, 1913. The heavy rain of 4·65 in. in two and a half hours on June 16, 1917, at Campden Hill in Kensington, is worthy of mention, since this amount is the largest on record for London for a rainfall day. It has been estimated that during the unprecedented storm at Cannington, near Bridgwater, on August 18, 1924, as much as 8 in. of rain (and hail) fell in 5 hours.

Variations of annual rainfall.—In the " Rainfall Atlas," to which reference has already been made, maps are given showing the fall of each of the 56 years in the series 1868 to 1923, as a percentage of the average. The maps indicate by means of shading, whether the annual rainfall at any place was below or above the average. The shading varies according to the degree of deficiency or of excess. Similar maps are published in the recent volumes of *British Rainfall* and the whole series gives a history of the rainfall fluctuations over the country during the last 60 years.

While the variations of rainfall from point to point in any one year or at the same point in successive years can be shown clearly on maps the variations from year to year of the total annual rainfall for any large area as a whole are shown more effectively by figures. The following table is taken from the *Meteorological Magazine* for June, 1923, and brought up to date by reference to the recent volumes of *British Rainfall.*

Annual rainfall for each year, 1868 *to* 1929, *expressed as a percentage of the average of the* 35 *years,* 1881 to 1915

Year	England and Wales	Scotland	Ireland	British Isles	Year	England and Wales	Scotland	Ireland	British Isles
1868 ..	99	113	104	104	1880 ..	113	86	95	102
1869 ..	105	100	98	102	1881 ..	109	95	100	103
1870 ..	82	80	95	84	1882 ..	127	113	113	120
1871 ..	97	92	98	96	1883 ..	107	106	110	108
1872 ..	144	134	128	137	1884 ..	88	104	98	94
1873 ..	89	105	94	94	1885 ..	101	91	92	96
1874 ..	95	108	98	99	1886 ..	117	94	109	110
1875 ..	114	99	99	107	1887 ..	74	80	77	77
1876 ..	117	114	104	113	1888 ..	98	93	98	97
1877 ..	126	131	123	127	1889 ..	94	85	93	92
1878 ..	110	92	96	102	1890 ..	90	103	97	95
1879 ..	109	91	96	100	1891 ..	111	100	98	105

Annual rainfall for each year, 1868 *to* 1929, *expressed as a percentage of the average of the* 35 *years,* 1881 to 1915—contd.

Year	England and Wales	Scotland	Ireland	British Isles	Year	England and Wales	Scotland	Ireland	British Isles
1892 ..	94	96	98	95	1911 ..	94	99	96	96
1893 ..	83	97	82	86	1912 ..	125	108	108	116
1894 ..	108	102	104	105	1913 ..	98	93	106	99
1895 ..	96	95	96	95	1914 ..	108	103	108	107
1896 ..	93	99	94	95	1915 ..	110	96	102	105
1897 ..	101	95	114	103	1916 ..	114	117	114	115
1898 ..	87	109	98	95	1917 ..	98	97	99	97
1899 ..	94	106	102	99	1918 ..	107	106	111	108
1900 ..	109	119	115	113	1919 ..	105	93	91	98
1901 ..	88	94	96	92	1920 ..	109	105	111	109
1902 ..	84	86	92	87	1921 ..	70	99	88	82
1903 ..	128	129	124	127	1922 ..	105	94	92	100
1904 ..	89	93	101	93	1923 ..	113	120	110	114
1905 ..	86	97	89	89	1924 ..	120	105	122	117
1906 ..	101	111	93	101	1925 ..	106	100	99	104
1907 ..	99	104	99	100	1926 ..	102	111	100	103
1908 ..	91	99	96	94	1927 ..	123	114	108	118
1909 ..	105	101	93	101	1928 ..	115	123	126	118
1910 ..	113	105	109	110	1929 ..	100	101	106	101

In this table the average rainfall for the 35 years 1881 to 1915 for each district dealt with is taken as 100, and the general rainfall for each year of the series is stated as a percentage of that amount. The table shows that for the British Isles as a whole wet and dry years have alternated irregularly. There was a run of nine consecutive wet years from 1875 to 1883. Then, commencing in 1891, there was a remarkable series of one wet year followed by two dry, repeated five times in regular succession. During the 19 years, 1884 to 1902, only five had a rainfall above the average. Subsequently a definite wet period set in and during the 20 years, 1909 to 1928, only five years can be regarded as dry. It is interesting to note that one of the driest years on record, namely 1887, occurred in the run of generally dry years while the other dry year, 1921, occurred in a definite wet period.

Rain, Artificial.—In endeavouring to alter the course of Nature as regards the incidence of rain, either in time or in space, magical, religious and scientific methods have been tried. An account of some of these earlier methods is set out in "Rain Making" by W. J. Humpreys of the United States Weather Bureau. While there is little difficulty in the formation of drops of water by physical processes in the laboratory from air containing moisture, the production of any quantity of water from the atmosphere can only be carried out at a trouble and cost which is prohibitive as a commercial proposition. If it were practicable to precipitate all the water vapour contained in the atmosphere over the British Isles under the most favourable conditions the atmosphere would only yield 1·4 in. of rain. Generally the water contained in the air over the British Isles is far less and in arid regions practically negligible. In the book mentioned above a computation is given showing that in order to produce half an inch of rain over about 60 square miles by mechanically raising moist air the work necessary is of the order of 75 million horse power for an hour. Similarly in order to produce half an inch of rain over one square mile under optimum conditions by heating moist air it is estimated that as much as 6,400 tons of coal would have to be burnt.

The possible association of the gun-fire in Flanders during the War, and later of the increase in broadcasting, with the heavy rain in the British

Isles with which they coincided, led to the consideration as to whether such means could be employed to produce rain artificially. It has been shown, however, that while there was heavy rain in the south of England during the War, the run of wet years commenced before 1914. Further, the run of wet years with excesses in the south followed similar runs of years in which the east or the west of the country had been unusually wet. It is not therefore necessary to introduce any new factor, such as heavy gun-fire, to account for the heavy rain of these years. The question of the relation of rainfall to the increase in broadcasting was dealt with in the *Radio Times* for June 29, 1928. The conclusion is arrived at that from the meteorological history, it would have been reasonable to expect the wet weather of 1924 to 1927 without the introduction of any artificial factor.

Rain-band.—A dark band in the solar spectrum on the red side of the sodium D lines, due to absorption by water vapour in the earth's atmosphere. The band may be best seen when the spectroscope is pointed at the sky rather than directly at the sun. The band is strengthened with increase of water vapour and also when the altitude of the sun is low and its light has to shine through a greater thickness of air. Taken alone the rain-band is of doubtful value as a prognostic of rain. Accurate measurements of the absorption may be utilized however to determine the quantity of moisture in the atmosphere whereas ordinary meteorological observations merely give the quantity of vapour near the ground.

Rainbow.—A rainbow is seen when the sun shines upon raindrops. The drops may be at any distance from the observer from a few yards to several miles. When sunlight falls upon a drop of water some of the light enters the drop, is reflected from the far side and emerges from the near side. The light which is reflected in this way does not come out in all directions but only in directions lying within about 42° from the direction of the sun. The reflected light is most intense near the limit. Accordingly an observer looking towards the raindrops receives a certain amount of light from all directions within 42° from the shadow of his head but most light along rays which make about 42° with the central line. The limiting angle depends on the colour of the light and in so much as white light is compounded of light of different spectral colours the observer sees a number of concentric arches of different colours.

Some of the light falling on a drop does not emerge until after it has been reflected twice. None of the twice reflected light which reaches an observer makes an angle of less than 50° with the line to the centre of his shadow. The colours of the outer bow formed in this way are in the reverse order to those of the inner bow. The space between the inner and outer bows appears darker than the space inside the inner or beyond the outer bow.

It is a common mistake to assume that the colours of all rainbows are the same. The coloration depends on the size of the drops. Drops larger than 1 mm. in diameter yield brilliant bows about 2° in width, the limiting colour is distinctly red. With drops about 0·3 mm. in diameter the limiting colour is orange and inside the violet there are bands in which pink predominates. With smaller drops supernumerary bows appear to be separate from the primary bow. With still smaller drops about ·05 mm. in diameter the rainbow degenerates into a white fog bow with faint traces of colour at the edges.

The wave theory of light has provided in the hands of Airy and Pernter a satisfactory explanation of all the variations in the colour of rainbows.

Rainbows are not infrequently observed by moonlight but as the human eye cannot distinguish colour with faint lights the lunar rainbow appears to be white.

Rain Day.—The definition adopted is that a rain day is a period of 24 hours, commencing normally at 9h., on which 01 in. or 0·2 mm. or more of rain is recorded. The following papers deal with average numbers of rain days in the British Isles :—

(1) The distribution over the British Isles in time and space of the annual number of days with rain. *British Rainfall*, 1926, p. 260–79.

(2) The distribution over the British Isles of the average number of days with rain during each month of the year. *Q.J.R. Meteor. Soc.*, **54,** 1928, p. 89–101. (See also WET DAY.)

Raindrops.—*Size and rate of fall of raindrops.*—The size of raindrops can be measured, if, for example, a shallow tray containing dry plaster of Paris is exposed for a few seconds during rain, each drop which falls into the tray will make a plaster cast of itself which can easily be measured. A better method is to collect the drops upon thick blotting paper. If, while still wet, the paper is dusted over with a dye powder a permanent record will be obtained consisting of circular spots whose diameter is a measure of the size of the drops. By comparing the diameters of the discs produced by raindrops with those produced by drops of water of known size, the amount of water contained in the former can be found. The following table contains some results obtained by P. Lenard* in this way at nine different times :—

Drops			Number of drops per m.² per second								
Diameter		Volume									
mm.	in.	mm.³	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0·5	·019	0·066	1,000	1,600	129	60	0	100	514	679	7
1·0	·039	0·523	200	120	100	280	50	1,300	423	524	233
1·5	·059	1·77	140	60	73	160	50	500	359	347	113
2·0	·079	4·19	140	200	100	20	150	200	138	295	46
2·5	·098	8·19	0	0	29	20	0	0	156	205	7
3·0	·118	14·2	0	0	57	0	200	0	138	81	0
3·5	·138	22·5	0	0	0	0	0	0	0	28	32
4·0	·157	33·5	0	0	0	0	50	0	0	20	39
4·5	·177	47·8	0	0	0	0	0	200	101	0	0
5·0	·196	65·5	0	0	0	0	0	0	0	0	25
Total number ..			1,480	1,980	486	540	500	2,300	1,840	2,190	500
Rate of rainfall .. (mm./min.)			0·09	0·06	0·11	0·05	0·32	0·72	0·57	0·34	0·26

* " Uber Regen." *Met. Zs.*, **21,** 1904, pp. 249–62.

(1) and (2) refer to a rain " looking very ordinary " which was general over the north of Switzerland. The wind had freshened between (1) and (2).
(3) Rain with breaks during which the sun shone.
(4) Beginning of a short fall like a thunder-shower. Distant thunder.
(5) Sudden rain from a small cloud. Calm ; sultry before.
(6) Violent rain like a cloud-burst, with some hail.
(7), (8) and (9) are for the heaviest period, a less heavy period and the period of stopping of a continuous fall which at times took the form of a cloudburst.

Probably the best method of measuring the sizes of small raindrops is that of Nolan and Enright (*Proc. R. Dublin Soc.*, **17,** p. 3). Glass microscope slides are prepared by spreading on each of them a layer of thick dark oil of density 0.9. When one of these slides is exposed to rain the drops falling on it pass into the oil layer and are there suspended in the form of perfect spheres, sinking very slowly. The rate of movement through the oil is so slow that the smallest drops do not reach the bottom of the layer until after 48 hours. The diameters of the drops are easily and accurately measured under a low-power microscope.

It is apparent from the table that by far the greater number of drops have a diameter of 2 mm. or less. In short showers, especially those occurring during thunderstorms the frequency of large drops is much greater. In such showers the diameter of the largest drops appears to be about 5 mm. We shall see later that it is impossible for a drop, whose diameter exceeds 5·5 mm. or rather less than a quarter of an inch, to fall intact.

The rate at which a raindrop, or any other object, can fall through still air depends upon its size. When let fall its speed will increase until the air resistance is exactly equal to the weight, when it will continue to move at that steady speed (see EQUILIBRIUM). The manner in which this "terminal velocity," as it is called, varies with the size of the raindrops is shown in Fig. 23 on which some of the actual observations made by Lenard have been plotted.

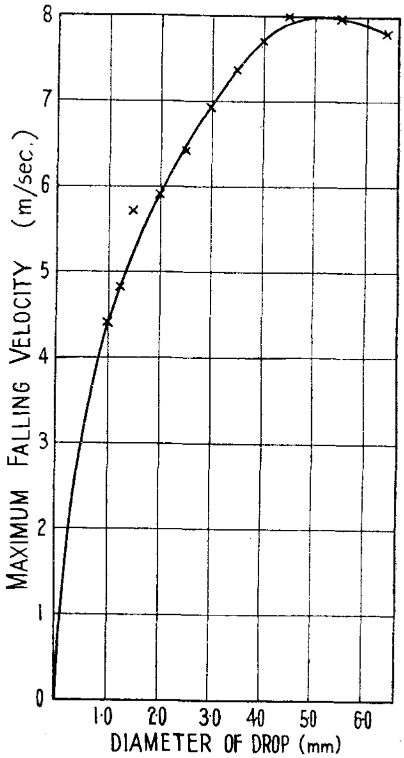

FIG. 23.

We may consider this diagram in another way. The frictional resistance offered by the air to the passage of a drop depends upon the relative motion of the two, and it is of no consequence whether the drop is moving and the air still, or the air moving and the drop still, or both air and drop moving if they have different velocities. The velocities given in the tables are those with which the air in a vertical current must rise in order just to keep the drops floating, without rising or falling. The above results were, in fact, actually determined by Lenard in this way, by means of experiments with vertical air currents on drops of known size. We see that beyond a certain point the terminal velocity does not increase with the size of the drops but tends to decrease. This is due to the fact that the drops become deformed, spreading out horizontally, with the result that the air resistance is increased. For drops greater than 5·5 mm. diameter, the deformation is sufficient to make the drops break up before the terminal velocity is reached.

An important consequence of Lenard's results is that no rain can fall through an ascending current of air whose vertical velocity is greater than 8 m./s. In such a current the drops will be carried upwards, either intact or after breaking up into droplets. There is good reason for believing that vertical currents exceeding this velocity frequently occur in nature.

On account of their inability to fall in an air current which is rising faster than their limiting velocity, raindrops formed in these currents will have ample opportunity to increase in size, and the electrical conditions will usually be favourable for the formation of large drops. These large drops can reach earth in two ways; either by being carried along in the outflow of air above the region of most active convection, or by the sudden cessation of or a lull in the vertical current. The violence of the precipitation under the latter conditions may be particularly disastrous. (See also CLOUDBURST AND HAIL.)

Rainfall.—For the purpose of meteorological observations the term is commonly taken to include that which is recorded by the rain-gauge, whether RAIN, snow, hail, fog, mist or dew, but PRECIPITATION is the proper inclusive word.

Rain-gauge.—An instrument for measuring rainfall. In the "Snowdon," "Meteorologial Office" and allied patterns, a funnel, usually 5 in. or 8 in. in diameter, is used to collect the rain. A brass tube of fairly narrow bore, to minimise evaporation, conducts the collected water into the collecting vessel which may be a bottle or a copper can. The funnel is supported by means of an outer can preferably of sheet copper. The rim is of stout brass with a sharp bevelled edge and the funnel is deep, with vertical sides to minimise errors due to splashing and to retain snow. The gauge is mounted in an open situation with its rim 12 in. above ground level.

In self-recording gauges, such as the HYETOGRAPH, the collected rainfall is usually made to raise a float to which is attached a pen writing on a chart wrapped round a clock-driven drum. Various methods, involving much ingenuity, have been adopted to secure sensitiveness and to return the pen to the zero line after a definite amount of rain has fallen.

Rain-making.—See RAIN, ARTIFICIAL.

Rain Shadow.—An area with a relatively small average rainfall due to sheltering by a range of hills from the prevailing rain-bearing winds. The phenomenon is noticeable in rainfall maps for months in which unusually strong W. winds have predominated, e.g. to the east of Wales.

Rain Spell.—A period of at least 15 consecutive days to each of which is credited ·01 in. of rain or more; thus the definition of the term "rain spell" is analogous to that of the term "absolute drought." (See DROUGHT.) During the 62 years, 1858–1919, there were seven rain spells at Camden Square (London). (See also WET SPELL.)

Réaumur.—René Antoine Ferchault de, d. 1757, whose name is given to a scale of temperature now almost obsolete. On it the freezing point of water is zero, and the boiling point 80°.

Recurvature of Storm.—This expression refers to the recurvature of the track of a tropical CYCLONE, which is a typical feature of the great majority of these phenomena. It is also known as the "recurve." In the northern hemisphere a tropical cyclone after proceeding in a more or less westerly direction recurves and normally takes a north-easterly direction; in the southern hemisphere the final direction is normally south-easterly. The tracks are often described as "parabolic," though in the majority of cases "hyperbolic" would be more accurate. The point to recurve is of great importance for the forecasting of the subsequent path. This point is often the seat of the maximum energy of the disturbance.

Reduction, as applied to meteorological observations, generally means the substitution for the values directly observed of others which are computed therefrom and which place the results upon a comparable basis. Thus REDUCTION TO SEA LEVEL in the case of barometer readings, means estimation according to certain rules of the value which the pressure would have at a fixed level lower than that of the place of observation, and the reduction of a set of mean values extending over a regular series of years to a uniform or normal period indicates a similar procedure based upon comparison with neighbouring stations.

Reduction to Sea Level.—Both temperature and pressure are "reduced to sea level" before they are plotted on charts. To reduce mean temperature to sea level 1° F. is added for each 300 ft. in the elevation of the station; 1°A. for 165 metres; other rates are used for maximum temperature and minimum temperature (see "Computer's Handbook" Introduction, p. 11). This reduction is regarded as necessary in forming maps of ISOTHERMS of regions with a considerable range of level, otherwise the isotherms simply reproduce the contours; but it reduces the practical utility of the maps because the addition of ten or twelve degrees to the temperature actually observed gives an entirely false idea of the actual state of things in the locality represented.

The same objection does not apply to the reduction of pressure to sea level because the human organism has no such separate perception of pressure as it has of temperature.

The *reduction of pressure to sea level* is carried out in accordance with the general rule for the relation of difference of pressure to difference of height. This goes according to the equation

$$h - h_0 = kT\,(\log_{10} p_0 - \log_{10} p)$$

where h, p, h_0, p_0 are corresponding values of height and pressure, T is the mean temperature of the air columns and k, a constant which is numerically equal to 67·4 when the height is to be given in metres, or to 221·1 when the height is to be given in feet. This equation is derived from the direct expression of the relation of pressure and height

$$g\rho\,dh = -\,dp.$$

The details of the technique of reducing pressure to mean sea level will be found in the "Computer's Handbook," chapter II.

The humidity of the air makes very little difference to the computation of height in our latitudes where temperature and moisture do not reach tropical figures. The best way for allowing approximately for humidity, which diminishes the density under standard conditions, is to regard the temperature as increased by one tenth of a degree for each millibar of water-vapour pressure in the atmosphere.

The vertical gradient of temperature varies according to the locality and the season, but in the reduction of temperature to sea level it is usually assumed to be at the rate of 0·5° C. per 100 metres or 1° F. per 300 ft. The International Meteorological Conference at their meeting at Innsbruck in 1905 recommended that these values should be employed in the reduction of pressure to mean sea level.

Reflection.—The reflection of light and of radiant heat is an important factor in the physics of the atmosphere. Reflection may be regular like the reflection from a smooth sheet of water or diffuse like the reflection from a sheet of white paper. The intensity of regularly reflected light depends on the angle of incidence. Of the light which comes from the sun a large proportion is reflected by the clouds. Some of this light may have passed through two or three drops before reflection. Aldrich* has measured the reflecting power of clouds and concludes that a cloud returns 78 per cent of the incident radiation, and that the amount of reflection is practically independent of the angle of incidence.

In some cases continuous refraction of light produces an effect equivalent to reflection. This is the explanation of MIRAGE.

Refraction.—The name applied to the bending to which rays of light are subjected in passing from one medium to another of different optical density. It plays an important part in many optical phenomena in the atmosphere; MIRAGE, HALOS, and RAINBOWS are refraction phenomena, the colours of the two latter being due to the fact that rays of different colours suffer a different amount of bending. Another refraction effect is that the apparent ALTITUDE of a heavenly body is greater than its real altitude because the rays of light entering the atmosphere are passing from a less dense to a more dense medium, and their final direction is nearer the vertical than their original direction.

Owing to refraction the setting sun is still seen above the horizon when its geometrical position is below that level. The rays from the lower limb of the sun are more refracted than those from the upper so that the

* *Smithsonian Misc. Collections*, **69**, No. 10, 1919.

sun may appear to be somewhat flattened. When the stratification of the air is such that there are rapid changes of density in the vertical, the sun may appear much distorted and in some cases it can fade out of sight without apparently reaching the horizon.

Under similar circumstances objects which are normally invisible may appear above the horizon. For instance the coast of France has been seen occasionally from Hastings.

Registering Balloon.—A small balloon, usually free, carrying a light meteorograph recording pressure, temperature, and humidity of the upper air, etc. (See SOUNDING BALLOON.)

Regression Equation.—An equation, generally linear, connecting two or more quantities, derived from the CORRELATION COEFFICIENT.

Relative Humidity.—The ratio of the actual amount of water vapour in a given volume of air to the amount which would be present were the air saturated, expressed as a percentage, is termed the relative humidity, or for the sake of shortness, simply " humidity."

In practice, at climatological stations, the humidity of air is determined from the readings of the dry and wet bulb thermometers, with the aid of tables prepared for the purpose and called humidity tables or psychrometric tables. But humidity is the most variable of the ordinary meteorological elements, as it depends not only on the sample of air under observation, but also on its temperature. Hence the record of a self-recording hair HYGROMETER, which can be obtained in a form not much different from an ordinary barograph, gives a most instructive record. In the spring and summer it sometimes shows very high humidity in the night and early mornings, approaching or actually reaching saturation, and very great dryness, perhaps only from 15 to 20 per cent humidity, in the sunny part of the day, with very rapid changes soon after sunrise and towards sunset. These are the changes which correspond with the characteristic changes in the feeling of the air at the beginning and end of the day.

Réseau Mondial.—An annual publication of the Meteorological Office, Air Ministry, issued under the auspices of the International Meteorological Committee. It was recognised early in the present century that the next important step in the progress of international meteorology, after the publication of normal values for pressure, temperature and rainfall for the world, was the compilation year by year of monthly means of pressure, temperature and rainfall at stations in all parts of the world, organised to secure the uniformity of practice necessary for the purposes of comparison. The Committee appointed a commission, the International Commission for the Réseau Mondial, to foster the enterprise and the publication of the data commenced in 1917 with the volume for 1911. Since then the volumes for 1910 and 1912 onwards have been published, that for 1922 being issued in 1929. The data are arranged on the basis of two stations for each ten-degree square of latitude and longitude, and in the volumes for 1910 to 1920 only land stations were included. In the volumes for 1921 onwards marine data are also included. The information published for each station includes mean pressure, mean and absolute maximum and minimum temperatures, the observed or deduced mean of 24 hourly temperature readings and the total rainfall, together with the differences from normal for all three elements.

Reshabar or **rrashaba.**—A name meaning " black wind " given to a strong, very gusty, north-easterly wind which blows down certain mountain ranges in southern Kurdistan. It is dry, comparatively hot in summer and cold in winter.

Residual.—The difference between an individual observation and the mean of a series, or the difference between an individual observation and the value derived from the adopted values of the constants which have been obtained by a discussion of the observations. Thus an observed quantity l may be known to be a function of variables x, y, z, and constants a, b, c, of the form of $ax + by + cz = l$. If a number of observed values of l are given for known values of x, y and z, there will be n equations to determine the 3 constants a, b, and c. The equation will not in general be accurately satisfied for any one observation, and the value of $l - (ax + by + cz)$ is called the residual.

Resultant.—The sum of a number of directed quantities or vectors. (See COMPONENT and VECTOR.)

Reversal.—A change of more than 90° in direction between the surface wind and the wind in the upper air. A reversal may take place near the ground or at any height up to 15,000 ft. or more. Reversals are common phenomena over coasts when land and sea breezes are blowing in directions greatly different from those that the general distribution of pressure would dictate. The most permanent case of a reversal is over the trade wind, where in the North Atlantic the north-earterly surface current is rdplaced by a south-westerly one in the upper air. A spectacular example of this is afforded when an eruption of the Soufriere in St. Vincent occurs, for then the dust, carried by the upper current, falls in Barbados, though it lies 100 miles to windward of St. Vincent.

Revolving Storm.—A term synonymous with tropical CYCLONE or hurricane. (See also LAW OF STORMS.)

Ridge.—An extension of an ANTICYCLONE or high-pressure area shown on a weather chart, corresponding with a ridge running out from the side of a mountain. It is the opposite to a trough of low pressure.

Rime.—Deposits of white rough ice that grow out to windward of exposed objects when frost and wet fog occur together. The minute supercooled drops of water, of which the fog is composed, freeze when they come in contact with a solid object. Hoar frost, on the other hand, is formed by the direct freezing of water vapour, generally upon objects cooled by radiation under a clear sky; the presence of fog, in so far as it checks such radiation, tends to hinder the formation of hoar frost.

Roaring Forties.—A nautical expression used to denote the prevailing westerly winds of temperate latitudes (below 40° S.) in the oceans of the southern hemisphere.

Roll Cumulus.—Banks of cloud arranged in long parallel rolls with clear spaces in between. A form of STRATO-CUMULUS. (See CLOUDS.)

St. Elmo's Fire.—Brush-like discharges of electricity sometimes seen on the masts and yards of ships at sea during stormy weather; it is also seen on mountains on projecting objects. It may be imitated by bringing a sharp pointed object, such as a needle, near a charged Leyden jar. According to Trabert's observations on the Sonnblick the character of St. Elmo's fire changes with the sign of the electricity which is being discharged into the air. The negative "fire" is concentrated so that an object like a mast is completely enveloped in fire. The positive fire takes the form of streamers some three or four inches long.

St. Luke's Summer.—A period of fine weather which is popularly supposed to occur about the time of St. Luke's day, October 18.

St. Martin's Summer.—A period of fine weather which is popularly supposed to occur about the time of St. Martin's day, November 11.

Salinity.—The salinity of a natural water, such as sea-water, is usually expressed in parts per thousand. Thus a salinity of 35 per mille (written $35\,^{\circ}/_{\circ\circ}$) indicates that there are 35 lb. of salt in 1,000 lb. of sea water. Since the direct determination of total dissolved solids cannot be effected with accuracy, salinity is derived in practice by applying factors to the halide-content, which can be exactly estimated, or to the specific gravity. The value above given is a rough average for surface ocean water.

Sand-pillar.—See DUST-DEVIL.

Sandstorm.—Any strong wind carrying dust or sand occurring over a considerable area at the same time, distinguished from a DUST-DEVIL or sand-pillar which is an isolated eddy carrying dust or sand. The wind may be associated with the approach of a well defined depression, as occurs in the khamsin season of Egypt, or with more localised disturbances of thundery type. The terms " haboob " applied in the northern and central Sudan, and SIMOOM, applied in the Sahara and Arabian deserts appear to apply generally to the latter type of sandstorm.

Sastrugi.—(pl. : from the Russian) : Irregularities or wave formations caused by persistent winds on a snow surface. They vary in size according to the force and duration of the wind, and the state of the snow surface in which they are formed.

Saturation.—A given volume of ordinary air which is exposed to a plane surface of water or ice has for a given temperature a definite saturation pressure of water vapour (see AQUEOUS VAPOUR), this saturation pressure increasing rapidly with increasing temperature. A fall of temperature would lead to CONDENSATION of some of this water vapour, while a rise of temperature would make the air unsaturated and therefore able to take up more water vapour. It may be noted that water can under certain conditions remain unfrozen at temperatures below 0°C. (32°F.) and the saturation pressure relative to a surface of such " supercooled " water is greater than that relative to ice at the same temperature.

Scalar.—A quantity which is completely specified by a number as opposed to directed quantities such as wind velocity, which require for their complete specification both a number or magnitude (the wind speed) and a direction. Examples of scalar quantities in meteorology are temperature, pressure, and humidity, but it must be noted that pressure gradient is not scalar but vectorial, as its complete specification demands a direction as well as a number giving the magnitude. (See VECTOR.)

Scintillation or Twinkling of the Stars.—A rapid apparent variation in brightness and in colour. Scintillation occurs only with stars comparatively low down in the sky. The elevation up to which scintillation occurs has been found to vary in the course of the year. According to a series of observations made at Lyons the maximum elevation 50° occurs in March and September, the minimum 22° in June.* Scintillation is certainly due to irregularities in the density of the air : the irregularities are carried along by the wind but how they are related to eddies and to wave motion in the atmosphere is not known.

Scirocco.—A warm, southerly or south-easterly wind which blows in front of a depression passing from west to east along the Mediterranean. As this wind comes from the Sahara desert it reaches the north coast of Africa as a hot, dry wind, its temperature having been further raised by the descent of the air from the inland plateau to the coastal regions. In crossing the Mediterranean evaporation occurs and the wind reaches Malta, Sicily and Italy and other parts of the European coast as a warm, moist wind.

The word scirocco seems to be used in some Mediterranean regions for a warm, southerly wind irrespective of whether it is moist or dry. Many of the warm, dry winds which are called sciroccos are probably FÖHN winds.

Scotch Mist.—In mountainous or hilly regions, rain clouds (nimbus) are often adjacent to the ground, and precipitation takes place in the form of minute waterdrops, the apparent effect being a combination of thick mist and heavy drizzle.

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* *La Météorologie, Paris*, 1927, p. 193.

The upland character of the greater part of Scotland and the consequent frequency of occurrence of the phenomenon in that country have secured for it the appellation by which it is generally known in the British Isles.

The base of a true nimbus or rain cloud rarely exceeds about 7,000 ft. (2·1 Km.) in elevation, and sometimes descends to within a few hundred feet of sea level, so that Scotch mist may be experienced in comparatively low-lying regions.

In the uplands of the Devon-Cornwall peninsula the same phenomenon, which is there of very frequent incidence, is known as "mizzle."

Screen, Stevenson.—The standard housing for meteorological thermometers designed by Thomas Stevenson, C.E. It consists of a wooden cupboard, with hinged door, mounted on a steel or timber stand, so that its base is about 3 ft. 6 in. above the ground, the whole painted white. Indirect ventilation is provided through the bottom, double roof and louvred sides, and thermometers placed within it give a close approximation to the true air temperature, undisturbed by the effects of direct solar or terrestrial radiation. The "ordinary" pattern accommodates the wet and dry bulb, maximum and minimum thermometers. In the "large" pattern additional accommodation is provided for a thermograph and hygrograph.

Scud.—A word used by sailors to describe ragged fragments of cloud drifting rapidly in a strong wind, often underneath rain clouds. The meteorological term is fracto-nimbus. (See CLOUDS.)

Sea Breeze.—See LAND AND SEA BREEZES.

Sea Disturbance.—The scale of sea disturbance in use on the high seas is as follows :—

Scale	Description of sea	Height of waves in feet from crest to trough
0	Calm	0
1	Smooth sea	Less than 1 foot.
2	Smooth sea	1 to 2 feet.
3	Slight sea	2 to 3 feet.
4	Moderate sea	3 to 5 feet.
5	Rather rough sea	5 to 8 feet.
6	Rough sea	8 to 12 feet.
7	High sea	12 to 20 feet.
8	Very high sea	20 to 40 feet.
9	Precipitous sea	40 feet and above.

Sea Level.—The "level" surface which a stagnant sea would assume in the absence of waves, swell and tides. The surface is such that the normal drawn to it at any point lies in the direction of the resultant of the accelerations due to gravity and to the centrifugal force of the earth's rotation. The surface is an oblate spheroid in which the short axis coincides with the axis of the earth.

Owing to waves, swell and tides, the actual level of the sea is constantly changing, and it is therefore usual to denote its mean position at any place by the expression "mean sea level." The amplitude of the fluctuation of sea level from its mean position varies considerably from time to time and from place to place, but it is believed that the mean position, or mean sea level, remains practically constant at any place.

Mean sea level is generally used as the standard to which the contour heights of the topography of the ground are referred.

The contours given on the Ordnance Survey maps of England have hitherto been referred to the supposed position of the mean sea level at Liverpool, but recently the standard has been changed to the ascertained position of mean sea level at Newlyn in Cornwall. The Newlyn datum is 0·13 ft. below the Liverpool datum. Newlyn is more suited to the purpose since it is situated on the edge of the Atlantic Ocean and is not subject to sources of disturbance to which a place on a tidal river on an enclosed sea is liable. Contours on the Ordnance Survey maps of Ireland are referred to an assumed mean sea level at Dublin, which has been estimated to be about 8 ft. below that of the " level " surface passing through the corresponding datum at Liverpool. For definitions of normal zero in the various national surveys of Europe see *Réseau Mondial* (M.O. 217 g), 1914, pp. x–xi. (See also LEVEL.)

Sea Temperature.—The normal method of measuring sea temperature is to draw water in a bucket from the ship's side, forward of all ejection pipes, and to read the temperature of the sample with a specially designed thermometer. The reading obtained is the mean temperature of the surface layer of the sea to the depth of about a foot, and is known as the sea surface temperature. No method has yet been devised for obtaining the temperature of the actual surface of the water. The mean annual surface temperature exceeds 80°F. over a broad belt of the equatorial region, and is somewhat less than 30°F. in the polar regions. The run of the isotherms varies in the two hemispheres and in the different oceans. The seasonal range of temperature is of the order of 10°F. in both polar and equatorial regions, and is greater in middle latitudes, where for the most part it lies between 10°F. and 30°F. The greatest range, 50°F. or more, is found in small areas, extending to the coast, of the western North Atlantic and western North Pacific Oceans. The diurnal variation of sea surface temperature is very small, 1°F. or less.

Seasons.—The seasons in this country according to the " farmer's year " are :—autumn : September, October, November ; winter : December, January, February ; spring : March, April, May ; summer : June, July, August.

The idea of four seasons in agriculture appropriate to these islands, the winter for tilling, the spring for sowing and early growth, the summer for maturing and harvesting, and the autumn for clearing and preparing, depends upon the peculiarity of our climate. Where the land is ice-bound in winter or rainless in summer another distribution has to be made.

Between the tropics there is nothing that can properly be called summer and winter ; the seasons depend upon the weather and rainfall, and not upon the position of the sun, and the periods of growth are adjusted accordingly. In India, or the north-western part of it, the divisions of the year are the cold weather, the hot weather, and the rains. At the polar margins the change from winter to summer and vice versa is so sudden that there the transition seasons spring and autumn largely disappear.

The selection of months to represent the seasons according to the farmer's year is guided by the consideration that each season shall comprise three months. This uniformity in the length of the seasons leads at times to paradoxical results. Thus, in a particular year, the warmest week may occur late in May or early in September, i.e. in spring or autumn and not in summer as defined above ; or again, the coldest week may occur late in November or early in March, i.e. in autumn or spring, and not in winter as defined above. From the point of view of weather, we have in this country about five months of moderate winter weather between October and April, and four months of summer weather from the middle of May to the middle of September, a short spring and a short autumn ; but the seasonal variations are not nearly so large here as they are in continental countries, and the change from winter to summer and vice versa in much less abrupt. Temperature, rainfall and sunshine data for individual stations and for districts are published in the *Weekly Weather Report* of the Meteorological Office and enable one to follow the course of the seasons in the British Isles. In the " Book of Normals of Meteorological Elements for the British Isles," Section II, are given normal values for each week of the year of mean temperature, rainfall and sunshine for each of twelve districts into which the British Isles have been divided. For information regarding the progress of rainfall from month to month in a normal year, the reader may consult in addition the "Rainfall Atlas of the British Isles," published by the Royal Meteorological Society. Some interesting particulars of the temperature of the several seasons in the British Isles are also given in "Temperature Tables of the British Isles," M.O. Publication 154 1902, which include diagrams showing the average daily maximum, minimum and mean temperatures and the highest and lowest values respectively recorded on each day throughout the year in the period 1871–1900 at four observatories: Aberdeen, Cahirciveen (Valentia Observatory), Falmouth and Richmond (Kew Observatory). The curves of mean temperature variation from day to day show numerous irregularities, but in their general form show a more or less progressive increase and decrease between a minimum in December or January and a maximum in July or August. At Richmond (Kew Observatory), the maximum temperature normally reaches its lowest value, 41°F., during the second week of January, then gradually rises to 50°F. at the end of March, 60°F. about the middle of May, reaching a maximum of 72°F. during the third week of July. After the third week of August there is a fairly rapid decrease, the maximum temperature falling to 60°F. at the end of September, to 50°F. about the middle of November and then more gradually to its minimum value in January. The mean minimum temperature ranges from about 32°F. in December to 56°F. in July. At Aberdeen the maximum temperature ranges on the average from 40°F. during the second week in January to 63°F. during the third week in July and the second week in August; the minimum temperature ranges on the average from about 32°F. towards the end of December to 52°F. during the first half of August. In the north and west generally the wettest month is December or January, and in the south and east, October. The driest month in the west generally is June or May, in the eastern districts April or March, and in the extreme east, February. The sunniest month is normally June, except in the north-west of Scotland and in Ireland, where May is the sunniest; in some districts along the south-east coast of England, July is the sunniest month.

Secondary Cold Front.—A COLD FRONT in polar air, following the first cold front. If the polar current is unstable, there is sometimes an irregular series of secondary cold fronts of limited length, accompanied by heavy squalls and sometimes by thunder. The fall of temperature is often due mainly to the precipitation, and after the squall passes the temperature sometimes recovers almost to its previous value.

Secondary Depression or "Secondary."—The isobars around a DEPRESSION are frequently not quite symmetrical, they sometimes show bulges or distortions, which are accompanied by marked deflections in the general circulation of the wind in the depression; such distortions are called secondaries; they may appear merely as sinuosities in the isobars, but at other times they enclose separate centres of low pressure and show separate wind circulations from that of the parent depression. In short, a secondary is a small area of low pressure accompanying a larger primary depression.

A secondary depression generally travels with its primary, but in addition to this the secondary, as a rule in the Northern Hemisphere, rotates about the primary in a counter-clockwise direction. On one synoptic chart the secondary may be shown on the western side of the primary depression while on the following day it may be on the eastern side of the depression, having as it were rolled round the southern side of the primary. Frequently the secondary becomes deeper while the primary becomes less intense; when such is the case the primary and the secondary tend to form a complex dumb-bell shaped depression, the two centres of low pressure revolving round each other in a counter-clockwise direction. Ultimately the secondary absorbs the parent depression, the two coalescing and forming one. When the secondary appears first as a sinuosity it often gives rise to precipitation of a more or less continuous type. As it develops and gradually attains a wind circulation about its own centre the weather tends to resemble that of an ordinary depression. Sometimes the secondary becomes so intense and deep that it gives rise to very violent and destructive gales. On the other hand a secondary may have, as frequently happens in summer, a very feeble wind circulation and such a secondary sometimes gives rise to thunderstorms. The weather, however, associated with these systems is very capricious.

The wind circulation in a secondary obeys BUYS BALLOT'S LAW, and thus in the northern hemisphere, the wind circulates around it in a counter-clockwise direction. The region between the primary depression and the secondary is generally one of light and variable airs, the strongest winds being found on the side away from the main depression.

It is interesting to note that the V-SHAPED DEPRESSION is an intermediate type of isobaric distribution between that of the secondary which is a mere sinuosity in the isobars of the primary depression and that which has its own centre of low pressure separate from that of the primary depression, and often well defined. (See Plate IV.)

Secular Trend.—In statistics, a persistent tendency for a variate to increase or decrease with the passage of time, apart from irregular variations of shorter period. In meteorology, examples are the increase of pressure and temperature at St. Helena and the decrease of rainfall at Sierra Leone.* Such changes obviously cannot continue indefinitely, and they are probably parts of oscillations of greater length than the available statistics. Secular trends can be determined by smoothing the data sufficiently, or by correlating with "time."

Seiche.—The name given to the quasi-tides which were first observed to occur in the Lake of Geneva. It was known for some three centuries that the water of this lake is apt to rise and fall, sometimes by a few inches, occasionally by several feet. The phenomena were first investigated in detail by Professor Forel of Lausanne, and it was found that oscillations of the water were to be observed every day, with amplitudes varying from a millimetre to about a metre, and with periods between 20 and 40 minutes.

The phenomena are described and discussed in considerable detail in G. H. Darwin's "The Tides," where it is shown that the oscillations in the level of the surface are to be explained as long waves in relatively shallow water. Anything which heaps up the water at one end of the lake, and then ceases to act, must tend to produce an oscillation of the whole. Among the important causes of seiches are winds, small earthquakes which tilt the bed of the lake, and probably the atmospheric oscillations which are recorded as waves by the microbarograph. Some of the Japanese lakes show marked periods round about eight minutes, in agreement with the periods of greatest frequency in the microbarograph in fine weather.

Another type of seiche, called a temperature seiche, was discovered by Watson and Wedderburn in some of the Scotch lakes. There is often a stratum of abrupt change of temperature below the surface of a lake, and the observers mentioned noted waves in this layer of transition.

Seiches are to be found in all lakes, and analogous phenomena are to be noted in landlocked areas of the sea. There is now a considerable literature dealing with the subject, and special reference should be made to papers in the Transactions of the Royal Society of Edinburgh from 1905 onwards, by Chrystal and his pupils White, Watson and Wedderburn.

Seismograph.—An earthquake recorder or instrument for automatically recording the tremors of the earth. A seismological observatory requires three seismographs to show the vertical and two horizontal components of the motion of the ground.

Seisms.—Oscillations of the crust of the earth. (See EARTHQUAKES, MICROSEISMS.)

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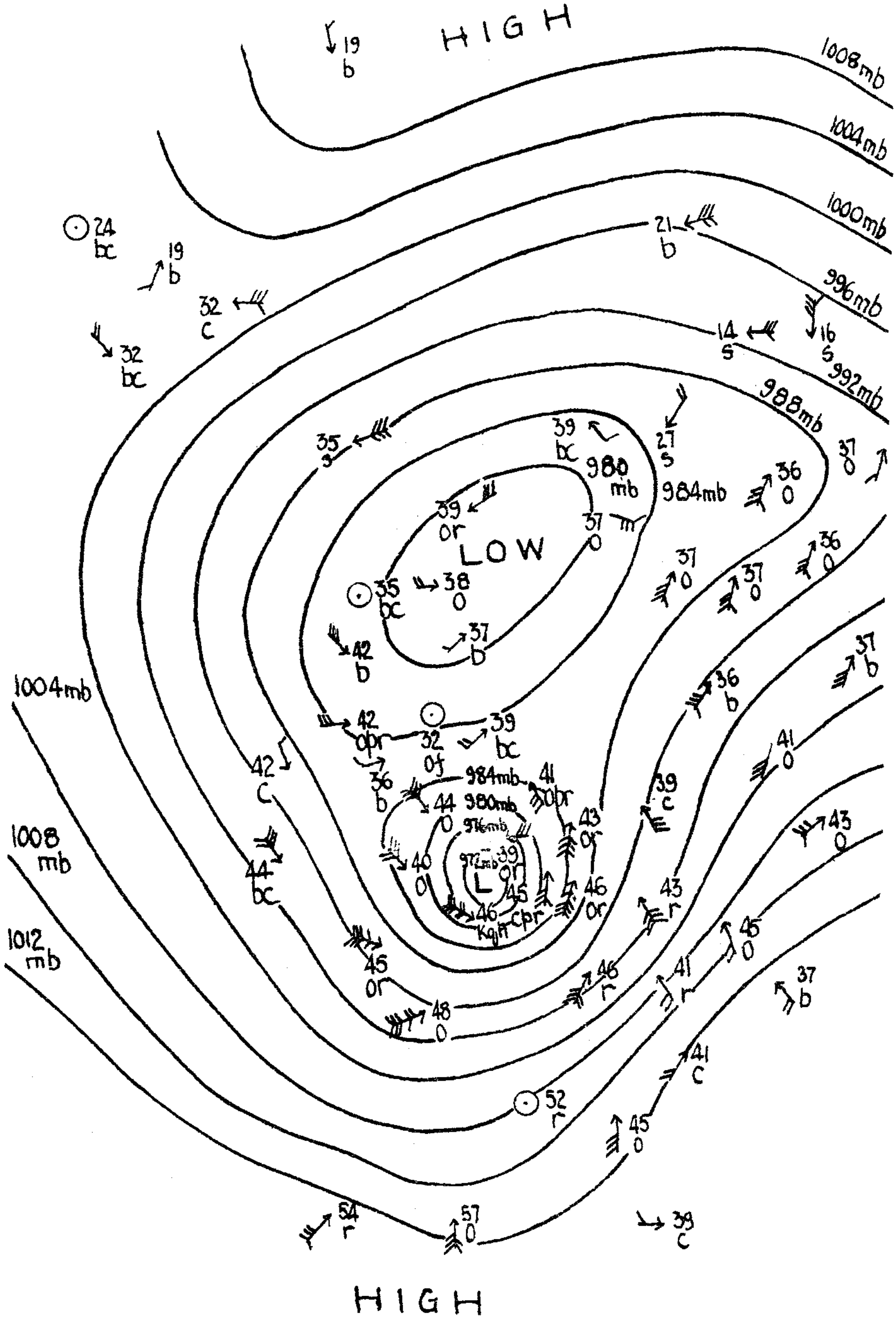
* See *London, Meteorological Office, Geophysical Memoirs*, No. 33, 1926.



8TH. MARCH, 1922. 7h.
SECONDARY.

Seistan Wind.—A strong northerly wind which blows in summer in the province of Seistan, in eastern Persia. It continues for about four months, and is therefore known as the "wind of 120 days." It sometimes reaches hurricane force.

Serein.—Fine rain falling from an apparently clear sky. It is very rare.

Shade Temperature.—The temperature of the air indicated by a thermometer sheltered from precipitation, from the direct rays of the sun and from heat radiation from the ground and neighbouring objects, and around which air circulates freely. Provided certain precautions are taken the result is a close approximation to the actual temperature of the air. (See SCREEN.)

Shadow of the Earth.—The shadow of the solid earth is the region from which direct sunshine is cut off by the intervention of the globe. The height of the shadow overhead is frequently made manifest by the changing illumination of the clouds. A small cloud which is in sunshine and appears a beautiful pink at one minute is in shadow the next and fades to a dull grey, whilst higher clouds are still illuminated. At such a time the background of the clouds is blue, for the air at greater heights is still illuminated by direct sunshine.

The shadow thrown on the air itself can also be observed with ease. Soon after sunset a dark segment is to be noticed in the eastern sky encroaching on the "counterglow" the band of reddish tint which runs round the horizon. This dark segment is the earth's shadow. As the boundary of the shadow rises the upper edge of the counterglow remains almost stationary and both are usually lost when the sun is about 4° below the horizon and the elevation of the boundary of the shadow is about 10°.

Whilst the shadow is perceptible all the air to the east of the observer is illuminated by light which has been scattered by the atmosphere, but the air at great heights is illuminated also by direct sunshine. The shadow is the part of the sky in which the additional light which comes to the observer from such great heights is inappreciable. The boundary is sharp when the line of sight is nearly parallel to the sun's rays but when the shadow climbs the observer is looking obliquely across the sun's rays and the boundary becomes indefinite and is lost.

When the sun is about 10° below the horizon directly illuminated air is to be seen only near the western horizon; the upper limit of the illuminated segment is the boundary of the earth's shadow. This boundary is sometimes called the TWILIGHT ARCH. By the time the sun is 18° below the horizon, if not before, the whole of the atmosphere within sight is in shadow, and TWILIGHT has ended.

Shamal.—A north-westerly wind which blows in summer over the Mesopotamian plane.

Shower.—In describing present or past weather, the following distinction is made between the use of the terms "showers" and "occasional precipitation." In general showers are of short duration and the fair periods between the showers are usually characterised by definite clearance of the sky. The clouds which give the showers are therefore isolated. The precipitation does not usually last more than fifteen minutes, although it may sometimes last for half an hour or more. Typical showers occur in the cooler W. or NW. current behind a depression which has passed eastwards (see INSTABILITY SHOWERS). Occasional precipitation, on the other hand, usually lasts for a longer time than the showers and the sky in the periods between the precipitation is usually cloudy or overcast.

Silver Thaw.—An expression of American origin. After a spell of severe frost the sudden setting in of a warm damp wind may lead to the formation of ice on exposed objects, which being still at a low temperature cause the moisture to freeze upon them and give rise to a "silver thaw." (See GLAZED FROST.)

Simoom.—A hot, dry suffocating wind or whirlwind which occurs in the deserts of Africa and Arabia. It usually, but not invariably, carries a large quantity of sand. It does not usually last long, not more than about 20 minutes. It is most frequent in the spring and summer.

Sine Curve.—See HARMONIC ANALYSIS.

Sirocco.—See SCIROCCO.

Site.—In order to secure observations comparable with those at other stations, the site of a meteorological STATION has to be carefully selected in accordance with certain rules which are set out in the "Meteorological Observer's Handbook." A rain-gauge requires a certain amount of protection from the wind, but for the other outdoor instruments the more open the site, the better. A compromise is usually effected. The latitude, longitude and height of the ground on which the rain-gauge stands are used to define the position of a station.

Sleet.—In this country the word denotes precipitation of rain and snow together, or of partially melted snow. In America the term is used in a different sense: Humphreys (in "Physics of the Air") defines it as "ice pellets, mere frozen raindrops or largely melted snowflakes re-frozen —frozen during the fall of the precipitation through a cold layer of air near the surface of the earth—that rattle when they strike a window."

Slide Rule, Pilot Balloon.—A slide rule designed to facilitate the rapid computation of the components of the wind velocity from observations of altitude and azimuth of a pilot balloon. Provision is also made, in the most recent type, for computing the height when the "tail" method of observation is employed.

Sling Thermometer.—A thermometer mounted on a frame pivoted about a handle so that it can be whirled in the hand, thus providing "ventilation." If the bulb is shielded from direct solar radiation satisfactory readings of air temperature can thus be obtained in a simple and inexpensive manner. A pair of thermometers, dry- and wet-bulb, similarly used, constitute a "sling" or "whirling" psychrometer. (See also PSYCHROMETER).

Snow is precipitation in the form of ice crystals of feathery or needle-like structure. The crystals may fall singly, or a large number of them may be matted together in the form of large flakes.

The characteristic shape of the simplest ice crystal is a small flat hexagonal plate, but most snow crystals show much more complicated structures, ranging from needles to six-pointed stars with numerous spreading branches. The method of formation of such stars has been described by Lehmann, who has watched under the microscope the development of star crystals of iodoform and other substances from a slightly supersaturated solution of the substance.

According to Lehmann the first step in the process is the formation of a minute flat crystal in the form of a regular hexagon. The crystal continues to grow in that form until it is seen from the lighter colour of the solution immediately bordering on it that the supersaturation is now confined to the parts of the liquid which are more distant from the crystal, while the solution in immediate contact with the crystal is only just saturated. Thereafter the crystal grows more slowly and only as the more concentrated liquid finds its way to the crystal by diffusion. The parts of the crystal nearest to the concentrated liquid (that is, the corners of the hexagon) are those first affected by this process of diffusion; consequently from this stage the crystal begins to develop pointed rays which grow outwards from the six angles of the original hexagon. This process proceeds until the rays are so long as to allow relatively concentrated solution to diffuse in between them ; this in turn induces sideways growths of spikes from the original arms of the star. If now a weakening of the concentration of the outside solution occurs, then the arms of the star will cease to grow outwards but facets will tend to form at their ends and the growth of the side spikes will continue. Alternations of increasing and decreasing concentration will produce varied forms of crystal.

Wegener is of opinion that snow crystals are formed in the same way from water vapour in air which is never far from the point of saturation with respect to ice, and is at a temperature below freezing. A large excess of supersaturation leads to the formation of HAIL and not snow. Snowflakes are aggregates of moist snow crystals, and are formed at temperatures not much below freezing. The best defined snow crystals are those produced at very low temperatures. They then fall singly and not in flakes ; they are of small size but are most suitable for microscopical examination.

The ratio which an inch of rain bears to an inch of snow varies according to the temperature, the thickness of the snow, the period during which it remains on the ground, etc. An average value of the ratio for freshly fallen snow is 12 to 1. According to Ward the variation extends from 5 to 1 to 50 to 1.

Snow Crystals.—Thin flat ice crystals of a hexagonal form. There are many patterns, and enlarged photographs of some of these by Bentley appear in the *Monthly Weather Review* of the United States Weather Bureau for November, 1924, and August, 1927. When snowflakes of various size are observed on any one occasion they are usually found to differ only by containing a larger or smaller number of such crystals.

Snow, Day of.—In British climatology any civil day upon which snow is observed to fall is regarded statistically as a " day of snow."

Snowdrift.—When snow falls on a day of strong wind it does not readily settle in open places, but will normally do so wherever there is a region which is sheltered from the full force of the wind. Much of the dislocation of traffic caused by heavy falls of snow is due to the " drifts " formed in this way. Drifts may even be formed when no snow is falling by the action of the wind upon already fallen snow ; snow carried in this way is called drift-snow and is denoted by a special symbol in the BEAUFORT NOTATION.

The word therefore has two meanings :—

(1) an accumulation of snow, forming drift ;
(2) snow that drifts with the wind.

Snow Line.—The lower limit in altitude of the region of perpetual snow. In high polar latitudes the snow line is at sea level, in northern Scandinavia, it is at about 4,000 ft., in the Alps at about 8,500 ft., in the Himalayas at about 15,000 ft. These figures are only approximate as the height of the snow line varies on the north and south sides of a mountain and from one mountain to another in the same latitude or region. It has no direct relation to the mean annual temperature, depending more on the summer temperature, but many other factors exert an influence, such as amount of snow in winter, prevailing winds, exposure and steepness of the slopes, etc.

Snow Lying.—This expression is used in the BEAUFORT NOTATION for occasions when more than half the country in sight from the observing station is covered with snow. In British climatological statistics it is used only when this state of affairs exists at the hour of morning observation (normally 9h., G.M.T.).

Snow Rollers.—Cylinders of snow, formed and rolled along by the wind.

Soft Hail.—Pellets of closely agglomerated ice needles, sometimes striated in structure. The conditions of formation are not always the same as for true HAIL. Soft hail has a rate of fall more comparable with that of snow. According to Wegener there are two kinds analogous to RIME and HOAR FROST. The first (*Reifgraupeln*) often breaks to pieces on striking the ground ; it appears to lie near the border line between snow and soft hail. The second (*Frostgraupeln*) is often conical ; the nucleus of true hail often resembles it.

Solano.—A hot, dusty, moist, south-easterly or easterly wind which occurs on the east coast of Spain and in the Straits of Gibraltar.

Solar Constant.—The so-called " solar constant " is the intensity of the radiation in the solar beam in free space at the earth's mean solar distance.

Recent investigations indicate that the solar constant is not invariable. These investigations, by Dr. C. G. Abbot and his colleagues in the Smithsonian Institution, are based on observations made at stations on high mountains in desert climates. The measurements are such that the extent to which the radiation is cut off by the atmosphere can be estimated and allowed for.

The mean value of the solar constant is about 1·93 gramme-calories per square centimetre per minute, 135 mw/cm.^{2} According to the observations made in Chile from 1918 to 1926 the range* of fluctuation in the monthly means was from 1·969 in September, 1921, to 1·912 in July, 1922. The changes in the solar constant are found to be associated with changes in the constitution of the radiation. The amount of radiation of long wave-lengths does not vary ; it is the energy in the blue, violet and especially in the ultra-violet that fluctuates. In other words the sun is a variable star which undergoes changes of colour.

Solar Day.—See EQUATION OF TIME, CALENDAR.

Solar-Radiation Thermometer.—See BLACK-BULB THERMOMETER.

Solarimeter.—An instrument designed by L. Gorczynski for determining the intensity of solar radiation. It consists essentially of a sensitive thermopile of low thermal capacity and low resistance connected in series with a millivoltmeter. According to the method of mounting, it may be used to determine the intensity of the normal solar radiation or the vertical component of the total radiation from sun and sky. If a recording milli-voltmeter is substituted for the direct reading instrument, the combination is known as a " solarigraph."

Solarisation.—Exposure to direct sunlight.

Solstice.—The time of maximum or minimum declination of the sun, when, for a few days, the altitude of the sun at noon shows no appreciable change from day to day. The summer solstice for the northern hemisphere, when the sun is farthest north of the equator, is about June 21, and the winter solstice, when it is farthest south, is about December 21. After the summer solstice the days get shorter until the winter solstice and vice versa.

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* *Smithsonian Misc. Coll.*, 82, No. 2, p. 6.

Sounding Balloon.—For the purpose of measuring pressures and temperatures, etc., in the upper air, a balloon is employed larger than a pilot balloon, having a diameter at ground level when inflated with hydrogen of about four feet. This balloon carries a light meteorograph attached to a bamboo framework or "spider." In order that the meteorograph may be some distance from the balloon, which is likely to become heated owing to sunshine, a special launcher is employed; this launcher gradually unwinds a length of cotton thread as the balloon ascends, finally leaving the meteorograph some hundred feet below the balloon. The balloon rises, expanding as it goes, and ultimately bursts, probably having reached an altitude of over 12 miles. The remains of the balloon, together with the instrument, then fall to the ground, the bamboo framework protecting the instrument from mechanical injury. A label is attached asking the finder to return the meteorograph. It occasionally happens that a balloon, which for some reason does not burst, floats for many hours and is carried hundreds of miles before falling to earth. The meteorograph, designed by the late W. H. Dines, weighs 2½ ounces, including the aluminium case, while the bamboo framework weighs about 1¾ ounces. Owing to this light weight, no parachute or other appliance in addition to the bamboo framework, is needed to break the fall.

The meteorograph referred to is constructed as follows. The pressure recorder operates by means of an aneroid box, the sides of which are connected by arms with the scribing point and the record plate, thus an expansion or contraction of the box results in a movement of the point across the plate. The thermograph for recording temperature consists of an invar rod and a thin strip of nickel silver, rigidly fastened together at their lower ends, and connected to a lever by spring joints at their upper ends. The expansion and contraction of the strip of nickel silver relative to the nearly invariant invar rod, cause a vertical movement of the scribing point relative to the plate. During calibration, definite marks at known pressures and temperatures are made on the actual record plate, and the final trace can be compared with these marks. The actual trace on a silvered plate is very durable, and even if the meteorograph lies out in the open for months before being found, the record is unlikely to be damaged.

A modification of the above arrangement is required in the case of temperature records over the sea. If a meteorograph were carried by a single balloon, the instrument would be lost owing to sinking should the balloon burst. It is necessary, therefore, to employ two balloons of a larger size than those mentioned above. The two balloons are flown tandem fashion, and the top balloon is inflated to have a lift of about 8 lb., while the lower balloon has a lift of some 2 lb. A sea-anchor float is carried about 30 ft. below the meteorograph. Upon release the balloons and meteorograph, etc., ascend, the upper balloon ultimately bursts (being more fully inflated than the lower balloon) and the lower balloon allows the apparatus to descend to the water, where, relieved of the weight of the sea-anchor, the small balloon is capable of supporting the meteorograph and keeping it clear of the surface of the sea. The floating balloon is easily observed and the meteorograph recovered. Instead of relying upon the upper balloon to burst, a special dropper may be used to release the top balloon at a given altitude. A similar system of two balloons is employed when heavier instruments are used.

The results of numerous ascents are given in the diagram (Fig. 24) which exhibits graphs of temperature and height for 45 soundings.* It will be noticed that, with one or two exceptions, the balloons reached a position (approximately six or seven miles) above which the temperature ceased to fall, yet the range of temperature at that level is large. (See STRATOSPHERE, TROPOSPHERE.)

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* See also *London, Meteor. Office, Geophys. Mem.* No. 5, 1913 The international kite and balloon ascents, by Ernest Gold.

CURVES SHOWING CHANGE OF TEMPERATURE WITH HEIGHT ABOVE SEA-LEVEL OBTAINED FROM BALLON-SONDE ASCENTS 1907-8.

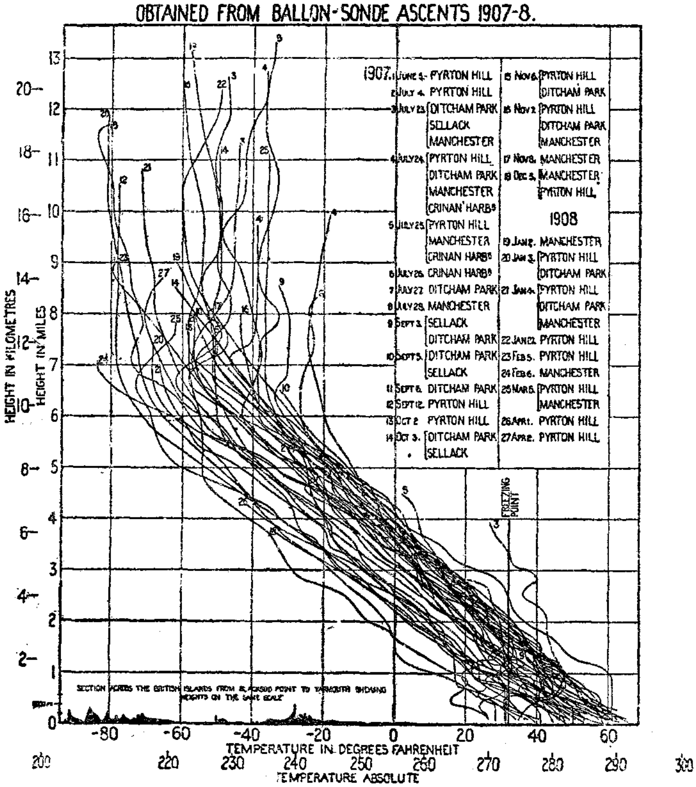

FIG. 24.

The separate curves represent the relation between temperature and height in miles or kilometres in the atmosphere. The numbers marking the separate curves indicate the date of ascent at the various stations as shown in the tabular columns. The difference of height at which the isothermal layer is reached, and the difference of its temperature for different days or for different localities, is also shown on the diagram by the courses of the lines.

Normal Pressure for the Several Months at Various Heights over S.E. England

(Computed from Sea-level Pressures at Kew, and the Temperatures in Table IV. 2 Computer's Handbook, II. * 2. 53.)

Height	January	February	March	April	May	June	July	August	September	October	November	December	Range
Km.					Pressure in	millibars.							
15	116	116	116	118	121	123	125	125	124	122	119	117	9
14	136	135	136	138	142	144	146	146	145	142	139	137	11
13	159	159	159	162	165	168	170	170	169	166	163	160	11
12	187	186	186	189	193	196	199	198	198	194	191	188	13
11	218	217	217	221	226	229	232	232	231	227	223	220	15
10	255	254	254	259	264	267	270	270	269	265	260	256	16
9	297	297	297	302	307	311	314	313	312	308	303	299	17
8	346	346	346	350	356	360	363	362	361	356	351	347	17
7	401	401	400	405	410	415	417	416	416	411	406	402	17
6	463	462	462	467	472	476	478	478	477	472	468	464	16
5	532	532	531	535	540	544	546	546	545	540	536	533	15
4	610	609	608	612	616	620	621	621	620	616	612	610	13
3	696	695	693	697	701	704	705	705	704	700	697	695	12
2	792	790	789	791	795	797	798	797	798	794	792	790	9
1	899	897	895	897	900	901	902	900	902	898	897	896	7
Gd.	1,018	1,016	1,014	1,014	1,016	1,016	1,016	1,015	1,017	1,014	1,014	1,014	4

At all heights above the ground level the maximum pressure occurs in the hottest months. The seasonal variation in the normal pressure at sea level is small.

Table of Results obtained with Sounding Balloons in the United Kingdom.

* Normal Temperature at different levels in the atmosphere up to twelve kilometres for the several months of the year.

Height in Km.	January	February	March	April	May	June	July	August	September	October.	November	December	Year
	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.
12	217	218	219	220	221	222	222	221	221	219	218	217	220
11	17	17	17	19	20	21	22	22	21	20	19	18	19
10	20	20	20	22	24	25	26	26	26	24	23	21	23
9	24	23	24	26	29	31	34	33	33	31	28	25	28
8	30	29	30	32	36	38	41	41	41	38	35	32	35
7	37	36	37	39	42	45	47	48	47	45	41	38	42
6	43	43	44	46	49	52	55	55	54	51	49	45	49
5	50	49	50	52	56	59	61	62	61	58	55	52	55
4	57	56	57	59	62	65	67	68	67	64	61	58	62
3	63	62	63	65	68	71	73	74	73	70	67	64	68
2	67	66	67	70	73	76	78	79	78	75	72	69	73
1	71	71	73	76	79	82	83	83	81	79	75	72	77
Gd.	76	76	77	82	85	88	89	89	86	83	80	77	82

* Taken from *London, Meteor. Office, Geophysical Memoirs* No. 2 (W. H. Dines).

Southerly Burster.—A name given in south and south-east Australia to a sudden change of wind from a north-easterly direction to a southerly or south-easterly direction, which is accompanied by a sudden fall in temperature. This change of direction occurs behind a V-SHAPED DEPRESSION, the point of the "V," in the southern hemisphere, being directed towards the equator, and if the rise of pressure is considerable the southerly wind is violent. The temperature sometimes falls as much as 30°F. or 40°F. in half an hour. These storms may last only a few hours, but sometimes they continue for several days. They are frequently accompanied by thunder and lightning. They are similar to the PAMPEROS of South America and the LINE SQUALLS of our latitudes. They are most prevalent from October to March.

Spring.—See SEASONS.

Squall.—A strong wind that rises suddenly, lasts for some minutes, and dies comparatively suddenly away. It is frequently, but not necessarily, associated with a temporary change in direction. The most important squalls in the British Isles, especially from the view-point of aviation, are the LINE-SQUALLS in which the heavy increase in velocity is accompanied by a veer of some 3 to 8 points and with which are associated the long arch of low black cloud (which gives the squalls their name) and rain or hail with a sudden drop of temperature. Squalls are to be distinguished from gusts, the constant fluctuations which occur in any wind due to local obstructions and surface friction.

Squall Line.—The name originally given to what is now known as the COLD FRONT of a depression. It marks the line along which cold air is undercutting warm air. Its passage is marked usually by squalls (hence the older name), and, in such countries as the British Isles, it is also associated with heavy cloud and rain or hail. With its passage the barometer rises abruptly and there is a sudden or rapid fall of temperature. (See LINE-SQUALL.)

Stability.—A state of steadiness not upset by small deplacements or disturbances. (See INSTABILITY.)

Standard.—A prescribed measure or scale of any kind, such as a weight, length, volume, etc., which is used as a unit or scale of reference. The legal magnitude of a unit of measure or weight.

Standard Atmosphere.—The standard atmosphere, regarded as a unit of pressure, is equal to the BAR.

The International Standard Atmosphere which is used as the basis of graduation of altimeters assumes at mean sea level a temperature of 15°C., a pressure of 1,013·2 mb., and a lapse rate of 6·5°C. per kilometre from sea level up to 11 Km., above which the temperature is assumed constant at − 56·5°C.

Standard Deviation.—If n observations of a quantity are x_1, x_2, . . x_n, and their mean or average is $\bar{x}$, defined by $n\bar{x}$ = sum of the n individual observations, the standard deviation σ is defined by the equation :—

$$n\,\sigma^2 = (x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ .\ .\ + (x_n - \bar{x})^2$$

When the observations are distributed according to the NORMAL LAW of errors, there are certain theoretical advantages in using $(n - 1)\ \sigma^2$ instead of $n\sigma^2$ on the left hand side of the equation above, but in practice the difference between the two formulae is small.

The square of the standard deviation is called the *variance.*

Standard Gravity.—The value of g, the acceleration due to gravity, to which observations of barometric pressure are reduced before being plotted on a synoptic chart. The value chosen is 980·665 dynes, which at the time of its adoption in 1887 was believed to be the true value at sea level in latitude 45°. More recent determinations give the value as 980·621 dynes, but the difference of ·044 dyne is within the range of variation on any parallel of latitude due to local anomalies.

Standard Temperature.—The temperature at which a mercurial barometer reads true millibars at sea level in lat. 45°. It is clearly desirable that in any barometer the standard temperature should not differ much from the average temperature of the place where it is used, and a value of 285°A. is aimed at for barometers used in this country. This is secured if the barometer has no index error and the scale is engraved in accordance with the relationship 1 barometer millibar = ·0295975 barometer inch.

Standard Time.—Time referred to the mean time of a specified meridian. The meridian of Greenwich is the standard for western Europe. The standard meridian for other countries is generally chosen, so that it differs from Greenwich by an exact number of hours or half-hours. (See also ZONE TIME.)

State of the Ground.—See GROUND, STATE OF.

State of the Sky.—Fraction of the sky obscured by cloud on a scale of 0 (cloudless) to 10 (an entirely overcast sky in which no patches of blue sky are visible). In the BEAUFORT NOTATION letters b, blue sky whether with clear or hazy atmosphere, c, cloudy, i.e. detached opening clouds, o, sky overcast with one impervious cloud, g, gloom, and u, ugly, threatening sky are also used in addition or alone to indicate the general appearance of the sky. (See " Meteorological Observer's Handbook.")

Station.—In meteorology, the word signifies a fixed place where regular meteorological observations are made. Stations vary greatly from one another in equipment and in the character and extent of the observations made, but at all stations which report to a central Meteorological Office the observations are made on a uniform plan and according to a set time-table, so that the results or summaries of them can be published in an orderly way, rendering comparisons easy and reliable.

The number of stations in the British Isles is about 5,000 ; by far the majority of these are maintained by voluntary observers who in most cases report measurements of rainfall only.

The International Congress of Meteorologists which assembled at Vienna in 1873, adopted a classification of stations, based on the scheme of observations to be taken, which is described in the "Meteorological Observer's Handbook," as follows :—

(1) First-order stations of the International Classification. Normal meteorological observatories : at which continuous records, or hourly readings, of pressure, temperature, wind, sunshine, and rain, with eye observations at fixed hours of the amount, form, and motion of clouds and notes on the weather, are taken.

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

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

This classification serves to indicate the kind of differences which still exist between meteorological stations at which observations are made of elements besides rainfall, but the classification does not take effective cognizance of types of stations which are now in operation for certain specific purposes. For example :—

(*a*) *At telegraphic reporting stations* observations are made daily at some or all of the hours 1h., 7h., 13h., 18h., 21h. G.M.T. and telegraphed to the central office for use in the preparation of synoptic charts for weather forecasting. Other kinds of observations have been introduced, particularly cloud height, change in barometer in last 3 hours, visibility, sea disturbance.

(*b*) *At stations on aerodromes* observations are often made every hour for the benefit of pilots. Visibility, cloud, and the motion of upper currents are important items of the programme. In addition, these stations are equipped as first-order stations and a corresponding programme of work is carried out.

(*c*) *At agricultural-meteorological stations* ("crop-weather" stations) special attention is given to humidity, wind and the temperature of the soil at depths of 4 in. and 8 in.

(*d*) *At health-resort stations* special observations are made in the late afternoon mainly for purposes of advertisement. These observations are telegraphed to London and issued to the daily press as a special bulletin.

Statistics.—Accumulations of numerical facts. The science of statistics is concerned with the development of methods of dealing with large quantities of numerical data, and of representing their essential features by a small number of parameters. A large amount of work on these lines has been done in connection with distributions of data which follow the normal error law, the essential features of the distribution being represented by the mean of the observations, and their probable error (or STANDARD DEVIATION). (See also ERROR, PROBABILITY.)

Stefan's Law.—The law, discovered empirically by Stefan and afterwards demonstrated theoretically by Boltzmann, that the total radiation in all directions from an element of a perfect radiator is proportional to the fourth power of its absolute temperature. (See RADIATION, *Black-body radiation*.)

Steppe.—A name given to the grassy, treeless plains in Russia and Siberia. The word is sometimes extended to mean similar plains and regions of semi-ARID climate elsewhere.

Storm.—The term "storm" is commonly used for any violent atmospheric commotion, such as a violent gale, a thunderstorm, a line-squall, a rainstorm, dust storm or snowstorm.

Winds with velocity between 64 and 75 miles per hour (force 11 on the BEAUFORT SCALE) are classed as storm winds.

Storm Cone.—See GALE WARNING.

Storm, Eye of.—See EYE OF STORM.

Strato-Cumulus (St.-Cu.).—*Large lumpy masses or rolls of dull grey cloud, frequently covering the whole sky, especially in winter* (Figs. 10 and 11). Generally strato-cumulus presents the appearance of a grey layer broken up into irregular masses and having on the margin smaller masses grouped in flocks like ALTO-CUMULUS. Sometimes this cloud form has the characteristic appearance of great rolls of cloud arranged in parallel lines close together. (ROLL-CUMULUS.) The rolls themselves are dense and dark, but in the intervening spaces the cloud is much lighter and blue sky may sometimes be seen through them. Strato-cumulus may be distinguished from NIMBUS by its lumpy or rolling appearance, and by the fact that it does not generally tend to bring rain. (See CLOUDS.)

Stratosphere.—The external layer of the atmosphere, in which there is no convection. It has also been called the advective region for this reason. The temperature of the air generally diminishes with increasing height until a point is reached where the fall ceases abruptly. Above this point lies the stratosphere, which is a region in which the temperature is practically constant in the vertical direction. The term "isothermal layer" has sometimes been applied to it, but this is misleading, as the temperature changes in a horizontal direction. Further a large proportion of ascents with sounding balloons made in different parts of the world reveal an increase of temperature with height in the lowest layers of the stratosphere. The horizontal temperature gradient is never large, but an inspection of the diagram reproduced under SOUNDING BALLOON, representing the result of a large number of soundings in the British Isles, shows that the range of temperature at the highest layer is greater than the range at the surface.

We are still without any effective explanation of the origin of differences of temperature which are found in the stratosphere; they must probably be classed among the most fundamental characteristics of the general circulation of the atmosphere and among the primary causes of the changes of weather, but hardly any light has been thrown on the mechanism of the process.

The height at which the stratosphere commences is often about ten kilometres, but varies. It is higher in the regions nearer the equator. (See TROPOSPHERE.)

Stratus (St.).—*A uniform layer of cloud like fog but not lying on the ground.*—The cloud layer of stratus is always very low. If it is divided into ragged masses it may be called fracto-stratus. The complete absence of details of structure differentiates stratus from other aggregated forms of cloud. (See CLOUDS.)

Subsidence.—The word used to denote the slow downward motion of the air over a large area which accompanies DIVERGENCE in the horizontal motion of the lower layers of the atmosphere. The greatest divergence is from regions of rapidly rising barometer and the subsidence is probably of the order of 100 to 300 ft. per hour is many cases. In stationary unchanging anticyclones the subsidence is due to the outward air flow at the earth's surface only, and is then very much slower. The subsiding air is warmed dynamically (see ADIABATIC) and its relative humidity therefore becomes low, occasionally falling below 10 per cent at about 4,000 to 6,000 ft. after prolonged subsidence. The downward movement and consequent warming increases with height, up to 10,000 ft. or perhaps more, so that the LAPSE-rate of temperature is *decreased, and* INVERSIONS *are often developed. The vertical velocity is obviously zero at the ground, but turbulence often mixes up the lower layers and brings* some of the warm dry air to the ground. Subsidence normally results in fine dry weather, but fog, stratus or strato-cumulus clouds may occur in certain conditions.

Sumatra.—A squall which occurs in the Malacca Straits usually blowing from the SW. It is accompanied by a characteristic cloud formation—a heavy bank or arch of cumulo-nimbus which rises to a great height. These squalls are more frequent at night, and between April and October. They are generally accompanied by thunder and lightning and torrential rain.

Summer.—See SEASONS.

Sun-dial.—The commonest form of sun-dial is a horizontal stone slab upon which a rod or style, called the gnomon, is set up in the astronomical meridian, inclined to the horizontal at an angle equal to the latitude of the place, or in other words, parallel with the earth's axis. The line traced by the shadow of the style at each hour of the day is engraved upon the slab. When the vertical plane through the style lies correctly in the meridian, after applying a correction for the EQUATION OF TIME, such a dial will give mean solar time whenever the sun is visible. To obtain Greenwich mean TIME a constant correction must be applied depending upon the longitude of the place.

By taking account of the length of the shadow as well as the line on the dial, the time of year can be indicated, and some dials are elaborately graduated as a perpetual calendar as well as time-keeper.

Sun-dogs.—A popular name for mock suns or PARHELIA.

The origin of the name sun-dog is not known. Possibly it implies that a parhelion follows the sun through the sky in the course of the day like a dog its master. The drawback to this explanation is that as a general rule sun-dogs do not last very long.

Sun Pillar.—A vertical column of light above (and sometimes below) the sun, most often observed at sunrise or sunset. The colour may be white, pale yellow, orange or pink. The phenomenon, which is due to the reflection of sunlight from small snow crystals, may be seen over a wide area. On March 13, 1924, it was observed all over the south of England from Cornwall to Norfolk.

Sunrise, Sunset.—The times at which the sun appears to rise and set, in consequence of the rotation of the earth on its axis. Owing to the effect of atmospheric refraction, which increases the apparent angular altitude of the sun when near the horizon by about 34′, sunrise is earlier and sunset later than geometrical theory indicates. There is a further uncertainty caused by the fact that the sun has an appreciable diameter so that time elapses between the first and last contacts with the horizon. For meteorological purposes allowance is made for refraction and it is assumed that sunrise and sunset occur when the *centre* of the sun's disc is on the horizon.

The times of sunrise and sunset vary with the latitude and with the declination of the sun. Diagrams illustrating the variations, so far as the British Isles are concerned, are given in the "Meteorological Observer's Handbook," while pamphlets (Forms 3301, 3302), which are obtainable from the Meteorological Office, contain tables suitable for the calculation of the possible duration of sunshine at any place between latitudes 50° and 60° and 30° and 48° N. respectively, at any time of year. From this information the times of sunrise and sunset are readily deduced.

Sunrise and Sunset Colours.—The general explanation of the variety of colours that are to be seen in the sky about the time of sunrise or sunset is as follows. White light such as that from the sun may be regarded as composite, the constituents being light of all the colours of the spectrum. When the light waves meet obstacles in their course, such obstacles as the molecules of the atmospheric gases or larger obstacles such as particles of dust, the waves are broken and secondary waves proceed in all directions from the obstacles. The direct light is therefore reduced in strength and the further the light goes through an atmosphere of such obstacles the more the strength is reduced, the energy being used up in producing scattered light. This effect is more pronounced with blue light for which the wave-length is short than with red light for which the wave-length is longer. Accordingly a beam of white light passing through air loses the constituents of shorter wave-length and becomes yellow, then orange and finally red.

This accounts for the changing colour of the sun as it nears the horizon. The scattering by air alone merely makes the setting sun yellow but if there is dust in the air or even the nuclei on which water vapour is condensed then the sun becomes orange or red before it sets.

Clouds which are illuminated by the light from the setting sun are also red whilst other clouds which are illuminated by scattered light in which the blue constituents are present are white or grey; higher clouds illuminated by light which has only passed through less dense and cleaner air may also appear white.

The colours of the sky itself are to be explained in the same way. When sunlight has already travelled a great distance through the lower atmosphere it has lost the constituents of short wave-length and in the light which remains to be scattered the longer wave-lengths predominate. Further in the passage of scattered light to the eye of the observer the longer wave-lengths have the preference.

When we look at the sky in a particular direction we receive light which has been scattered by the atmosphere at all heights; in the light scattered at great heights blue may predominate whilst that coming from the lower levels may be red. The combination of light from both ends of the spectrum gives us purple. On the other hand in other parts of the sky the middle wave-lengths may predominate and the resulting colours are green or yellow. It may even happen that the result is practically white as in the *Dämmerungschein* sometimes observed above the sun when it is near the horizon.

Detailed descriptions of the changing illumination of the sky about the time of twilight have been published by several observers, the latest and most detailed being in a work by Gruner and Kleinert (Hamburg, 1927) devoted to observations in Switzerland.

The popular and ancient belief that a "red sky at night" is a good prognostic of fine weather is probably justified since the "red sky" implies present fine weather over a considerable area to the west. Statistical investigations in London bear this out to some extent, and also the tendency for a "red sky in the morning" to be followed by rain. (*Meteorological Magazine*, **61**, 1926, p. 16.)

Sunshine.—An important climatological factor that is determined by a SUNSHINE RECORDER. Radiation from the sun is a mixture of radiations of different wave-lengths at different intensities. The sunshine which renders objects visible to the eye comprises that portion of the whole of the radiation from the sun which has wave-lengths varying from about $0 \cdot 4\mu$ (μ = one thousandth of a millimetre) to about $0 \cdot 8\mu$, the former corresponding with violet light and the latter with red light, while in between the two are found the other "colours of the rainbow" in the order indigo, blue, green, yellow, orange. As received at the confines of the earth's atmosphere the intensity of the violet light is much greater than that of the red light, but the radiation of shorter wave-length is more readily scattered by the earth's atmosphere than that of longer length, hence the proportions at the surface are very different. When the sunlight has to pass through a long length of dust-laden atmosphere, as at sunset in many cases, the longer wave-lengths so preponderate that red is the dominant colour of the setting sun.

The sunshine recorder referred to above makes use of the heat radiation of the sun, which comprises principally the red rays and the infra-red. The latter are invisible and of slightly longer wave-length than the red rays. Sunshine recorders have also been constructed which utilise the so-called " actinic " or photographic rays of the sun. These are in the violet and ultra-violet portion of the sun's spectrum, the ultra-violet being invisible rays of rather lower wave-length than the violet. The results given by the two types of instrument cannot be expected to be comparable and indeed they are not so.

The therapeutic qualities of ultra-violet light have received much attention of late. Sunshine rich in this light is found at high levels above the lower and denser layers of the atmosphere.

Sunshine records obtained in the British Isles show that sunshine is more abundant on the coast than inland, and that, broadly speaking, the mean sunshine per day expressed in hours increases from the north-west towards the south-east in all months of the year, in spite of the fact that at mid-summer the possible daily duration of sunshine in the north of Scotland is about two hours greater than in the south of England.

Normal values of sunshine duration for stations and districts of the British Isles for the 35 years 1881–1915 are given in the " Book of Normals of Meteorological Elements for the British Isles," Sections I–III. In the following table district values for the year have been expressed as percentages of the total possible duration for each district.

Percentages of possible duration of sunshine for the whole year for districts in the British Isles (averages from records extending over the 35 *years,* 1881–1915)

Western side	Per cent	Middle districts	Per cent	Eastern side	Per cent
Scotland, W. ..	30	Scotland, N. ..	25	Scotland, E. ..	30
Ireland, N. ..	29	England, N.W. ..	32	England, N.E. ..	32
Ireland, S. ..	32	Midland Counties	31	England, E. ..	35
		England, S.W. ..	35	England, S.E. ..	37
		English Channel ..	42		

Sunshine Recorder.—An instrument for recording the duration of bright sunshine. In the Campbell-Stokes recorder a spherical glass lens focuses the solar image on a graduated card held in a frame of special design. The duration of sunshine is indicated by the length of the burnt track of the image. (See "Meteorological Observer's Handbook.")

Sunspot Numbers.—The numbers which are used to represent the variation in the sun's surface from year to year as regards spots. The occurrences of dark spots, sometimes large, sometimes small, which are to be seen from time to time on the sun's face between its equator and forty degrees of latitude north or south, have long been the subject of observation. An irregular periodicity in their number was discovered by Schwabe of Dessau in 1851, using 25 years of observation. Professor R. Wolf of Zürich, by means of records in a variety of places, made out a continuous history of the sun's surface from 1610 to his own time, which is now continued by his successor, Professor Wolfer. The sunspot number N is obtained by the formula $N = k\,(10g + f)$, in which g is the number of groups of spots and single spots, f is the total number of spots which can be counted in these groups and single spots combined, k is a multiplier representing " personal equation " which depends on the conditions of observation and the telescope employed. For himself when observing with a three-inch telescope and a power of 64 Wolf took k as unity.

The method of obtaining the number seems very arbitrary, but from the examination of photographic records by Balfour Stewart and others it is proved that the numbers correspond approximately with the " spotted area" of the sun. One hundred as a sunspot number corresponds with about 1/500 of the sun's visible disc covered by spots including both umbras and penumbras. (See "The Sun," by C. G. Abbot, 1912.)

Spots are now regarded as vortical disturbances of the sun's atmosphere. The sense in which the vortices rotate can be determined by spectroscopic observations. It is doubtful whether individual sunspots have any direct influence on terrestrial phenomena but the epochs at which sunspots are numerous are those at which other forms of solar activity develop. The clearest evidence for this association is in the case of auroral displays and magnetic storms. The amplitude of the regular diurnal changes in terrestial magnetism even on quiet days free from magnetic storms is increased at the epochs of high sunspot numbers. There is evidence that the amount of heat received from the sun is higher at such epochs and that in certain tropical regions rainfall and cloudiness increase. One of the most striking relations is the correlation between the sunspot number and the variation of level of the water in Lake Victoria at Port Florence.* In this case the correlation coefficient is + ·8.

The mean interval between the maxima in sunspot numbers is 11·1 years but the recurrence is by no means strictly periodic ; the maxima are not of equal strength and the interval fluctuates between 9 and 13 years.

The following is the list of sunspot numbers since 1750 :—

TABLE OF SUNSPOT NUMBERS, 1750–1927.

—	0	1	2	3	4	5	6	7	8	9
1750 ..	83	48	48	31	12	10	10	32	48	54
1760 ..	63	86	61	45	36	21	11	38	70	106
1770 ..	101	82	66	35	31	7	20	92	154	126
1780 ..	85	68	38	23	10	24	83	132	131	118
1790 ..	90	67	60	47	41	21	16	6	4	7
1800 ..	14	34	45	43	48	42	28	10	8	2
1810 ..	0	1	5	12	14	35	46	41	30	24
1820 ..	16	7	4	2	8	17	39	50	62	67
1830 ..	71	48	28	8	13	57	122	138	103	86
1840 ..	63	37	24	11	15	40	62	98	124	96
1850 ..	66	65	54	39	21	7	4	23	55	94
1860 ..	96	77	59	44	47	30	16	7	37	74
1870 ..	139	111	102	66	45	17	11	12	3	6
1880 ..	32	54	60	64	64	52	25	13	7	6
1890 ..	7	36	73	85	78	64	42	26	27	12
1900 ..	10	3	5	24	42	64	54	62	49	44
1910 ..	19	6	4	1	10	46	55	104	81	64
1920 ..	39	25	15	6	17	44	64	69		

Supersaturation.—The definition of SATURATION implies that minute particles of solid or liquid matter are present without which condensation of water vapour cannot take place. When such particles are artificially removed, the air can hold more water vapour than suffices for saturation as defined in this way, and under these conditions supersaturation takes place if saturated air be cooled.

Surface of Discontinuity.—In idealised theory this is regarded as a real impenetrable boundary surface separating the atmosphere into two portions which differ in temperature, humidity and wind velocity. Actually the discontinuity is usually primarily one of temperature and therefore of density, the pressure at any point on the surface being the same on the two sides. If the surface is sloping the isobaric surfaces are refracted at the surface of discontinuity, so that there is a discontinuity of wind velocity.

* *London, Meteor. Office, Geophys. Mem.*, No. 20, 1923.

The term is most often used in connection with FRONTS. The frontal surfaces are frequently not very sharp, but the term discontinuity is justified when one is dealing with large-scale phenomena. The SURFACES OF SUBSIDENCE are generally sharp.

Surface of Subsidence.—A SURFACE OF DISCONTINUITY is often developed in a subsiding mass of air, which is usually polar in origin. The primary cause is the dynamical warming due to the descending motion, as the result of which the air above the discontinuity has a low relative humidity. Frequently there is a sharp temperature INVERSION. These discontinuities are most frequent in anticyclones, and are then either horizontal or inclined at a very small angle. They also frequently occur some distance below a frontal surface (see FRONT) sloping down towards the line of the front on the ground, but inclined at only a small angle, usually of the order of 1 in 200. This angle is quite sufficient to give a pronounced wind discontinuity. The term "surface of subsidence" was introduced to apply more especially to such sloping surfaces, and to distinguish them from the frontal surfaces proper. The origin of the sharp inversion is not yet clearly understood, but it is almost certainly connected with the cloud-sheet (either continuous or broken) which is found under the inversion, at least while it is developing. These clouds are maintained by convection and turbulence, which are especially active when POLAR AIR is passing over a warmer sea surface, extending up to a limit which becomes lower and sharper as the air subsides. Above this level the descending air warms at the dry ADIABATIC rate, and below it at a lower average rate, depending on the amount of cloud. Probably radiation also helps to sharpen the inversion.

Surge.—First used by Abercromby to denote a general change of pressure superposed upon the changes which are due to the movements of DEPRESSIONS and ANTICYCLONES. Sometimes between two consecutive weather maps the isobaric systems are seen to have travelled across the map but to have changed their shape little while on closer examination it is found that pressure over the whole area has risen. A change of this type is referred to as a "surge."

Swell.—Swell is wave motion in the ocean persisting after the originating cause of the wave motion has ceased or passed away. It often so continues for a considerable time with unchanged direction, as long as the waves travel in deep water. The height of the waves rapidly diminishes but the length and velocity remain the same, so that the long low regular undulations characteristic of swell are formed. Swell is often observed to have a wave-length greatly in excess of that of waves seen during a storm: the probable explanation is that the longer waves are then masked by the shorter and steeper storm waves. Swell observations are useful as denoting the direction in which sea disturbance due to tropical cyclones or other storms has taken place.

Sympiesometer.—A form of BAROMETER, now obsolete, in which the greater part of the atmospheric pressure was balanced by enclosing air above the liquid. By using glycerine as the barometric fluid, a very open scale was obtained in a compact instrument, but temperature effects were troublesome.

Synoptic.—An adjective derived from the noun Synopsis "a brief or condensed statement presenting a combined or general view of something." In meteorology the word is generally used either in connexion with charts or with wireless or telegraphic messages. A synoptic chart shows the weather conditions over a large area at a given instant of time. Such charts are discussed under WEATHER MAP. A synoptic message contains reports from a selection of observing stations in a country or continent chosen to give a representation of the weather over that country or continent.

Temperature.—The condition which determines the flow of heat from one substance to another. Temperature must be clearly distinguished from HEAT, heat being a form of energy, while temperature is a factor which affects the availability of the energy. Temperature may be measured according to various scales, those in most frequent use being FAHRENHEIT, CENTIGRADE and ABSOLUTE TEMPERATURE. The word is used in a special sense in ACCUMULATED TEMPERATURE.

For the highest and lowest recorded air temperatures see ABSOLUTE EXTREMES.

Temperature Gradient.—When observations were first taken in the free air and the change of temperature with height became known, the term "temperature gradient" was used to express this change. The term thus meant the change of temperature in unit height. The word GRADIENT is used in other cases to denote the change of elements in the horizontal. Thus by "pressure gradient" is meant change of pressure per unit horizontal distance. It is better that the meaning of the word should be confined to change in the horizontal and the term "lapse-rate" or more shortly LAPSE has therefore been introduced for changes of temperature in the vertical leaving the term "temperature gradient" for changes of temperature in the horizontal.

Tendency.—See BAROMETRIC TENDENCY.

Tension of Vapour.—An old term for the pressure exerted by a vapour. (See VAPOUR PRESSURE.)

Tenuity Factor.—In BALLISTICS, the ratio of the density of air having the observed pressure at the surface, and temperature equal to the ballistic temperature, to the density of air at pressure 30 inches of mercury and temperature 60° F.

Tephigram.—A diagram on which is represented the condition of the atmosphere at different levels in terms of its temperature t and entropy ϕ, hence the name $t\,\phi$gram.

Tercentesimal Scale.—An approximate absolute scale of temperature, the tercentesimal temperature being obtained by adding 273° to the Centigrade temperature. (See ABSOLUTE TEMPERATURE).

Terrestrial Magnetism.—The earth has been happily described as a great magnet; the distribution of magnetic force at its surface may as a first approximation be regarded as that due to a uniformly magnetized sphere, whose magnetic axis, however, is inclined at some 10° or 12° to the axis of rotation (polar axis) of the earth. The actual magnetic poles are the one to the north of Canada (between Victoria and Baffin Islands), the other in the Antarctic (South Victoria Land). At these poles the dip needle is vertical, and the horizontal component of magnetic force vanishes; the compass needle has no guiding force and points anyhow. These poles do not coincide with the poles of the axis of uniform magnetization, nor are they at opposite ends of a diameter. At what may be called the magnetic equator, which is nowhere very far (comparatively speaking) from the geographical equator, the vertical force vanishes: the dip needle is horizontal, and the horizontal force has its largest values. The horizontal force in London is only about half that where the magnetic equator crosses India. The direction of the horizontal component of magnetic force is exactly true north-south (i.e., the magnetic declination is zero) only along two lines or narrow belts. One of these crosses Canada, the United States, and South America; whilst the other after crossing Finland, eastern Russia and Arabia, encircles China, Japan and a large part of Siberia in a large oval loop, and thence passes near to Sumatra and across western Australia towards the south magnetic pole. Within the region bordered on the west by the first and on the east by the second of these *agonic lines*, and within the east-Asian loop, declination is westerly. If we travel westward from the Asiatic-European agonic line the declination becomes increasingly westerly until we pass the western limits of Europe. Thus, the mean values for 1928 are at Helwan (Cairo)* 0° 24′ W., at Seddin 5° 59′ W., at Val Joyeux (Paris) 11° 20′ W., at Abinger (Surrey, England) 12° 47′ W., at Eskdalemuir (Dumfrieshire, Scotland) 15° 11′ W., at Cahirciveen (Kerry, Ireland) *17° 49′ W., and at Coimbra (Portugal) *14° 10′ W.. The values of the magnetic elements and the positions of isomagnetic lines change gradually with time, having what is known as "secular change," (see SECULAR TREND), the rate and the sense of which vary with time and locality. At London a change from easterly to westerly declination occurred about 1760; westerly declination increased to 24·6° in about 1818, since when there has been a continuous swing of the north end of the needle towards east. The rate of decrease in westerly declination in the British Isles has increased in recent years, the average annual rate since 1920 being 12′ as compared with about 9′ between 1910 and 1920 and 5′ between 1900 and 1910. In the same area the horizontal force has been decreasing since 1911, but changes in inclination (dip) are small at present. Various theories (including the existence of a permanently magnetised core, the rotation of electric charge or of separate electric charges, direct magnetisation by rotation) have been advanced in explanation of the cause of the earth's magnetism but none has been adequate to explain all the observed facts.

Diurnal variation.—In addition to secular change the earth's magnetic field experiences regular diurnal variation and also frequent irregular changes of varying magnitude. In magnetically quiet conditions, and more especially in non-polar localities, the regular diurnal changes are largest in daylight hours. In the northern hemisphere the prominent part of the daily variation in declination is a westerly movement from about 7h. to 13h. (local time), followed by a slower easterly movement. Speaking generally, the range of the diurnal variation in declination is least near the equator, where it may average less than 3′, and greatest near the magnetic poles, where it may exceed 1°. On the average quiet day in England the lowest value of horizontal force occurs between 10h. and noon, and the highest value in the evening or early forenoon according to the season; dip is greatest at from 9h. to 11h. (earlier in summer than in winter) and least at about 6h. in winter and at 18h. to 20h. in summer. Not only the type but the range of the diurnal variation varies with the season: the range being least in winter and largest in one of the summer months. At Kew Observatory, for instance, the diurnal inequality ranges in December and in the summer of the average year of the period 1890–1900 were respectively:—declination, 3′·3, 11′; dip, o′ ·6, 2′ ·1; horizontal force, ·00011, ·00039 c.g.s. units. The range of the regular diurnal variation and the mean absolute daily range vary considerably from year to year, showing a remarkably similar progression to that of sunspot frequency. In a year of sunspot maximum the range of the diurnal variation may be 50 per cent. or more larger than a few years earlier or later at sunspot minimum. The relative increase in diurnal inequality range associated with increase in sunspot number tends to be greatest in winter months; it appears to vary with locality and is not the same for all the magnetic elements.

Disturbance.—Disturbance or irregular fluctuation is present in varying degree on all but a comparatively few days, and is more prominent as the magnetic polar regions are approached. In a quiet year irregular changes in declination at Lerwick were found to be more than twice as large, on the average, as corresponding changes at Kew. Irregular disturbance changes in high latitudes are not only larger than, but may differ in sense and general character from, those simultaneously in progress in lower latitudes. In the latter regions of the earth disturbance changes tend to be largest in the horizontal component of force, but irregular changes in vertical force become increasingly important in higher latitudes. The frequency of occurrence of disturbance is greater in equinoctial than in other months; and, in Europe, greater between 15h. and 4h. G.M.T. than at other hours, being least during the three or four hours before noon. The incidence of

* Results derived from absolute observations only.

disturbance is greater in sunspot maximum than in sunspot minimum years, but the numerical relationship with the available measures of solar activity is smaller in the case of measures of magnetic activity than in the case of the range of the diurnal inequality. Disturbed, and also quiet, magnetic conditions tend to recur after the lapse of one or more solar rotation periods. No very close relationship has been established as yet between the degree of magnetic disturbance on a given day and solar conditions (as at present observed) on the same or on the few preceding days.

Causes of magnetic variations.—According to a widely accepted theory, due in the first instance to Balfour Stewart, the solar diurnal (and the much smaller lunar diurnal) magnetic variations are ascribed primarily to the existence of electric currents circulating in the upper atmosphere, such currents being engendered by electromotive forces induced by the large-scale tidal or quasi-tidal motions of the highly ionised upper atmospheric strata across the permanent magnetic field of the earth. The necessarily high degree of ionization of the atmospheric shell in question is attributed to the agency of solar ultra-violet radiation, and the known facts as to the magnetic diurnal variations suggest that the degree of ionization, and therefore the intensity of the ionising agent, varies with season and with the phase of the solar cycle. Magnetic disturbance originates in the polar regions and is apparently due to intense electric currents located in the upper atmosphere near to the zones of maximum auroral frequency (see AURORA). The high, and probably irregularly distributed, ionization of these polar belts is held to be produced by solar corpuscular emissions which, owing to the deflective force exerted by the earth's magnetic field, impinge on the atmosphere in a somewhat restricted region around each magnetic pole, giving rise to aurora. It is now well known that there is a close association between the problems of terrestrial magnetism and of radio-transmission and it is probable that work in these allied fields will go far to elucidate many of the mysteries as to the properties and also the movements of the upper atmosphere. Very recently certain of the inferences drawn from radio-transmission and other data as to the properties of the highly ionized region of the atmosphere have led to the suggestion that the regular diurnal, and possibly the disturbance, magnetic variations may be the result of the diamagnetic effect caused by ions (produced by ultra-violet radiation) spiralling about the earth's magnetic field in the region of long free paths.

Terrestrial Radiation.—See sub-heading under RADIATION.

Thaw.—The transition by melting from ice to water ; the term used to indicate the break-up or cessation of a FROST. In the British Isles the final disappearance of frost is due usually to the displacement of cold northerly or easterly winds by warm winds from the Atlantic, e.g., the final break up early in March of the prolonged frost of February, 1895 was due to the interruption of the air supply from the cold continent by the invasion as a southerly wind of a relatively warm current of air associated with the approach of a depression from the Atlantic. In more northern latitudes the "spring thaw" is a periodic event, denoting the seasonal progression, the unlocking of ice-bound seas, and the melting of the snow. In these latitudes in western Europe, though not in Canada or Asia, the sun is generally at sufficient altitude about noon, except near mid-winter, to effect a partial thaw by day, even in the midst of a protracted frost, if the sky is clear.

Theodolite, Pilot Balloon.—An instrument consisting of a telescope mounted to permit of rotation in altitude and azimuth and fitted with divided circles to permit of those co-ordinates being read. The telescope is fitted with a right-angled prism so that the observer continues to look horizontally into the eyepiece no matter what the altitude of the balloon.

Thermal Equator.—The line passing through the centre of the belt of high temperature which exists near the geographical equator. The thermal equator varies with the season, migrating north in the northern-hemisphere summer and south in the southern-hemisphere summer ; the amount of its migration, however, is less than that of the sun. It is also considerably influenced by the distribution of land and sea and the effect of ocean currents; for this reason its mean position does not coincide with the geographical equator, but lies to the north of it.

Thermodynamics.—That part of the science of heat which deals with the transformation of heat into other forms of energy and vice versa. See ENERGY and ENTROPY.

Thermogram.—The continuous record of temperature yielded by a THERMOGRAPH.

Thermograph.—A recording THERMOMETER. Many patterns are in use, the sensitive member being either a bimetallic spiral (Meteorological Office pattern), a Bourdon tube (Richard), a resistance element (Cambridge and similar recorders), a steel bulb filled with mercury (Negretti and Zambra distance thermograph) or an air bubble in the tube of a mercury in glass thermometer (photographic thermographs).

Thermometer.—An instrument for determining temperature, usually by means of the changes in volume of mercury or spirit contained in a glass tube with a bulb at one end. Mercury is preferred in all cases when the instrument is not required to indicate below $-40°$ F. or to show the minimum temperature over an interval.

In meteorology, the temperature of the air is usually required and precautions must be taken to avoid errors due to the effects of radiation, etc. Sufficient accuracy for practical purposes is obtained by exposing thermometers in a STEVENSON SCREEN. Alternatively the thermometers may be whirled or aspirated as in the Assmann PSYCHROMETER.

A spirit thermometer may be made to indicate the minimum temperature by inserting in the stem, before sealing, a dumbbell-shaped light glass index, and mounting the thermometer horizontally. As the temperature falls, the index is drawn towards the bulb, but is left behind when the temperature rises. A mercurial thermometer may be made to indicate the maximum temperature by constricting the stem just above the bulb. Mercury is forced through the constriction when the temperature rises, but is unable to return when the temperature falls.

For special purposes, use may be made of changes in electrical conductivity, of thermo-electric currents or of the dissimilar expansion of different metals, for indicating or recording temperature.

Thunder.—The noise which follows a flash of lightning, attributed to the vibrations set up by the sudden heating and expansion of the air along the path of the lightning, followed by rapid cooling and contraction. The distance of the lightning flash may be roughly estimated from the interval that elapses between seeing the flash and hearing the thunder, counting a mile for every five seconds.

The long continuance of the thunder is explained by the fact that the sounds from different parts of the lightning flash have different distances to travel to reach the observer. The changes in intensity are partly due to the crookedness of the flash but they may also be caused by variations in the amount of energy developed along its course. The fact that what appears to the eye to be a single flash may really be half a dozen flashes, all occurring within a second or less and following the same path, complicates the question. The sound may echo back from mountain sides but whether echoes from the clouds add to the reverberation is doubtful.

The distance at which thunder can be heard is, as a rule, surprisingly small, being usually less than 10 miles, though distances ranging up to 40 miles and over have been reported in extreme cases. Mr. R. S. Breton writing to the *Meteorological Magazine** from Tung Song, S. Siam, stated

* *Meteor. Mag., London,* **63,** 1928, p. **113.**

that he had timed thunder reaching him 200 seconds after flashes from a distant storm and that it was not rare for thunder to be heard there 180 seconds after the lightning. C. Veenema* quotes observations of 255 and 310 seconds made at Norderney, Prussia, on September 5, 1899. Observations made with the aid of balloons or on mountains have shown that sound does not travel easily downwards, and for this reason thunder caused by lightning flashes to the ground carries farther than thunder caused by flashes in the clouds. The sound travels farthest at night when the surface layers are in a stable condition, which is favourable for sound transmission.

Thundercloud.—A towering cumulus cloud which is always associated with thunderstorms. The technical name is CUMULO-NIMBUS. (See also CLOUDS.)

Thunderstorm.—Thunderstorms are caused by the powerful rising currents within fully developed CUMULO-NIMBUS clouds. In the British Isles they are neither so numerous nor so severe as in the tropics. They are most frequent in our eastern and midland districts, and a large majority, including all the really violent examples, occur in the summer half-year, especially from May to August. They are most frequent in the afternoons and evenings of sunny days, and in such conditions the heavy rain or hail causes marked local cooling and sometimes violent out-rushing squalls.

On the western coastal districts of the British Isles the storms are of a somewhat different type and occur with nearly equal frequency in the summer and winter seasons. (See attached table.)

The conditions required for a thunderstorm are, first, an adequate supply of moisture for cloud development (in the British Isles always below 10,000 ft., and almost always below 6,000 ft.); secondly, a LAPSE-rate of temperature in excess of the saturated ADIABATIC through a range of height of not less than 10,000 ft. above the cloud base, and usually much more in the case of severe storms. There are many hot summer days, especially in anticyclones, when these conditions are not fulfilled, so that the hottest summers are not in general the most thundery. The requisite conditions exist most frequently in shallow DEPRESSIONS or COLS. Given the favourable conditions up above, it is quite possible for severe storms to develop at night, provided there is some initial impulse to start off the cloud formation. This impulse is probably supplied by CONVERGENCE—an important factor at any time of day. Sometimes the convergence occurs along COLD FRONTS, which are often accompanied by thunderstorms, but only when the upper air conditions are suitable. They do not therefore, constitute an independent class of thunderstorms. The cold-front storms sweep broadside over the country, while some other storms develop along a belt and move end on, occasionally lasting for some hours at one place. In general thunderstorms drift with the wind at their level, but the variation of wind with height, and the development and dissolution of parts of the cloud mass, often make their movements complex. They occasionally travel at a high speed (up to 50 mi./hr.) from south or south-west, while near the ground the wind is relatively light, and usually blows from the E. or S.E.

Showers in deep POLAR CURRENTS are often accompanied by thunder, especially near the western seaboard in winter, and in eastern districts on summer days, with a temperature frequently below normal even at the surface, but with a much greater deficiency above. Such storms are usually of slight intensity.

For an account of the distribution of thunderstorm frequency in other parts of the world see *London, Meteor. Office, Geophysical Memoirs*, No. 24.

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* *Wetter, Berlin*, **34**, 1917, p. 192.

Immunity from Thunderstorms in various parts of the United Kingdom as shown by observations extending mainly over the 35 years 1881–1915.

Table of "odds against one," expressing the random chance of a thunderstorm on any day in the several seasons of the year

		Station	Spring	Summer	Autumn	Winter
SCOTLAND	NORTH	Sumburgh Hd. (Shetland) ..	804	178	317	350
		Deerness (Orkneys)	152	34	61	54
		Stornoway (Stornoway) ..	200	82	132	82
		Wick (E. Coast)	133	37	132	242
		Fort Augustus (Inland) ..	114	44	302	192
		Dunrobin Castle (N.E. Coast)	459	74	530	1,578
	EAST	Nairn (N.E. Coast)	188	30	397	1,578
		Aberdeen (E. Coast) ..	100	19	176	630
		Dundee (E. Coast)	63	16	109	1,051
		Leith (E. Coast)	123	24	186	350
	WEST	Laudale (W. Coast)	37	24	40	29
		Rothesay (Island)	43	32	71	78
		Glasgow (W. Coast) ..	59	22	144	112
		Pinmore (Sub Coastal) ..	81	39	86	89
		Douglas (Isle of Man) ..	53	20	43	174
IRELAND	NORTH	Malin Hd. (N. Coast) ..	105	34	127	139
		Blacksod Point (W. Coast) ..	133	62	176	82
		Markree Castle (Inland) ..	53	24	105	46
		Armagh (Inland)	88	24	415	411
		Donaghadee (E. Coast) ..	97	38	167	350
	SOUTH	Dublin (E. Coast)	63	16	85	224
		Birr Castle (Inland) ..	86	35	211	350
		Valentia (S.W. Coast) ..	66	52	70	47
		Roches Point (S. Coast) ..	74	37	109	185
SCILLY AND CHANNEL ISLANDS		St. Mary's (Scilly)	91	44	68	68
		St. Aubins (Jersey)	35	17	27	52
ENGLAND	NORTH-EAST	N. Shields (E. Coast) ..	80	20	105	350
		Durham (Inland)	26	10	83	525
		York (Inland)	28	12	79	630
		Spurn Head (E. Coast) ..	29	10	65	394
	EAST	Yarmouth (E. Coast) ..	44	12	75	262
		Cambridge (Inland)	23	9	53	350
	MIDLAND COUNTIES	Loughborough	31	10	64	788
		Cheltenham	32	14	78	209
		Oxford	32	12	63	525
	SOUTH-EAST	Margate (E. Coast)	48	17	103	698
		St. Leonards (S. Coast) ..	41	14	39	157
		Dover (S.E. Coast)	42	15	52	262
		Southampton (Estuarine) ..	36	17	55	149
	NORTH-WEST	Stonyhurst (Inland)	21	8	26	84
		Liverpool (W. Coast) ..	43	19	68	174
		Llandudno (W. Coast) ..	63	29	61	157
		Holyhead (W. Coast) ..	63	27	57	209
	SOUTH-WEST	Portland Bill (S. Coast) ..	63	32	77	209
		Pembroke (W. Coast) ..	123	72	93	315
		Falmouth (S.W. Coast) ..	108	43	61	89

Tide, Influence on Winds.—In some bays and estuaries where the rise and fall of the tide is considerable a slight motion of the air, landward where the tide is coming in or seaward where the tide is going out, is said to have been observed, giving rise to an appreciable wind in calm weather or to an increase in force and gustiness where the tide assists the direction of the general wind at the time. The subject cannot, however, be said to have really been investigated and such winds if they exist will be extremely local and transitory in character. To establish them fully they would have to be distinguished not only from the general wind prevailing over a wide area at the time, but also from other local winds, in particular from land and sea breezes. Sailors and others have also asserted that weather changes set in with "the turn of the tide" and the upcoming tide in estuaries is said to produce showers of a very local type, not extending far from the river banks, on days when the weather conditions are such that precipitation is imminent. Abercromby observed a well-defined tidal variation of the trade wind in Fiji and Hazen found a marked increase of thunderstorms in the United States with a rising as opposed to a falling tide. There is always the risk that meteorological events may be related in the popular mind with tidal changes simply because the latter afford a convenient subdivision of the 24-hour day with which to associate changes that may really have been distributed over periods of several hours.

Time.—When the centre of the sun is due south of an observer, the time is called 12h., or noon, *local apparent time* (L.A.T.). The sun is said to "transit" at this time. The interval between two consecutive transits of the sun can be divided into 24 equal parts, and the times where the lines of division fall are numbered 13h., 14h., etc. . . . 23h., 24h. (or midnight), 1h., 2h. . . . 12h. Local apparent time is recorded by sunshine recorders and sundials.

The interval of time between successive transits of the sun is not quite constant, but goes through a cycle of changes during the year. This is due to the two facts that the orbit of the earth is elliptical, and that the earth's axis is not at right angles to its orbit. For details books on astronomy may be consulted. As it would be very inconvenient in daily life if the length of the day varied in this way, astronomers have invented an imaginary body called the "mean sun." The apparent position of this body is always very close to that of the real sun and on the average of a year the apparent positions of the two coincide. The apparent motion of the mean sun is such that it rotates *uniformly* round the earth at all times of the year. At a transit of the mean sun the time is called 12h. (or noon) *local mean time* (L.M.T.). The interval between successive transits is called a DAY, and each day is divided into 24 equal parts called *hours*, which are numbered as before. All hours are equal to one another, and all days are equal to one another in duration. To get local mean time from local apparent time it is necessary to add (or subtract if sign is minus) the so-called *equation of time* which is given very accurately in the *Nautical Almanack* and elsewhere, and sufficiently accurately for meteorological purposes in the "Meteorological Observer's Handbook." The equation of time varies from about $+14\frac{1}{2}$ minutes in the middle of February to about $-16\frac{1}{2}$ minutes at the beginning of November.

Local mean time at Greenwich is called *Greenwich Mean Time* (G.M.T.).

The difference between the local mean times at two places depends only on the difference in longitude between the two places. Since the earth makes one complete rotation relative to the mean sun in 24 hours, 360° of longitude corresponds with 24 hours, and therefore, 1° of longitude corresponds with 4 minutes of time. Hence L.M.T. for any place is derived from G.M.T. by subtracting or adding a correction to G.M.T. at the rate of 4 minutes of time for each degree of longitude of the place, according as the place is to the west or east of the meridian of Greenwich.

In order to avoid the great inconvenience which would be produced if every place adopted its own local mean time, it has been enacted that

Greenwich mean time should be used for all common purposes in this country, except in summer, when clocks are advanced by one hour. (See BRITISH SUMMER TIME.)

The statement commonly made that the sun is in the south at noon is thus seen to be true only when "noon" means 12h. local apparent time. Considerable divergencies occur from place to place and from time to time if "noon" means 12 o'clock by legal time.

In meteorological work Greenwich mean time and local mean time are used as far as possible for purposes of defining the hours of observation—summer time is not generally used. Meteorologists are closely interested in good timekeeping, because punctuality is of importance in taking meteorological observations. The records of self-recording instruments are for many purposes useless unless marks are made on the records at known times, so that allowance can be made for the irregularities in running of the clock. Regulation of clocks in this country is effected by telegraphic, radiotelegraphic, and radiotelephonic signals originating from Greenwich Observatory, where the standard clock is controlled by frequent observations of the fixed stars.

Tornado.—(1) In West Africa, the squall which accompanies a thunderstorm; it blows outwards from the front of the storm at about the time the rain commences. West African tornadoes occur most frequently during the transition months between rainy and dry seasons.*

(2) A very violent counter-clockwise whirl of small area averaging a few hundred feet in diameter, which gives wind velocities estimated to exceed 200 miles per hour in some examples. Such tornadoes are most frequent in the United States, east of the Rocky Mountains, especially in the central plains of the Mississippi region; they occur also in Australia, and are not unknown in Europe, although less intense. In the United States tornadoes are associated with thundery conditions, especially in SECONDARY or V-SHAPED DEPRESSIONS, where the interaction of winds with a large difference in temperature gives opportunity for violent vertical convection. The tornado is a local phenomenon, and usually travels towards the north-east with an average speed of about 30 miles an hour. In the comparatively narrow track of the tornado, trees are uprooted and buildings are completely destroyed, the large and rapid decrease of pressure near the centre of the tornado allowing the air inside buildings to produce almost an explosive effect. Heavy rain, and generally thunder and lightning occur with the tornado.†

The few tornadoes known to have occurred in Europe have been of comparatively small intensity, although they have caused a certain amount of damage. Examples occurred in South Wales on October 27, 1913, in Holland on August 10, 1925, and in London on October 26, 1928.

Torricelli, Evangelista.—The inventor of the barometer, born at Piancaldoli in 1608. He became amanuensis to Galileo in 1641 until Galileo's death three months later and subsequently became professor to the Florentine Academy until his death in 1647. Torricelli deduced from the fact that water would only rise about 32 feet in a suction pipe, that the air had weight, and could, therefore, exert a definite pressure equivalent to a height of 32 ft. of water or 2½ ft. of mercury. This conclusion was confirmed by the well-known Torricellian experiment.

Trace of Rainfall.—The word "trace" is entered in the daily record sheet when some rain (or other form of precipitation) is known to have fallen and the amount in the gauge is not large enough to be measured. (See RAIN DAY.)

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* Hubert: "Mission Scientifique au Soudan." Paris, 1916, pp. 169 and 221.

† De Courcy Ward: "The tornadoes of the United States as climatic phenomena." *London, Q.J.R. Meteor. Soc.*, **43**, 1917, pp. 317–29.

Trade Winds.—This is the name given to the winds which blow from the tropical high pressure belts towards the equatorial region of low pressure, from the NE. in the northern hemisphere and SE. in the southern hemisphere. The name originated in the nautical phrase "to blow trade," meaning to blow in a regular course or constantly in the same direction, afterwards shortened to "trade." The word is allied to the words "track" and "tread" and its use in the sense of commerce was a later development of meaning not implied in its original application. The monsoons were formerly grouped with the true trades under the same name. Other names were also given to the trade winds either as a whole or locally. Of these the term "general wind" has survived in some countries, as for example the modern Spanish "vientos generales." Columbus discovered the regularity of the NE. trade in his first transatlantic voyage in 1492 and this is usually accepted as the discovery of the trade winds though previous navigators must have encountered them to some extent, probably as far back as the time of the Phoenicians. The Spaniards soon learned the value of the trade winds and in latter years the galleons regularly utilised the NE. trade of the Pacific in their journeys from Acapulco (Mexico) to Manila. More or less detailed descriptions of the trades are extant dating back to the sixteenth century, and knowledge of their characteristics was gradually accumulated by mariners. Lieutenant M. F. Maury, U.S.N., was the first to treat the trade winds statistically, which he did by means of data collected from ships on a uniform plan. The results were included in his "Wind and Current Charts" and "Sailing Directions," published about the middle of the nineteenth century. As a result of Maury's work, the most important part of which consisted in finding the quickest sailing-ship routes through the Doldrums, passages were very materially shortened.

Excluding the Indian Ocean north of the equator, which is subject to the régime of the monsoons, the trade wind belts occupy a region extending over 1,000 to 1,400 miles of latitude in all oceans both north and south of the equator. The average direction of the wind is not the same in different longitudes of the same ocean. Thus in the North Atlantic, proceeding from the eastern to the western side of the ocean, the trade wind veers from NE., or even from NNE. or N. in some months, through ENE. to E. or to a point slightly S. of E. In the southern hemisphere corresponding differences are found, the changes being from S. or SSE. through SE. to E. or even a little N. of E. The trade winds represent the circulation of the air on the eastern and equatorial sides of the great permanent oceanic anticyclones which are found in latitudes of about 30° N. and S. It is interesting to note that the western margins of the anticyclones are in all oceans much less clearly marked than are the eastern margins. The easterly winds on their equatorial sides, such as those of the Caribbean Sea, are really part of the equatorial flow and the name of "intertropical flow" has been suggested for them. It is the usual custom to call all the winds between these high-pressure areas and the Doldrums by the name of trade winds, but the really characteristic trades are the flows from the eastern sides of the anticyclones, which are roughly speaking NE. in the northern hemisphere and SE. in the southern hemisphere.

The trade winds are not, as is popularly supposed, perfectly steady and regular either in force or direction. They vary, within limits, from day to day, from season to season, and from year to year. This applies to all oceans, but the Atlantic trades are more regular than those of the Pacific, and the SE. Atlantic trade is more regular than the NE. Atlantic trade. Following the seasonal changes in the sun's declination the trade winds, together with the Doldrums and the region of light and variable wind on the poleward side of the trades, move on the average northward and southward. There is, however, a considerable time lag behind the sun, thus the NE. Atlantic trade does not reach the most northerly latitude until August. The rate of motion is greatest just after the equinoxes. The annual range varies in different oceans, different longitudes and different hemispheres, but averages about 5° of latitude. Usually the total width of the belt fluctuates, the motions of the north and south sides not being the same. In the Atlantic and Pacific Oceans the SE. trade crosses the equator during the northern summer, but the NE. trade never extends south of the equator. In the Indian Ocean the SE. trade never crosses the equator. The day-to-day fluctuations of the trade winds have their origin in the day-to-day variations in the position and intensity of the oceanic anticyclones, which affect not only the force and direction of the trades but also the limiting latitudes.

A table showing the strength of the Atlantic trades is given below.

Average monthly strength of the trades of the Atlantic in miles per hour

	January	February	March	April	May	June	July	August	September	October	November	December	Year
NE. trade ..	10	11	11	12	11	10	9	7	8	6	8	10	9·4
SE. trade ..	12	13	12	13	13	13	11	13	13	12	13	13	12·6
St. Helena ..	14	13	13	12	11	12	12	15	17	15	16	15	13·8

The St. Helena observations made at an altitude of 1,960 ft. have been reduced by 15 per cent for the purposes of the table, which it is considered gives the velocities that would have been recorded at sea level. The other figures are derived from Captain Hepworth's investigation of the NE. trade in lat. 10° N. to 30° N., between long. 30° W. and the west coast of Africa, and of the SE. trade in lat. 0° to 20° S., long. 0° to 10° W., and lat. 10° to 30° S., long. 0° to 10° E. It should be noted that the coast of Africa disturbs the regularity of the NE. trade in the eastern part of the area selected. In the above table Captain Hepworth's results have been reduced by a little more than a mile per hour to bring then into conformity with the conversion values of the Beaufort wind numbers now in use by the Meteorological Office. It will be seen that the St. Helena winds are appreciably stronger than the SE. trade marine observations and show a much more definite seasonal variation. No satisfactory explanation of this fact has been given. The St. Helena and NE. trade observations are almost exactly complementary; thus September, the month of weakest NE. trade, is the month of strongest wind at St. Helena and so on. Maury derived a ratio of the strength of the NE. and SE. Atlantic trades from the observed speeds of sailing ships, and this ratio (6 to 8·8) is exactly the same as the ratio NE. trade/St. Helena for the year in the above table and does not differ greatly from the ratio NE. trade/SE. trade. Seasonal variation is seen to be marked in the case of the NE. trade.

As in the Atlantic, the NE. trade wind of the Pacific lies to the west of and not opposite to the SE. trade wind, on account of the similarity of curvature of the eastern coast lines of these two oceans. No definite figures can be quoted for the strength of the Pacific trades, but they are certainly less than those of the Atlantic, and the relative strengths of the NE. and SE. trades are reversed, the SE. Pacific trade exhibiting least strength and steadiness. The SE. trade of the Indian Ocean is most stable when the SW. monsoon is blowing north of the equator from May to September.

Comparatively little exact information is available as to the diurnal variation of the trades. Gallé found that the SE. trade of the Indian Ocean reaches a maximum at night from May to October, but observations at Porto Rico and St. Helena give day maxima, less marked at the latter island. There are many local wind modifications of the trades on continental coasts or among islands. An interesting feature of the NE. trade is the very large area of dustfall from the Canary Isles to south of Cape Verde, extending as far as longitude 40° W.

The explanation of the origin of the trade winds which is given in all books on physical geography is due originally to a paper published by

Edmund Halley in 1686. It attributes the flow of air northward and southward on either side of the equator to the replacement of air which has been heated by the warmth of the equatorial belt and has, in consequence, ascended. Halley's explanation of the easterly component was not satisfactory, and John Hadley gave the true explanation of this in 1735 by bringing the effect of the earth's rotation into account. Halley also developed the theory of the return upper currents, the "counter-trades," or ANTI-TRADES, blowing from SW. in the northern hemisphere and NW. in the southern hemisphere. At the present time the only satisfactory explanation of the trades and counter-trades is to be found by associating these winds with the pressure distributions obtaining at the surface and at a suitable height in the upper air. Thus, as has been stated, the surface trades form part of the circulation round the great oceanic anticyclones. The untenability of Halley's theory is seen by considering the winds at Suva, Fiji (lat. 18°S., long. 177°E.). Here the frequency of SE. wind is only about 10 per cent. Winds from all directions are experienced, that from NE. being the most frequent. Yet the situation of the island in respect to the equatorial belt of high temperature is similar to that of St. Helena, where the SE. Atlantic trade blows steadily. The greater part of the air brought to equatorial regions by the trades turns eastward and passes away round the western boundaries of the oceanic anticyclones. Some part of it may go to feed the rainstorms of the Doldrums.

Direct upper-air observation has shown that the height to which the NE. Atlantic trade attains is normally little over 3,000 ft., but very great variations are found to occur, and it may attain the height of 13,000 ft. It blows sometimes at the summit of the Peak of Tenerife (12,160 ft.). Similar fluctuations have been found in the height at which the counter-trade is met which has been observed to vary from 6,000 ft. to 30,000 ft. The counter-trade of the North Atlantic Ocean is associated with the high pressure area which exists over the western Sahara at altitudes of 6,000 ft. and upwards. The counter-trade of the South Atlantic is similarly associated with a high-pressure area at this height over southern Africa. The normal directions for the counter-trade, proceeding northward over the region of the NE. trade, are successively SE., S. and SW., finally becoming westerly over the region of the Azores. For the SE. trade they are successively NE., N., NW., finally becoming westerly. These directions are confirmed by such observations as are available. The counter-trades therefore form connecting links between the upper easterly current over equatorial regions and the upper westerly current of temperate latitudes. Over the western parts of the oceans the upper winds over the trades are easterly. This part of the circulation has a much greater area in the Pacific, where the surface oceanic anticyclones lie much closer to the eastern shores than they do in the Atlantic.

The weather in trade-wind regions is normally fine and quiet, though four of the six areas in which tropical cyclones occur lie within their boundaries. The typical cloud is the detached trade cumulus but ROLL-CUMULUS is of frequent occurrence. There is normally an increase of wind with height above the sea up to a point which Cave in 1909 at Barbados found to be about 1,600 ft. Temperature inversion and low humidity have been found above the trade cumulus in the Atlantic and Indian Oceans.

Trajectory.—The path traced out by a particle of air in its movement over the earth's surface.

If the wind arrows around an ANTICYCLONE are examined they will be found to suggest a spiral outward motion of the air, while in a DEPRESSION the spiral motion is inward towards the centre. Thus, if an anticyclone and a depression remained stationary in close proximity for a sufficient period of time a particle of air might be found which after rotating around the anticyclone in the outward spiral was drawn into the depression, its path finally leaving the earth's surface, as the air rose at the centre of the latter system. A path of this kind used to be regarded as typical of air movements associated with anticyclones and depressions. The fact was overlooked that a depression itself as a system normally moves with a velocity about as large as that of the individual air particles in their rotation round it and that before a particle has had time to make a complete rotation, the system will have moved away and the particle no longer remain under its influence.

Shaw and Lempfert in the "Life History of Surface Air Currents," a publication of the Meteorological Office issued in 1906, examined the matter by tracing the actual motion of air along the surface as deduced from selected series of hourly maps and by noting the progress of the air from map to map. One case selected was that of the storm of March 24–25, 1902, and the plates* appended at the end of this article show (*a*) the isobaric distribution at 18 h. on March 24, and (*b*) trajectories of selected air particles, the trajectories being lettered from L to S, and each trajectory carrying figures representing the course of its progress with the hours. An examination of this chart, and of any other in the series studied by Shaw and Lempfert, will reveal how inadequate the older idea was to express the true trajectory of a given particle in a depression. As the distribution of cloud and precipitation in a depression is dependent upon the properties gained by the air within it in the course of that air's travel, the importance of the study of air trajectories becomes manifest.

During the years that have elapsed since the publication of the "Life History of Surface Air Currents" much further work has been done on the subject and the Norwegian school of meteorologists especially, emphasise the importance to the forecaster of the source of any given portion of air, whether polar or equatorial, and of the subsequent travel of that air.

Tramontana.—A local name for a northerly wind which blows down from the mountains in Italy.

Transparency.—The capacity for allowing rays of light or some other form of radiation to pass. Thus glass is transparent for the visible radiation of light. Rock-salt is specially transparent for the rays of radiant heat. (See VISIBILITY and DIATHERMANCY.)

Tremor.—See EARTHQUAKES.

Tropic.—One or other of the circles of 23½° (23° 27′) of latitude north and south of the equator, which represent the furthest position reached by the sun in summer and winter in consequence of the tilting of the earth's axis with reference to the plane of the ecliptic. The term applies also to the zone of the earth lying between them. The northern circle is called the tropic of Cancer, the southern the tropic of Capricorn.

Tropical.—Belonging to the regions of the tropics, or similar to what is experienced there. The word tropical is often used for the region between the tropics, which is more strictly called intertropical.

Tropical Air.—See EQUATORIAL AIR.

Tropical Cyclone.—See CYCLONE.

Tropopause.—The lower limit of the STRATOSPHERE.

Troposphere.—A term suggested by Teisserenc de Bort for the lower layers of the atmosphere. The temperature falls with increasing altitude up to a certain height (see LAPSE), and the part of the atmosphere in which this fall occurs is called the troposphere. In these latitudes (50°) it extends from the surface for a thickness of some 7 miles, or 11 kilometres; in the tropics the thickness may reach 10 miles, or 16 kilometres.

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* From *Geophysical Memoirs* No. 12.

Trough.—The trough line of a circular DEPRESSION is the line through the centre perpendicular to the line of advance of the centre.

During the passage of a depression over any given place the pressure at first falls and later rises; the trough line passes over the place during the period of transition from the falling to the rising barometer. On the southern side of a depression, north of the equator, the passage of the trough is frequently very well marked by phenomena of the type of a LINE-SQUALL, a sudden rise of pressure takes place, the wind veers, the temperature drops and there are frequent squalls of rain or hail; the phenomena observed really indicate the passage of a COLD FRONT.

The word trough is sometimes used in a more general sense than that given above for any "valley" of low pressure, and is thus the opposite of a RIDGE of high pressure.

Tundra.—A Russian word meaning a marshy plain. It is frequently applied to the treeless plains bordering the Arctic coasts of Europe, Asia, and North America. The tundras may be compared with the STEPPES further south. (See DESERT.)

Turbulence.—The irregular motion which appears in fluids, whether liquid or gaseous, when they flow past solid surfaces or when neighbouring streams flow past or over each other, provided the velocity of flow is greater than a certain limit. The distinction between steady (stream-line) flow and turbulent motion was first demonstrated by Osborne Reynolds in a series of experiments on the flow of water in glass tubes of various diameters up to 2 in. The tubes had bell-mouthed entrances, and a little aniline dye was introduced into the entrance and the motion of the coloured water observed. At low velocities the coloured water was drawn out into a fine straight band, but as the velocity of flow was increased, a limit was attained at which the motion became sinuous or turbulent. There was a lower limit at which any turbulence originally present in the fluid entering the tube was damped out.

The motion is usually extremely irregular, and little can be said of the detailed motion of any element of fluid. Even when a fluid flows past a rectilinear barrier, and eddies form at the barrier and are detached periodically, the detailed motion is not repeated in successive eddies. Hitherto little effort has been made in meteorology to trace the history of an individual eddy. It is, however, possible to form a reasonable picture of the effect of a large number of eddies on the properties of the atmosphere, much as it is possible to trace the effects of the molecular motion in a fluid without tracing the motions of individual molecules. The presence of eddies endows a fluid with a power of diffusing certain properties throughout its mass, far in excess of its molecular diffusion. Since an eddy may detach itself from its original environment and proceed to a new position, carrying with it its original content of heat, water vapour, dust, linear momentum in a given azimuth, etc., and may later merge into its new environment by mixing with it, the eddy may be regarded as a carrier of any of these properties.

The motion of the atmosphere is, at least in the lower layer, usually turbulent. The effect of roughness of the earth's surface, of contours and obstacles of any kind, is to cause the formation of eddies, whose existence is readily demonstrated by smoke from a chimney. The smoke from a garden bonfire always shows a definite irregularity. Smoke from a high chimney or from a ship's funnel at sea may occasionally be seen to spread out into a narrow ribbon, corresponding with streamline motion. The intensity of the eddying or turbulent motion depends on a number of factors, among which are to be mentioned the mean velocity of the wind at a standard height, the rate of change of wind velocity with height, and the LAPSE-rate of temperature. If the lapse-rate is equal to or greater than the ADIABATIC, eddies can readily spread upward, but if the lapse-rate is less than this limit, and the atmosphere is therefore stable, eddies cannot readily spread upward, and any turbulence which forms at the ground is restricted to a thin layer. This is particularly noticeable when an inversion of temperature exists, both on account of the fact that the inversion tends to restrict the upward motion of eddies, and because the wind at the ground is light in inversions.

Mathematical methods were first applied to the discussion of the effects of turbulence in the atmosphere by G. I. Taylor,* who showed that the effects of eddies might be regarded as endowing the atmosphere with a coefficient of viscosity and a coefficient of heat conduction far greater than the ordinary coefficients of molecular viscosity and conduction. Taylor showed that the components of the eddying velocity in three dimensions horizontally down wind, horizontally cross wind, and vertically, were roughly equal. This yields an equipartition in three dimensions of the energy associated with the eddies, much as the energy of molecular motion shows equipartition. So far as the equipartition between the horizontal components is concerned, a test can be made by means of the records of wind velocity and direction from an anemometer. It can be readily shown that if we take a portion of the ribbon-like trace shown on the velocity chart, and measure V. max. and V. min., the velocities in the gusts and lulls respectively, and if θ is the angular width of the corresponding direction trace, then the condition that the down wind and cross wind components shall be on the average equal is

$$\frac{V.\,\text{max.} - V.\,\text{min.}}{V.\,\text{max.} + V.\,\text{min.}} = \sin\frac{\theta}{2}$$

Taylor showed that, on the average, this condition is fairly closely fulfilled.

In Taylor's discussion the effects of turbulence are stated in terms of a coefficient K, which has the value $\frac{1}{2}\,\bar{w}\,d$ where $\bar{w}$ is the mean vertical velocity in the eddy, and d is the diameter of the eddy. K is the coefficient which replaces the ordinary molecular coefficient of kinematic viscosity (see VISCOSITY), or the coefficient of thermal conduction, in the ordinary equations of motion or of heat transfer. A striking suggestion is made by Taylor that K has the same value whether we are discussing the transfer of momentum, heat, water vapour, or any other property of the fluid.

Taylor gave the variation of wind with height in terms of his coefficient K and showed that the calculated distribution is in reasonable agreement with the observed facts.

In discussing the vertical transfer of heat by eddies we must take account of the lapse-rate. Eddies carry heat in the direction from high potential temperature to low potential temperature. When the lapse rate is less than the adiabatic, and the atmosphere is, therefore, in stable equilibrium, the eddy transfer of heat is downward. When the lapse-rate exceeds the adiabatic, and the atmosphere is unstable the transfer of heat is upward. In either case the effect of the mixing produced by turbulence is to bring the lapse-rate nearer to the adiabatic, and if mixing proceeded for a sufficiently long time, with steady boundary conditions at the earth's surface, the lapse-rate would approach nearer and nearer to the adiabatic limit.

The defect which is present in all existing theories on the effect of turbulence is their inability to take account of the fact that at any instant there are present in the atmosphere eddies of widely varying sizes. The quantity K in terms of which we may state the results of turbulence fails to take account of this. In fact K ought to be some kind of function of the dimensions of the portion of the atmosphere with which we are dealing. In the form $K = \frac{1}{2}\,\bar{w}d$, it is clear that the size of the portion of the atmosphere with which we can deal is limited by d, and that as we deal with increasing portions of the atmosphere we must take account of larger eddies, or of larger values of d. If we have two elements of mass A and B at a distance l apart, in a turbulent fluid, the rate of separation of A and B will depend upon the eddies which can act on one but not on both of them.

* "Eddy motion in the atmosphere." London, *Phil. Trans. R. Soc.* A, **215**, 1915, pp. 1–26.

An eddy much larger in dimensions than l might contain both of them or neither, and so would not affect their rate of separation. In the course of time by the progressive effect of eddies, A and B might be separated by a large distance, so that eddies which in the earlier stage would affect neither or both (thus not causing any separation) will now be able to assist in separating them. Two pilot balloons which started off together would at first separate very slowly, but afterwards more rapidly as they moved further apart. Thus the K which measures the separation of two masses A and B is a function of l, their distance apart.

Twilight.—Twilight is caused by the intervention of the atmosphere between the sun and the earth's surface. When the sun is some distance below the horizon the upper layers of air are still illuminated and are reflecting light to us. The amount of reflected light diminishes as the sun's distance below the horizon increases, because higher and more diffuse layers alone are seen in direct sunlight. In the later stages of twilight the light which reaches us has been reflected more than once.

So early as the 11th century the period of Astronomical Twilight between sunset and the disappearance of the last trace of daylight was determined as ending when the sun was 18° below the horizon. Another period, Civil Twilight, is recognised ending when the sun is about 6° below the horizon and conditioned by the insufficiency of light for outdoor labour after that time. Of course both definitions imply skies free from cloud and haze.

The following table shows the duration of astronomical and civil twilight according to these definitions.

	Equator.		50°		60°	
	A.T.	C.T.	A.T.	C.T.	A.T.	C.T.
	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Winter solstice	1 16	0 26	2 1	0 45	2 48	1 9
Equinoxes	1 10	0 24	1 52	0 37	2 31	0 48
Summer solstice	1 15	0 26	—	0 51	—	1 59

At midsummer between the Arctic Circle and latitude 48½° there is a belt with no true night, twilight extending from sunset to sunrise.

The following figures are quoted from Kimball and Thiessen for the intensity of illumination during twilight with a cloudless sky; they refer to the illumination of a horizontal surface.

At sunset, 33 foot-candles = 1,600 times light due to full moon in zenith.

Sun 6° below horizon, 0·4 foot-candles = 19 times light due to full moon in zenith.

Sun 18° below horizon, ·0001 foot-candles = ·004 times light due to full moon in zenith.

For comparison the intensity of the illumination due to the sun in the zenith is given as 9,600 foot-candles.

Twilight Arch.—This term has been used with more than one meaning. Probably the best practice is to confine it to the boundary between the illuminated segment and the dark sky above as seen in the later stages of twilight. In Von Bezold's nomenclature several twilight arches are recognized; the first western twilight arch is the boundary seen even before sunset between the extended tinted band or segment of light along the horizon and the blue sky above: this arch persists through the development and disappearance of the "purple light" and may be visible together with the second western or true twilight arch.

The boundary of the SHADOW OF THE EARTH as seen just after sunset Von Bezold calls the "first eastern twilight arch." [The name twilight arch is confined to this phenomenon in the fourth issue of the first edition of the Glossary.]

Type.—Different distributions of atmospheric pressure are characterised by more or less definite kinds of weather, and accordingly when a certain form of pressure distribution is seen on a chart the weather is described as belonging to such-and-such a type. The types are therefore defined by the shape or general trend of the isobars, thus "an anticyclonic" or a "cyclonic" type denotes that an ANTICYCLONE or a DEPRESSION is the main feature of the pressure distribution; on the other hand a "westerly" type indicates that the isobars run in more or less parallel lines over a considerable distance from west to east, having the lowest pressure to the north; a "northerly" type will have isobars running north and south with the low pressure to the east, etc.

The weather associated with each type varies with the season but members of the same type have nearly always something in common; thus, an anticyclonic type has usually rainless weather, the cyclonic wet weather; the southerly type in the northern hemisphere will in general be relatively warm and the northerly type cold. The westerly type is a very persistent one and often gives rise to long periods of rather unsettled weather. The easterly type gives in winter suitable conditions for severe frosts while in summer in at least the southern part of the British Isles the weather is usually very warm.

Typhoon.—A name of Chinese origin (meaning "great wind") applied to the tropical CYCLONES which occur in the western Pacific Ocean. They are of essentially the same type as the West Indian hurricane of the Atlantic and the cyclone of the Bay of Bengal.

"Ulloa's Circle" or "Ring."—A white rainbow or fog bow. (See RAINBOW and BOUGUER'S HALO.)

Ultra-violet Radiation.—See RADIATION.

Units.—All physical measurements consist of two parts, (1) a number and (2) an indication of the magnitude of the "unit" number, i.e. the magnitude of the measurement if the number became 1. Thus we may say that a certain article has a length of 10 in., or of 25·4 centimetres. Here the units are *inch* and *centimetre* respectively, the numbers are 10 and 25·4 respectively, and in view of the relation between the inch and centimetre the two measurements are consistent.

Much difficulty has arisen in meteorology because the units of length and of temperature in common use in the British Isles, namely, the inch and the Fahrenheit degree, differ from those in use on the Continent, the centimetre and the Centigrade degree. (See also ELECTRICAL UNITS.)

The units adopted in the publications of the Meteorological Office are as follows:—

Heights of stations	*metres or feet.
Latitude and longitude ..	degrees and minutes of arc.
Pressure (including vapour pressure).	millibars (1 mb. = 1,000 dyne/cm².)
Temperature..	*absolute Centigrade degrees or Fahrenheit degrees.
Rainfall	*millimetres or inches.
Wind-speed	*metres per second or miles per hour.
Radiation	milliwatts per square cm.
Potential gradient	volts per metre.
Magnetic force	1 γ (= 10^{-5} C.G.S.) magnetic unit.
Magnetic declination ..	degrees and minutes of arc.
Magnetic inclination ..	degrees and minutes of arc.

* The former of the two alternatives shown is used exclusively in the serial volumes entitled *Observatories' Year Book*, and *Réseau Mondial*, and also in some cases in other statistical publications of the Office, in addition to the second alternative unit.

Upbank Thaw.—A state of affairs in which the usual fall of temperature with height is reversed, a thaw, or an increase of temperature occurring on mountains, sometimes many hours before a similar change is manifested in the valleys.

It is due to the superimposition of a warm wind blowing from a direction differing from that of the surface wind, and occurs most usually at the break-up of a frost, on the approach of a cyclonic system, but sometimes during the prevalence of anticyclonic conditions, when a down-current of air is dynamically heated in its descent from a great height. Under these conditions, at 9 h. on February 19, 1895, at the end of a great frost, the temperature at the summit of Ben Nevis was 17·6° F. higher than at Fort William, 4,400 ft. below.

This INVERSION of the normal temperature gradient is a contributory cause of the phenomenon known as GLAZED FROST.

Upper Air.—That part of the atmosphere which is not in close proximity to the earth's surface. The detailed study of the upper air is an important branch of modern meteorology, the pressure, temperature, and humidity at various heights being obtained by self-recording instruments carried up by SOUNDING BALLOONS, and the winds by observations on pilot balloons.

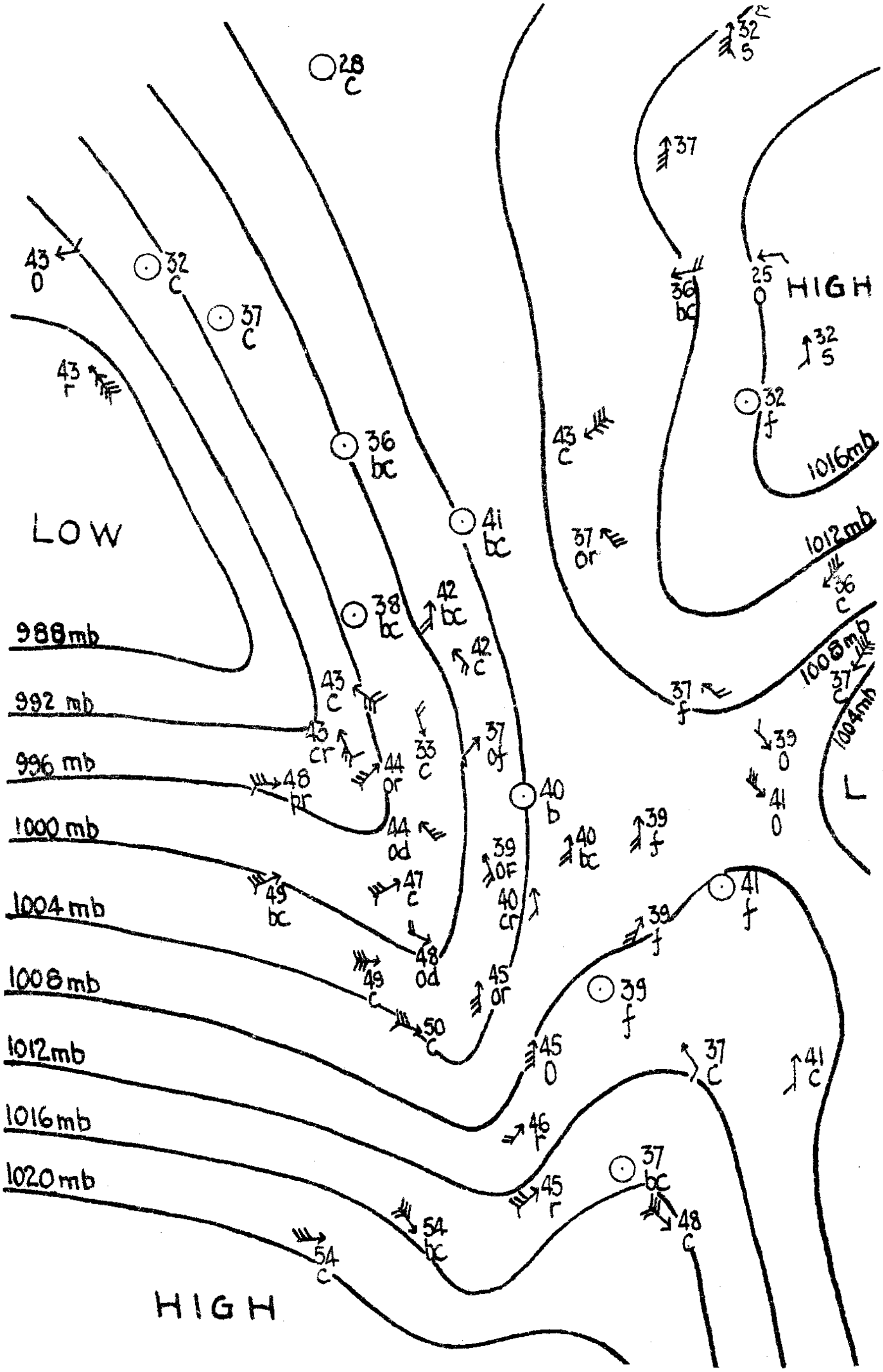
V-Shaped Depression.—Used to describe isobars, having the shape of the letter V, which embrace an area of low pressure. The isobars forming the V-shaped area are usually on the equatorial or southern side of the depression. On the eastern side of such a V-shaped depression there is a warm southerly or south-westerly air current and on the western side a cool north-westerly one. The line of separation between the two currents is frequently very sharply defined and as the V crosses any given place the wind suddenly veers from SW. to NW. the temperature falls, the pressure begins to rise and there are often squalls with which are associated rain or hail and sometimes thunder. On the other hand it occasionally happens in winter that the V-shaped depression stretches from west to east across the British Isles and the winds in the front part are easterly, and much colder than those behind the trough. In such a case the cold easterly winds are replaced by warmer southerly to south-westerly winds and conditions are favourable for a fall of snow which is later followed by sleet or rain.

In the former case the trough line is of the COLD-FRONT type and in the latter of the WARM-FRONT type. (See Plate V.). (See POLAR FRONT.)

Valley Breeze.—A breeze which blows during the day up valleys and mountain slopes. During the day the air in the valley is warmed and decreases in density, it rises therefore and flows up the valley and up the slopes of the mountain. (See ANABATIC.)

Vapour Pressure.—The pressure exerted by a vapour when it is in a confined space. In meteorology vapour pressure refers exclusively to the pressure of water vapour. When several gases or vapours are mixed together in the same space each one exerts the same pressure as it would if the others were not present; the vapour pressure is that part of the whole atmospheric pressure which is due to water vapour.

Vector.—A straight line of a definite length drawn from a definite point in a definite direction. A vector quantity is a quantity which has a direction, as well as magnitude. In meteorology the wind and the motion of the clouds are examples of vector quantities; the directions, as well as the magnitudes, are required, whereas in the case of the barometer or the temperature the figures expressing magnitude tell us everything. They are called SCALAR quantities. All vectors obey the parallelogram law. That is to say, that any vector A may be exactly replaced by any two vectors B and C, provided that B and C are adjacent sides of any parallelogram, and A the diagonal through the point where B and C meet. Also the converse holds.



29TH. MARCH, 1927. 7h.
V-SHAPED DEPRESSION.

The position of an airship a given time after starting is an example. The two vector quantities that bring about the final result are the velocity and the direction of the airship through the air, and the velocity and direction of the air, i.e. the wind. Suppose an airship pointing south-west and with speed of 40 miles an hour. After two hours its position on a calm day is 80 miles south-west of the starting point. Now suppose the airship has to move in a S. wind of 30 miles an hour; after two hours this wind alone would place the airship 60 miles north of the starting point. The real position will be given by drawing two lines representing these velocities and finding the opposite corner of the parallelogram of which they form adjacent sides. (See COMPONENT.)

Veering.—The changing of the wind in the direction of the motion of the hands of a watch, in either hemisphere. The opposite to BACKING.

Velocity.—Velocity is the ratio of the space passed over by the moving body to the time that is taken. It is expressed by the number of units of length passed over in unit time, but in no other sense is it equal to this space. It can be expressed in a variety of units. For winds metres per second, kilometres per hour and miles per hour are most common. When a velocity is variable a very short time is chosen in which to measure it. Thus the statement " at 11h. the wind was blowing at the rate of 60 miles per hour " means that for one second or so at just 11h. the wind had such a rate, that had that rate continued for an hour the air would have travelled 60 miles in that hour.

Vendavales.—SW. winds in the Straits of Gibraltar very troublesome to navigation.

Veranillo.—The two or three weeks of fine weather which break the rainy season near midsummer in tropical America.

Verano.—The long dry season near midwinter in tropical America.

Vernier.—A contrivance for estimating fractions of a scale division when the reading to the nearest whole division is not sufficiently accurate. The vernier is a uniformly divided scale which is arranged to slide alongside the main scale of an instrument. Information as to the graduation of a vernier and the method of reading is given in "The Meteorological Observer's Handbook."

Viscosity.—The " internal friction " or resistance to distortion which is exhibited by all real fluids to a greater or lesser extent, and which tends to dissipate any relative motion of the fluid, the energy lost to the motion being converted into heat. Maxwell (Theory of Heat) defines viscosity as follows :—" The viscosity of a substance is measured by the tangential force on unit area of either of two horizontal planes at the unit of distance apart, one of which is fixed, while the other moves with the unit of velocity, the space between them being filled with the viscous substance." The coefficient of viscosity as defined above is usually represented by the symbol μ. In liquids μ decreases with increasing temperature. For water at $0°$ C. $\mu = \cdot 0179$, while at $100°$ C. $\mu = \cdot 0028$. For air at $0°$ C. $\mu = 170 \times 10^6$, and at $100°$ C. $\mu = 217 \times 10^6$. If ρ be the density of the fluid, $v = \frac{\mu}{\rho}$ is called the kinematic viscosity. The kinematic viscosity of water is less than that of air.

A *very viscous fluid* is distinguished from a soft solid by the fact that any disturbing force, however small, will produce a sensible effect provided that it is continued for a sufficiently long time. See (TURBULENCE.)

Visibility.—A term used in describing the transparency of the atmosphere and defined by the maximum distance at which an object can be seen and the clearness with which its details can be discerned. It depends chiefly upon the amount of solid or liquid particles held in suspension by the air and to a smaller extent upon the uniformity of temperature and humidity in the layers of air through which an object is viewed. Visibility may vary very considerably in different directions. On a sunny day visibility is usually better, i.e. objects can be seen more clearly, when looking away from the sun than when looking towards it. On a cloudy day, provided rain is not falling, it is frequently equally good in all directions.

In a general way visibility is usually good in air which originates in high latitudes and which has had a relatively direct track while moving towards the equator. Where the equatorial movement is less rapid the visibility tends to deteriorate as the air moves southwards. On the other hand air which originates in lower latitudes and moves polewards usually has less good visibility than air originating near the poles.

The visibility of objects on the ground, when looked at from above, is sometimes bad even when the visibility between two points on the ground is good. This condition is due to a layer of haze at a definite height above the ground. Haze is due to the presence of solid particles in the air and is often connected with the proximity of large towns. A light north-easterly wind sometimes carries a smoke haze 70 miles south-west of London while even longer tracks have been noted to leeward of large industrial areas. The smoke haze has been found to have a sharply defined upper level but the height of this surface above the ground varies.

J. Aitken made measurements with a " dust counter " which determined the number of hygroscopic particles per c.c. in the atmosphere. He found values ranging between 16 and 7,000 in the open country and as many as 48,000 for London. The apparatus used took no account of the size or composition of the particles.

More recently J. S. Owens has used a more sensitive form of dust counter in which a measured volume of air is drawn through a disc of filter paper of standard size. The discoloration of this disc is compared with a scale of shades and the number of particles per c.c. estimated. He has found in Norfolk with a light NE. wind 100–200 particles per c.c. with a size of 0·3–1·7 microns, while in London smoke the number may rise to 50,000 per c.c. In London in winter with the air fairly clear the amount of suspended matter is of the order of 1 milligram per cubic metre of air but it may fall much below this figure on clear nights between midnight and 6 a.m. During a dense fog the amount may rise rapidly to 5 milligrams per cubic metre.

In measuring visibility pecularities of the eye play an important part. The visibility involves the light emitted by the object and the capacity of the eye to receive it. The visibility or otherwise of an object depends upon the contrast between it and its surroundings and when depending upon differences of illumination, this difference must be a certain percentage of the total illumination. Differences of form and colour also play a part, the red fading first as the intensity of illumination is decreased, then the green and so on until finally a uniform grey is seen.

During the day in non-foggy weather the visibility will usually be decreased compared with that obtaining in the early morning and near to and after sunset, on account of turbulence. In regions where there are ascending columns of air the refractive index of the air at any height will often differ from that in a descending column of air or air at rest, on account of slight differences of temperature and density. The light coming to the eye from an object will be refracted in passing from one column of air to another and objects are distorted and become indistinct in consequence. This effect is observed frequently over sandy deserts.

To obtain a numerical measure of visibility a number of objects are selected at fixed distances. These distances are 25, 50, 100, 200 and 500 metres, 1, 2, 4, 7, 10, 20, 30 and 50 kilometres. The most distant of the selected objects which can be seen and recognised is noted and its distance away provides a measure of the visibility. As far as possible objects are selected which show against the sky line or if this is not possible, those which show distinctly in contrast with their background.

An instrument has been devised recently by Wigand to measure the visibility. The principle of the method is to add to the obscurity of the atmosphere, an artificial obscurity until a fixed object when viewed through the filter becomes just indistinguishable. The artificial obscurity is produced by filters which consist of ground glass, and are graded in opacity in successive steps. The visibility can then be stated in terms of the particular filter which renders the object just indistinguishable.

Volcanic Dust.—See DUST.

Warm Front.—The boundary line between advancing warm air and a mass of colder air over which it rises. The surface of separation or frontal surface rises from the warm front over the cold air at a smaller angle than at a COLD FRONT, about 1 in 200 being a usual figure.

The rising of the warm air over the cold air usually causes considerable precipitation in advance of the front, while after it has passed there is either no precipitation or only slight rain or drizzle as a rule. Warm fronts are chiefly characteristic of high latitudes, and in the British Isles are most often found in winter. (See DEPRESSION.)

Warm Sector.—In the early stages of the life history of at least the majority of the DEPRESSIONS of temperate latitudes, and of more important SECONDARIES, there is a sector of warm air, which disappears as the system deepens and the cold front catches up the warm front (see OCCLUSION). The warm sector is usually composed of EQUATORIAL AIR, sometimes of maritime POLAR AIR.

Water.—The name used for a large variety of substances such as sea water, rain water, spring water, fresh water, of which water in the chemical sense is the chief ingredient. Chemically pure water is a combination of hydrogen and oxygen in the proportion by weight of one part to eight, or by volume, at the same pressure and temperature, of two to one, but the capacity of water for dissolving or absorbing varying quantities of other substances, solid liquid or gaseous, is so potent that the properties of chemically pure water are known more by inference than by practical experience. They are in many important respects different from those of the water of practical life.

The most characteristic property of ordinary water is that we find it in all three of the molecular states ; we know it in the solid state as ice, as a liquid (over a considerable range of temperature so well recognised as to be used for graduating thermometers), and as a gas. Thus, freezing and boiling are the common experience of many specimens of the water of ordinary life, and yet it is difficult to say in what circumstances perfectly pure water can be made to freeze or to boil.

Ordinary water is a palatable beverage, and is a medium in which a variety of forms of vegetable and animal life can thrive, but pure water freed from dissolved gases is perfectly sterile and quite unpalatable.

Ordinary water has a mass of 1 gramme per cubic centimetre (62·3 lbs. per cubic foot) at 277°A. Sea water contains dissolved salts to the extent of as much as 35 parts per 1,000 parts of water, and its density varies from 1·01 to 1·05 g/c.c.

Rain water is the purest form of ordinary water ; it contains only slight amounts of impurity in the form of ammonium salts derived from the atmosphere. Spring water contains varying amounts of salt dissolved from the strata of soil or rock through which it has percolated ; the most common of these salts is carbonate of calcium, which is specially soluble in water that is already aerated with carbonic acid gas ; sulphates of calcium and other earthy metals are also found, and sometimes a considerable quantity of magnesia. These dissolved salts give the waters of certain springs a medicinal character. In some districts underground water is impregnated with common salt and its allied compounds to such an extent that it is no longer called water, but brine.

When impure water evaporates, the gas that passes away consists of water alone, the salts, which are not volatile, are left behind ; similarly when water freezes in ordinary circumstances the ice is formed of pure water, the salts remain behind in the solution ; so that, except for the slight amount of impurity due to mechanical processes, pure water can be got from sea water or any impure water, either by distilling it, or by freezing it.

Besides the solid constituents which give it a certain degree of what is called "hardness," ordinary water contains also small quantities of gases in solution, presumably oxygen and carbonic acid. When the water freezes the ice consists of pure water, and the dissolved gases collect in crowds of small bubbles.

The thermal properties of water, in the state of purity represented by rainwater, are very remarkable. Starting from ordinary temperatures, such as 290°A. (62·6° F.) and going upwards in the scale, the water increases in bulk, and part evaporates from the surface, until the boiling point is reached, a temperature which depends upon the pressure, as indicated on p. 103. Then the water gradually boils away without any increase of temperature, but with the absorption of a great amount of heat. Going downwards, the bulk of the water contracts slightly until the temperature of 277°A. (4° C., 39·1° F.) is reached ; that is known as the temperature of maximum density of water. From that point to the freezing point of water, there is a slight expansion of one eight-thousandth part, and in the act of freezing there is a large expansion amounting to one eleventh of the volume of water. It is in consequence of this change of density in freezing that ice floats in water with a one eleventh of its volume projecting, if the ice is clean, solid ice, and the water of the density of fresh water. Salt water would cause a still larger fraction to project, but floating ice carries with it a considerable amount of air in cavities and sometimes a load of earth so that the relation of the whole volume of an iceberg to the projecting fraction is not at all definite.

Water Atmosphere.—A general term used to indicate the distribution of water vapour above the earth's surface. The limitation of the quantity of water vapour in the atmosphere by the dependence of the pressure of saturation upon temperature, places the distribution of water vapour on a different footing from that of the other gases. Water vapour evaporated at the earth's surface is distributed in the troposphere by convection, which may cause so much rarefaction and consequent cooling that some of the water vapour condenses to form cloud.

Watershed.—In physical geography the line separating the head streams tributary to two different river systems or basins, i.e. the line enclosing a CATCHMENT AREA.

Waterspout.—The term used for the funnel-shaped TORNADO cloud when it occurs at sea.

Waterspouts are seen more frequently in the tropics than in higher latitudes. Their formation appears to follow a certain course. From the lower side of heavy nimbus clouds a point like an inverted cone appears to descend slowly. Beneath this point the surface of the sea appears agitated, and a cloud of vapour or spray forms. The point of cloud descends until it dips into the centre of the cloud of spray; at the same time the spout assumes the appearance of a column of water. It may attain a thickness (judged by eye) of 20 or 30 ft., and may be 200 to 350 ft. in height. It lasts from 10 minutes to half an hour, and its upper part is often observed to be travelling at a different velocity from its base until it assumes an oblique or bent form. Its dissolution begins with attenuation, and it finally parts at about a third of its height from the base and quickly disappears. The wind in its neighbourhood follows a circular path round the vortex and, although very local, is often of considerable violence, causing a rough and confused, but not high, sea.

Water Vapour.—See AQUEOUS VAPOUR.

Watt.—The unit of power associated with the practical system of ELECTRICAL UNITS. It is the rate at which energy is transformed into heat in a lamp using 1 ampere at 1 volt.

1 watt = 1 ampere-volt = 1 joule per second
= 10^7 ergs per second.
1,000 watt = 1 kilowatt = $1\frac{1}{3}$ horse-power.

Units derived from the watt are used by meteorologists for the measurement of the intensity of radiation.

1 milliwatt per $cm.^2$ = 1 kilowatt per $dekametre^2$
= ·01435 g. calories per $cm.^2$ per min.

Wave Motion.—The commonest example of wave motion is that seen on the surface of the sea, which is disturbed by gravitational waves of a sinusoidal form, the waves having a progressive motion perpendicular to their length. In progressive waves on deep water the water has no steady forward motion, and oscillates about its mean position. Tidal waves are those in which the motion of the fluid is mainly horizontal, and therefore sensibly the same for all particles in a vertical line. Gravitational waves can also occur in the atmosphere, and Helmholtz suggested that when a cold current is separated from a warm current by a relatively sharply defined surface of separation, gravitational waves should form in the surface of separation. The fundamental feature of wave motion is the alternation of potential and kinetic energy. Further, the disturbance is in general not propagated with the velocity of the masses involved in it.

The term wave motion can be applied to a wide variety of vibrating systems. Waves of compression and rarefaction in the atmosphere are motions transverse to the direction of propagation of the disturbance. The period of such a motion is the interval from one maximum of pressure to the next maximum.

Waves.—Any regular periodic OSCILLATIONS, the most noticeable case being that of waves on the sea. The three magnitudes that should be known about a wave are the amplitude, the wave length, and the period. The amplitude is half the distance between the extremes of the oscillations, in a sea wave it is half the vertical distance between the trough and crest, the wave length is the distance between two successive crests, and the period is the time interval between two crests passing the same point. In meteorological matters the wave is generally an oscillation with regard to time, like the seasonal variation of temperature, and in such cases the wave length and the period become identical.

If a quantity varies so as to form a regular series of waves it is usual to express it by a simple mathematical formula of the form $y = a \sin (nt + \alpha)$. Full explanation cannot be given here, it must suffice to say that the method of expressing periodic oscillations by one or more terms of the form $a \sin (nt + \alpha)$ is known as "putting into a sine curve," "putting into a Fourier series," or as "HARMONIC ANALYSIS."

Any periodic oscillations either of the air, water, temperature, or any other variable, recurring more or less regularly, may be referred to as waves. During the passage of sound waves the pressure of the air at any point alternately rises above and falls below its mean value at the time. A pure note is the result of waves of this sort that are all similar, that is to say, that have the same amplitude and wave length. The amplitude is defined in this simple case as the extent of the variation from the mean, while the wave length is the distance between successive maximum values. The period is defined as the time taken for the pressure to pass through the whole cycle of its variations and return to its initial value. Another good example of wave form is provided by the variations in the temperature of the air experienced in these latitudes on passing from winter to summer. This is not a simple wave form because of the irregular fluctuations of temperature from day to day, and the amplitude of the annual wave cannot be determined until these have been smoothed out by a mathematical process. Fourier has shown that any irregular wave of this sort is equivalent to the sum of a number of regular waves of the same and shorter wave length. In America " heat waves " and " cold waves " are spoken of. These are spells of hot and cold weather without any definite duration, and do not recur regularly.

Waves of Explosions are among the causes which may produce a rapid variation of pressure which begins with an increase, and is followed by a considerable decrease. The transmission is in the same mode as that of a wave of sound. The damage done by a wave of explosion is often attributed to the low pressure which follows the initial rise. In the same way the destructive effect of wind is sometimes due to the reduction of pressure behind a structure resulting in the bulging outwards of the structure itself in its weaker parts. (See AUDIBILITY.)

Weather.—The term weather may be taken to include all the changing atmospheric conditions which affect mankind but by meteorologists it is more commonly used in a limited sense to denote the state of the sky and whether rain, snow or other precipitation is falling. Atmospheric obscurity in the form of fog or mist is also included. In order that the different types of weather might be recorded concisely a system of notation was introduced by Admiral Sir Francis Beaufort which, with some slight modifications and additions, is in use at the present time. Particulars will be found under " Beaufort Notation."

Weather Map.—A weather map, as the name implies, is one on which may be found particulars relating to the weather over the area represented by the map. The particulars may refer to a given instant of time or to the mean conditions over a period.

A single observer can only observe the weather conditions over a very limited area ; but by means of an organised corps of observers, synchronous observations covering a wide area can be made and communicated to a central office, where they may be used in the construction of a weather map which is in this case sometimes also called a SYNOPTIC chart.

The meteorological elements most frequently found on a synoptic chart or weather map are the barometer readings, corrected and reduced to mean sea level, together with the BAROMETRIC TENDENCY ; the direction and strength of the wind ; the temperature ; the state of the WEATHER indicated by means of letters and symbols, showing whether it is raining, snowing or otherwise ; the amount and type of cloud and the visibility. Such a chart when completed presents a bird's eye view of the general weather situation and a series of such charts gives the foundations on which our weather forecasts are based. In order, however, to make a forecast for any given area it is necessary for the weather map to embrace particulars of the weather distribution both inside and outside the given area. Therefore, by international agreement, weather information is now distributed by wireless telegraphy by most countries, some giving the information concerning their own country only and others, in addition, giving a collective message embracing observations from many countries. It is now possible to construct daily a weather map based upon observations taken over most of the inhabited regions of the northern hemisphere.

Weather Maxim.—From the earliest times man has generalised about the weather with the result that a very large number of weather maxims have come into existence, the maxims being intended as means whereby the weather to come may be foretold. A voluminous collection was compiled and published by Richard Inwards under the title of " Weather Lore."

It may be said at once that only a few of these sayings are true, that a large number contain only a partial truth, that some are mutually contradictory, and that many are entirely fallacious. This lack of correctness must be ascribed to the propensity of man to count the " hits " and to neglect the " misses."

Many maxims concern themselves with the weather that actually occurs on a specified day and draw conclusions from these conditions as to the weather during a following period. Of these, a typical case is that of St. Swithin's Day (July 15) in England, of which it is said—

" If St. Swithin's greets, the proverb says,
The weather will be foul for forty days."

The most cursory examination of this over a few years will amply demonstrate its unreliability. There is, however, a further point about the saying, illustrative of the vagaries to be found in weather lore, and that is that neighbouring nations within a circumscribed area have similar predictions but relating to other, and widely separated, days in the calendar. In France, the day of augury is that of St. Medard (June 8), in Germany that of the Seven Sleepers (June 27), and in Belgium, that of St. Godelieve (July 27).

Other sayings concern themselves with the weather in a part of a given month, and state that that weather has a controlling influence on another period. Once again, even cursory examination reveals the lack of truth. March may come in " like a lion " but that does not mean that it will go out " like a lamb."

Many other sayings relate to the behaviour of animals. Of these it may be said that whilst it is highly probable that animals respond to *present* conditions, no satisfactory evidence has yet been adduced that they are capable of forecasting *coming* conditions.

Other sayings that have gained much currency concern themselves with the moon, ascribing to that satellite the power of influencing terrestrial weather ; but this influence has never been demonstrated in an adequate manner to the satisfaction of meteorologists.

Still other maxims deal with sky colours. Of these, perhaps the best known is the one—

" A red sky at night
Is the shepherd's delight :
A red sky at morning
Is the shepherd's warning."

which often proves reliable but, on the other hand, quite often proves " a broken reed."*

In short, no weather maxim should be accepted, no matter how often it may be quoted, or how traditional, unless it has been subjected to statistical examination over a long period and has not been found wanting, or unless it can be definitely connected with specific conditions, as shown by the weather chart.

Most weather maxims are quite unable to survive the searching tests implied in the foregoing paragraph. A few of the sailor's sayings, however, come out better. Of these, three may be mentioned. The saying—

" First rise after low
Foretells a stronger blow."

is often true of the squalls associated with the COLD FRONT of a DEPRESSION. Similarly, the couplet—

" Long foretold, long last ;
Short notice, soon past."

is often true inasmuch as the more extensive depressions with their large areas of bad weather travel more slowly, as a rule, than do the smaller ones, and thus their warning signs last longer. Yet again, the—

" A nor-wester is not long in debt to a sou-wester."

is often true, due to the fact that depressions frequently follow one another closely.

Wedge.—Between two DEPRESSIONS there is often a region of high pressure where the isobars are shaped like an inverted V ; as the first depression moves away the pressure rises but as the second approaches it

* See *Meteorological Magazine*, **61**, 1926, p. 15.

begins to fall. This region of high pressure is termed a " wedge " and sometimes a " ridge." It is really a wedge of high pressure between the two depressions. Since depressions move generally in an easterly direction, it follows that the motion of the wedge is also generally eastwards. The weather in the front part of a wedge is often very fine with north-westerly to northerly winds and very good visibility. When cirrus clouds are seen they will nearly always be found to be travelling rapidly from the north-west. On the central part of the wedge the winds are frequently light and variable in direction, but when this part passes the winds begin to freshen from the S. or SW., the skies become cloudy, the visibility deteriorates and rain usually follows as the new depression approaches. When the weather rapidly clears up after the passage of a depression it may be taken as an indication of the approach of a wedge and thus of a period, perhaps only a few hours, of mainly fine weather. (See Plate VI.)

Weighting.—In statistics, varying the share which different figures contribute to some final result in accordance with their reliability or for other reasons. For example, in calculating the SOLAR CONSTANT from the observations made at stations of the Smithsonian Astrophysical Observatory, observations under the most favourable conditions are given a weight of four, while those only just good enough for inclusion receive a weight of one. The former are counted four times, the latter only once.

Wet Air.—A term used to signify that everything becomes wet although rain is not falling and dew is not being deposited. This may happen when a rise of temperature is caused by the arrival of a wind bringing practically saturated air.

Wet Bulb.—A thermometer whose bulb is covered with muslin wetted with pure water, used in conjunction with a " dry " bulb, reading the air temperature, as a PSYCHROMETER. The reading of the wet bulb also has some independent value as a measure of the temperature which would be reached by a shaded body from whose surface evaporation is taking place, as from a human body. The wet-bulb temperature is therefore nearer the " sensible " temperature than is the temperature of the air. The highest known reading of the wet bulb is 100°F., in Kamaran Island in the Red Sea and in Sierra Leone.

Wet Day.—A wet day is defined technically as a period of 24 hours, commencing normally at 9 a.m., on which ·04 in. or 1·0 mm. or more of rain is recorded. On many occasions this definition is inconsistent with popular ideas of what constitutes a " wet day," since these involve considerations of duration of rainfall and time of incidence of the fall. (See also RAIN DAY.)

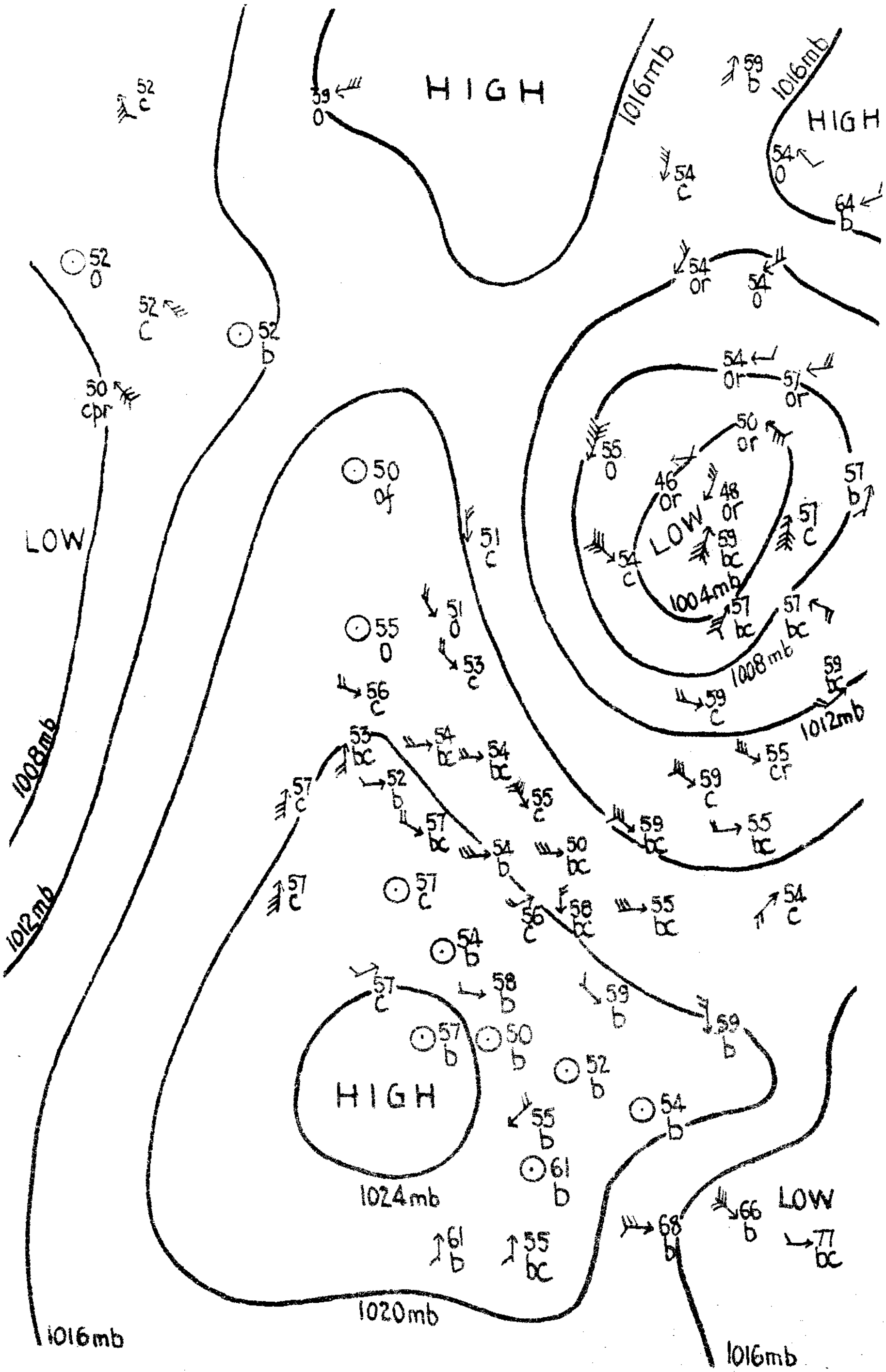
Wet Fog.—A fog, accompanied by a very high relative humidity, which wets objects exposed to it. Many town fogs are due largely to smoke, and can occur with relatively dry air.

Wet Spell.—The definition of the term " WET SPELL " is analogous to that of the term " DRY SPELL." Thus a wet spell is a period of at least 15 consecutive days to each of which is credited ·04 in. of rain or more. (See also RAIN SPELL.)

Whirlwind.—A small revolving storm of wind in which the air whirls round a core of low pressure. Whirlwinds sometimes extend upwards to a height of many hundred feet, and cause dust storms when formed over a desert.

Willy-Willy.—The name given in western Australia to a severe CYCLONE.

To face page 194.



17TH. AUGUST, 1928. 7h.

WEDGE.

H.M.S.O. Press, Kingsway, W.C.2.

Ps 25375/1369 Wt 19580 B. D 684/1030 5000. 8/30.

Wind.—Defined more than 2,000 years ago as "motion of the air." Little change is necessary, save the addition of some restricting clause such as "along, or nearly parallel to the ground," in view of the importance of the advances which have been made, mostly of late years, in the study of the vertical motion of the air.

For the ordinary purposes of synoptic meteorology and climatology, an observation of wind includes a statement of the direction and force (see BEAUFORT SCALE OF WIND FORCE) or velocity of the wind near the ground. The direction stated is that from which the wind is blowing (point of the COMPASS or AZIMUTH) this procedure being probably connected with the early system of describing the wind by some personified characteristic, the Greeks, for example about the second century B.C. having a system of eight personified winds, of which Boreas is the only survivor in our literature. The WIND VANE, it may be mentioned is the earliest meteorological instrument, dating from before the Christian era, though the rain-gauge was probably a close second. The method of describing a wind by some well-defined characteristic, or locality of occurrence is still in use (SOUTHERLY BURSTER, KHAMSIN, LEVANTER, and other local winds too numerous to mention. Of these the HELM WIND is the only British representative.)

The observation of wind force seems to be a much later development, the system in use amongst seamen being standardised for use in the Navy about 1805 and finally adapted in its present form for use on land in 1906. (The terms BACKING and VEERING have also been transferred to land meteorology.)

A form of pressure anemometer was invented by Sir Christopher Wren in the 17th century, while the windmill anemometer dates from the 19th century. Later developments permit the measurement of GUSTS.

When sufficient observations have been collected frequency summaries may be made showing the prevailing wind, that is the wind of most frequently occurring direction, while for certain purposes, as in the planning of air-transport routes, it may be of advantage to determine the resultant wind, the VECTOR sum of the individual observations or the COMPONENTS along some specified directions, generally north and east. Another form of mean wind is of importance in gunnery (BALLISTIC WIND.)

It is easily determined that near the ground, or near buildings, the velocity of the air is changing with height. Observations close to the surface show that at 4 ft. the velocity is from 83 to 90 per cent of that at 6 ft. above ground, according to the nature of the ground. The velocity doubles itself, more or less within 500 metres; the actual figure depends upon the time of day, among other things. So a measure of wind is as much dependent upon the exposure of the particular point at which the observation was taken as on the unrestricted flow of air in an unobstructed position, and no exact scientific meaning can be attached to the comparison of measurements of wind when the observations are made close to the surface of the earth (see EXPOSURE.)

The empirical discovery of the relation of wind to pressure distribution (BUYS BALLOT'S LAW) preceded the application of mathematical methods to the problems of air motion (see GRADIENT WIND). It should be noted that in the application of these methods various simplifying assumptions have to be made, but while modern theories of TURBULENCE give a satisfactory account of the deviation of the wind observed at the surface from the wind computed from the isobars of surface pressure, strickly speaking, in dealing with winds at a considerable height one should employ the system of isobars appropriate to the particular height, and not the sea-level isobars.

The ideas of wind and pressure distribution have become in a sense interchangeable, so that a study of the winds of the earth usually means equally a study of the pressure distribution (see GENERAL CIRCULATION). (See, however, KATABATIC and ANABATIC for winds which are not related to the pressure distribution.)

Wind at the earth's surface is subject to considerable diurnal variation, velocity being greatest in the early afternoon and least before dawn. At the tops of mountains and presumably at higher levels generally the reverse is the case. Fig. 25 illustrates the diurnal and seasonal variation of wind velocity at a station near the ground and also at 1,000 ft. above it. These curves show the effect of turbulence in transferring momentum from higher to lower levels during the hours when the lower layers of air are warmed by contact with the ground heated by the sun. There is also a diurnal variation of wind direction, shown as a tendency for veering during the day and backing at night, but this is liable to be over-ruled by local influences (such as LAND AND SEA BREEZES).

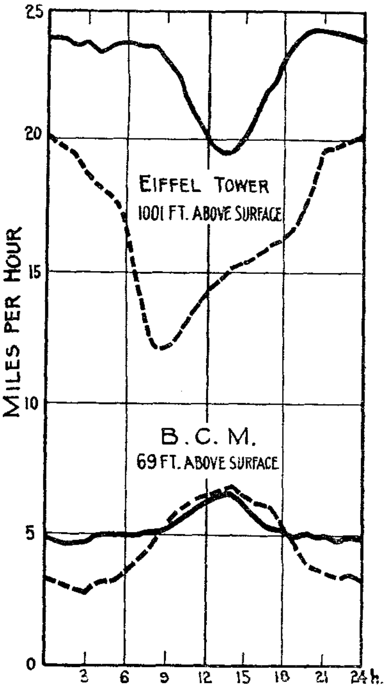


FIG. 25.—Diurnal variation of wind speed.
January ——— July - - - - -

Apart from the variations already described more important differences may be observed between the velocity and direction at the surface and those at higher levels. Cave* has described 5 types of wind structure over the British Isles :

(*a*) (1) " Solid " current : little change in velocity or direction : the wind reaches the gradient value and does not increase very much at greater altitudes.

(2) No current up to great heights.

(*b*) Considerable increase of velocity ; gradient value reached and surpassed ; increase often accounted for by surface temperatures.

(*c*) Decrease in velocity in the upper layers.

(*d*) Reversals or great changes of direction.

(*e*) Upper wind blowing outward from centres of low pressure ; frequently reversals at a lower layer.

(1) Upper wind between W. and N.

(2) Upper wind between S. and W.

These classes refer to winds in the TROPOSPHERE ; in the STRATOSPHERE the air above this country generally moves from a westerly to an easterly point. In other parts of the world the distribution of upper winds is more regular. Above the TRADE WINDS for example the wind direction is reversed at a moderate height, forming the ANTI-TRADE. For methods of observing upper winds see SOUNDING BALLOON, NEPHOSCOPE.

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* Cave, C. J. P. : " The structure of the atmosphere in clear weather." Cambridge, 1912.

For convenience in studying the winds it is usual to classify them in some way. One of the earlist systems was due to Dove, who described three classes of winds, permanent, periodic and irregular.

Later Davis proposed a classification into winds due to the influence of the sun's heat, the moon's attraction, or the earth's heat. Such classifications take no account of the relative importance of the various types of wind.

Milham* adopts a classification based on that of Davis, but places the various classes of winds in order of their importance :

Planetary winds (trade winds, doldrums, westerlies).

Terrestrial winds (planetary system as modified by the changes in the sun's declination).

Continental winds (terrestrial winds modified by influence of distribution of land and sea).

Monsoons.

Land and sea breezes.

Mountain and valley breezes.

Eclipse, landslide, tidal and volcanic winds.

Cyclonic storms.

Jeffreys† has developed a classification based on dynamical principles, in which winds are divided into three main groups, " according as the pressure differences between places at the same level are mainly occupied (*a*) in producing acceleration relative to the ground, (*b*) in guiding the wind under the influence of the earth's rotation, or (*c*) in overcoming friction." These classes are entitled (*a*) " Eulerian (a reference to the form of the equations of motion involved), (*b*) geostrophic, and (*c*) antitriptic. " Tropical cyclones and tornadoes are Eulerian, while all winds of wide extent from the travelling cyclone of temperate regions to the general circulation, are approximately geostrophic ; land and sea breezes and mountain and valley winds are mainly antitriptic."

Wind Rose.—A diagram showing, for a definite locality or district, and usually for a more or less extended period, the proportion of winds blowing from each of the leading points of the compass. As a rule the " rose " indicates also the strength of the wind from each quarter, and the number or proportion of cases in which the air was quite calm.

(*a*) The simplest form of wind rose is shown in Fig. 26 in which the number or proportion of winds blowing from each of the principal eight points of the compass is represented by lines converging towards a small circle, the proportion of winds from each direction being indicated by the varying length of the lines. The figure in the circle gives the number, or percentage, of cases in which the air was calm.

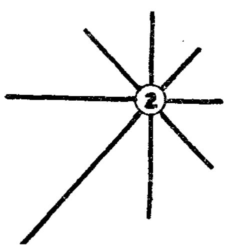

FIG. 26.—Simplest form of wind rose.

(*b*) The Baillie wind rose was introduced by Nav.-Lieut. C. W. Baillie in 1892. In this form of wind rose, the arrows which fly with the wind show by their length the frequency of winds of various directions and by their thickness the frequencies of the various forces—light winds, Beaufort forces 1 to 3 ; moderate winds, 4 to 7 ; and gales, 8 to 12. The circle supplies a scale for estimating the frequency of winds from any direction ; the length from the heads of the arrows to the circle measures 5 per cent of the total number of observed winds (100 per cent = 2 inches), the radius of the circle being one-fifth inch or equivalent to 10 per cent on the scale.

* Milham, W. I. : " Meteorology." New York, 1918.

† Jeffreys, H. : " On the dynamics of wind." *Q.J.R. Meteor. Soc.*, **48**, 1922, pp. 29–47.

The directions of the observed winds are given to the nearest second point of the true compass. The upper figure in the centre of the wind rose indicates the total number of observations upon which it is based and the lower figure gives the percentage of observations of calms.

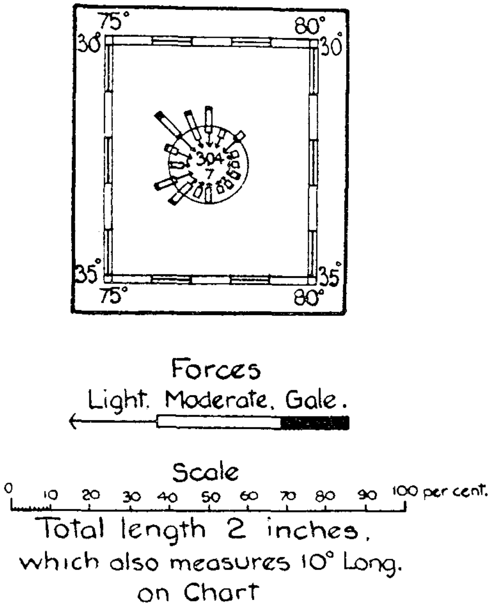

FIG. 27.—The Baillie wind rose.

A rose may be devised in a similar manner to indicate the relation of other meteorological phenomena, such as temperature, cloud, etc., to the direction of the wind.

Wind Vane.—A device for indicating the direction from which the wind is blowing. In the Meteorological Office pattern a horizontal arm pivoted on a steel spindle is provided with a pointer at one end and an aerofoil of stream line section at the other. Below the vane is a fixed framework showing the four cardinal points. If well exposed and accurately balanced, almost any type of vane will show the correct direction in moderate or strong winds, but ornamental vanes are rarely sensitive enough for meteorological purposes in light winds.

Winter.—See SEASONS.

Wireless Telegraphy.—This subject is of interest to meteorologists in many ways. One of the first practical applications of wireless telegraphy was in the transmission of weather reports from ships to land. Such reports were supplied to the Meteorological Office from ships in the Atlantic in 1907. Synoptic reports summarizing meteorological observations over a large area were first broadcast from the Eiffel Tower in 1911. The interchange of weather information between the services of different countries is now mostly by wireless telegraphy. Information for the public is broadcast by wireless telephony.

The phenomena which interfere with the operation of wireless telegraphy and telephony and are known as "ATMOSPHERICS" are attributed to meteorological causes principally, if not entirely, distant thunderstorms.

The transmission of wireless messages to very great distances is affected by the condition of the higher strata in the atmosphere. It is on account of the conductivity of these strata, known as the Heaviside layer, that the electromagnetic waves are able to pass round the globe.

Year.—The time taken by the earth to revolve once in its orbit round the sun. (See CALENDAR.)

Zenith.—The point of the sky in the vertical produced upwards from the observer. The word is now commonly used as denoting a more or less extensive stretch of sky immediately overhead.

Zephyr.—A westerly breeze with pleasant warm weather supposed to prevail at the summer solstice.

Zero.—The " point of origin " in graduating an instrument. In Centigrade and Réaumur thermometers the zero of temperature is taken to be the melting point of ice, which is accordingly marked " 0 " on the scale. Fahrenheit took as his zero the lowest temperature he could obtain from mixtures of ice and common salt. In these cases the zero is an arbitrarily selected point, and negative values are accordingly possible. Theory indicates that a temperature below $-273°$C. is impossible and that point is accordingly called the " absolute zero " of temperature, and marked " 0 " on the absolute scale. An error in positioning the entire scale of an instrument may be looked upon as an incorrect allocation of the zero and the term " zero error " is commonly applied to it.

Zodiac.—The series of constellations in which the sun is apparently placed in succession, on account of the revolution of the earth round the sun, are called the Signs of the Zodiac, and in older writings give their names and symbols to the months, thus :—

March	is associated	with	Aries, the Ram.
April	,,	,,	Taurus, the Bull.
May	,,	,,	Gemini, the Heavenly Twins.
June	,,	,,	Cancer, the Crab.
July	,,	,,	Leo, the Lion.
August	,,	,,	Virgo, the Virgin.
September	,,	,,	Libra, the Scales.
October	,,	,,	Scorpio, the Scorpion.
November	,,	,,	Sagittarius, the Archer.
December	,,	,,	Capricornus, the Goat.
January	,,	,,	Aquarius, the Watercarrier.
February	,,	,,	Pisces, the Fishes.

Owing to precession, the position of the sun relative to the zodiacal constellations has altered a good deal since classical times. The sun now enters Aries late in April but in text books of astronomy the point at which the sun crosses the equator at the spring equinox, March 21, is still called the first point of Aries.

Zodiacal Light.—A cone of faint light in the sky, which is seen stretching along the Zodiac from the western horizon after the twilight of sunset has faded, and from the eastern horizon before the twilight of sunrise has begun. In our latitudes it is best seen from January to March after sunset, and in the autumn before sunrise. In the TROPICS it is seen at all seasons in the absence of moonlight. The light is usually fainter than that of the Milky Way. The luminosity is probably due to the scattering of sunlight by an exceedingly rare gas which is rotating round the sun like an extended atmosphere. There is no sharp limit to this atmosphere and indeed the *Gegenschein*, a luminous patch to be observed in the midnight sky opposite to the position of the sun is thought to be due to sunlight reflected from beyond the earth's orbit. According to Jeffreys the apparent luminosity of the zodiacal light is about 10^{-7} of that of the sky by day. He deduces that the density of the gas from which the zodiacal light is reflected is of the order 10^{-18} grammes per cubic centimetre.

Zone of Silence.—See AUDIBILITY.

Zone Time.—Formerly it was the custom for each country to adopt as standard of civil time the local mean time of its principal astronomical observatory; thus in England, Ireland and France time was regulated by the local mean times at Greenwich, Dublin and Paris respectively. Consequently Irish time was 25 minutes after English time and French time was about 5 minutes ahead of English time.

To avoid the confusion so produced zone time was introduced and is now almost universally adopted. Under this system national standards of time differ from one another by multiples of half an hour or one hour corresponding with $7\frac{1}{2}°$ or $15°$ of longitude (see TIME). In countries such as the United States, which cover vast distances in longitude, two or three zone times are in use simultaneously. The current practice in respect of zone time is set out on a chart published by the Hydrographic Office, Admiralty, and will be found in Whitaker's Almanack.

Conversion of degrees Fahrenheit into degrees absolute

°F.	0	1	2	3	4	5	6	7	8	9
					degrees absolute					
0 ..	255·2	255·8	256·3	256·9	257·4	258·0	258·6	259·1	259·7	260·2
10 ..	260·8	261·3	261·9	262·4	263·0	263·6	264·1	264·7	265·2	265·8
20 ..	266·3	266·9	267·4	268·0	268·6	269·1	269·7	270·2	270·8	271·3
30 ..	271·9	272·4	273·0	273·6	274·1	274·7	275·2	275·8	276·3	276·9
40 ..	277·4	278·0	278·6	279·1	279·7	280·2	280·8	281·3	281·9	282·4
50 ..	283·0	283·6	284·1	284·7	285·2	285·8	286·3	286·9	287·4	288·0
60 ..	288·6	289·1	289·7	290·2	290·8	291·3	291·9	292·4	293·0	293·6
70 ..	294·1	294·7	295·2	295·8	296·3	296·9	297·4	298·0	298·6	299·1
80 ..	299·7	300·2	300·8	301·3	301·9	302·4	303·0	303·6	304·1	304·7
90 ..	305·2	305·8	306·3	306·9	307·4	308·0	308·6	309·1	309·7	310·2
100 ..	310·8	311·3	311·9	312·4	313·0	313·6	314·1	314·7	315·2	315·8
110 ..	316·3	316·9	317·4	318·0	318·6	319·1	319·7	320·2	320·8	321·3

Conversion of barometric height in inches of mercury at 32° F. and latitude 45°, to atmospheric pressure in millibars.

Inches	·00	·01	·02	·03	·04	·05	·06	·07	·08	·09
					millibars					
28·50 ..	965·1	965·4	965·8	966·1	966·5	966·8	967·1	967·5	967·8	968·1
28·60 ..	968·5	968·8	969·2	969·5	969·8	970·2	970·5	970·9	971·2	971·5
28·70 ..	971·9	972·2	972·6	972·9	973·2	973·6	973·9	974·2	974·6	974·9
28·80 ..	975·3	975·6	975·9	976·3	976·6	976·9	977·3	977·6	978·0	978·3
28·90 ..	978·6	979·0	979·3	979·7	980·0	980·3	980·7	981·0	981·4	981·7
29·00 ..	982·0	982·4	982·7	983·0	983·4	983·7	984·1	984·4	984·7	985·1
29·10 ..	985·4	985·8	986·1	986·4	986·8	987·1	987·5	987·8	988·1	988·5
29·20 ..	988·8	989·1	989·5	989·8	990·2	990·5	990·8	991·2	991·5	991·9
29·30 ..	992·2	992·5	992·9	993·2	993·5	993·9	994·2	994·6	994·9	995·2
29·40 ..	995·6	995·9	996·3	996·6	996·9	997·3	997·6	997·9	998·3	998·6
29·50 ..	999·0	999·3	999·6	1000·0	1000·3	1000·7	1001·0	1001·3	1001·7	1002·0
29·60 ..	1002·4	1002·7	1003·0	1003·4	1003·7	1004·0	1004·4	1004·7	1005·1	1005·4
29·70 ..	1005·7	1006·1	1006·4	1006·8	1007·1	1007·4	1007·8	1008·1	1008·4	1008·8
29·80 ..	1009·1	1009·5	1009·8	1010·1	1010·5	1010·8	1011·2	1011·5	1011·8	1012·2
29·90 ..	1012·5	1012·8	1013·2	1013·5	1013·9	1014·2	1014·5	1014·9	1015·2	1015·6
30·00 ..	1015·9	1016·2	1016·6	1016·9	1017·3	1017·6	1017·9	1018·3	1018·6	1018·9
30·10 ..	1019·3	1019·6	1020·0	1020·3	1020·6	1021·0	1021·3	1021·7	1022·0	1022·3
30·20 ..	1022·7	1023·0	1023·3	1023·7	1024·0	1024·4	1024·7	1025·0	1025·4	1025·7
30·30 ..	1026·1	1026·4	1026·7	1027·1	1027·4	1027·7	1028·1	1028·4	1028·8	1029·1
30·40 ..	1029·4	1029·8	1030·1	1030·5	1030·8	1031·1	1031·5	1031·8	1032·2	1032·5
30·50 ..	1032·8	1033·2	1033·5	1033·8	1034·2	1034·5	1034·9	1035·2	1035·5	1035·9

LIST OF

The following pages give the equivalents in various languages of a number of the terms identical in all languages, and these have been omitted from the lists. The complete lists

English	Danish	Dutch
Absorption (atmospheric)	Atmosfærisk Absorption	Absorbtie (atmospherische)
Accumulated temperature	Temperaturoverskud	Overmaat van temperatuur
Accuracy	Nøjagtighed	Nauwkeurigheid
Actinic rays	Aktiniske Straaler	Actinische (photographisch werkzame) stralen
Afterglow	Efterglød	Naschemering
Air	Luft	Lucht
Air-meter	Vindhastighedsmaaler, Anemometer	Windsnelheidsmeter
Air pockets	Lufthuller	Remou's
Air trajectory	Luft-Strømningslinje	Luchtbaan
Altimeter	Højdemaaler	Hoogtemeter
Altitude	Højde	Hoogte
Anabatic	Anabatisk	Stijgend
Anemogram	Anemogram	Windregistreering
Anemometer	Vindstyrkemaaler, Anemometer	Windmeter
Anemoscope	Anemoskop	Windaanwijzer
Anthelion	Modsol (Bisol)	Tegenzon
Anticyclone	Anticyklon	Gebied van hooge drukking-maximum
Antitrades	Antipassat	Antipassaat
Anvil cloud	Ambolt Sky	Aambeeld wolk
Aqueous vapour	Vanddamp	Waterdamp
Arid	Tørt	Droog, aride
Atmosphere	Atmosfære	Dampkring, atmospheer
Atmospheric pollution	Luftens Urenhed	Verontreiniging van de Atmospheer (dampkring)
Atmospheric pressure	Lufttryk	Luchtdrukking
Atmospherics	Luftelektriske Forstyrrelser	Luchtstoringen
Attached thermometer	Paasat Termometer	Aangehechte Thermometer
Audibility	Hørevidde	Hoorbaarheid
Aurora	Polarlys, Nordlys	Poollicht, Noorderlicht
Autumn	Efteraar	Herfst
Avalanche wind	Faldvind	Lawine-wind
Average	Middel—	Gemiddelde, middelwaarde
Backing	Vinden drejer til venstre, dreier mod Solen	Krimpend
Ball lightning	Kuglelyn	Bolbliksem
Balloon	Ballon	Ballon
Bearing	Pejling	Peiling
Beaufort notation	Beaufort's Vejr-Kode	Beaufort teekens
Beaufort scale of wind force	Beaufort's Vindskala	Beaufortschaal voor windkracht
Black-bulb thermometer	Sortkugletermometer	Zwarte-bolthermometer (stralingsthermometer)

EQUIVALENTS.

defined in the Glossary. Many of the words were found to be practically of translations are available for reference in the Meteorological Office Library.

French	German
Absorption (atmosphérique)	Absorption (atmosphärische)
Températures accumulées	Wärmesumme, Temperatursumme
Exactitude, précision	Genauigkeit
Rayons actinique	Aktinische Strahlen
Lueurs crépusculaires	Nachglühen
Air	Luft
Anémomètre à main	Anemometer, Windmesser
Trous d'air	Luftlöcher
Trajectoire de l'Air	Luftbahn, Trajektorie
Altimètre	Höhenmesser
Altitude	Höhe
Anabatique	Anabatisch, konvektiv
Anémogramme	Anemogramm, Windregistrierung
Anémomètre	Windmesser
Anémoscope	Windfahne
Anthélie	Gegensonne
Anticyclone	Antizyklone, Hoch, Hochdruckgebiet
Contre Alizés	Antipassat, Gegenpassat
Nuage en enclume	Ambosswolke
Vapeur d'eau	Wasserdampf
Aride	Trocken
Atmosphère	Atmosphäre, Lufthülle
Impuretés atmosphériques	Staubgehalt, Beimengungen, Verunreinigung der Luft
Pression atmosphérique	Luftdruck
Atmosphériques	Atmosphärische Störungen (drahtl. Telegraphie)
Thermomètre de baromètre	Attachiertes (eingefügtes) Thermometer
Audibilité	Hörbarkeit
Aurore	Nordlicht
Automne	Herbst
Vent d'avalanche	Lawinenwind
Moyenne	Mittelwert
Mouvement levogyre, Recul du vent	Zurückdrehen
Eclair en boule	Kugelblitz
Ballon	Ballon
Azimut, relèvement (terme de marine)	Peilung
Notation de Beaufort	Beauforts Wetterskala
Echelle de Beaufort pour la force du Vent	Beauforts Windstärkeskala
Thermomètre à boule noire	Schwarzkugelthermometer

ENGLISH	DANISH	DUTCH
Blizzard	Blizzard	Sneeuwstorm of sneeuwdrift
Blood-rain	Blod-Regn	Bloedregen
Blue of the sky	Himlens blaa Farve	Hemelblauw
Brave West Winds	Brave Vestenvinde	Westenwind gebied
Breeze	Bris, Brise	Bries (wind)
Bumpiness	Ujævnhed i Luften	Onrust van de Atmospheer
Buoyancy	Opdrift	Veerkracht
Calibration	Kalibrering	IJking
Calm	Vindstille	Windstilte
Cap	Skykappe	Kap(je)
Catchment area	Nedbørsopland	Draagoppervlakte
Clear sky, Day of	Klar Dag	Heldere dag
Climatic changes	Klimaændring	Klimaatschommelingen
Cloud-burst	Skybrud	Wolkbreuk
Cloudiness	Skydække	Bewolking ('s-graad)
Clouds	Skyer	Wolken
Col	Saddel	Zadel
Cold front	Kold Front	Koud front
Cold wave	Kuldebølge	Kou-inval. Kougolf
Compass	Kompas	Kompas
Conduction	Ledning	Geleiding
Corona	Korona	Krans
Crepuscular rays	Tusmørkestraaler	Schemeringstralen
Curve fitting	Udjævning med Kurve	Kromme aanpassen
Damp air	Fugtig Luft	Vochtige lucht
Dawn	Daggry	Dageraad, Morgenschemering
Day	Dag	Dag
Debacle	Isbrud, Isgang	IJsgang
Density	Tæthed	Dichtheid
Depression	Lavtryk	Depressie, minimum
Desert	Ørken	Woestijn
Desiccation	Udtørring	Uitdroging
Deviation	Deviation	Afwijking
Dew	Dug	Dauw
Diathermancy	Gennemstraalelighed	Doorlaatbaarheid voor warmte
Diffraction	Bøjning	Buiging, diffractie
Diurnal	Daglig	Dagelijksch
Doldrums	Doldrum	Kalmtegordels
Drizzle	Støvregn	Motregen, miezeren
Drops	Draaber	Druppels
Drought	Tørke	Droogte
Dry spell	Tørt Tidsram	Tijdperk van Droogte
Duration of sunshine	Varighed af Solskin	Duur van Zonneschijn
Dusk	Tusmørke	Avondduister
Dust	Støv	Stof

—continued.

FRENCH	GERMAN
Blizzard	Blizzard, Schneesturm
Pluie de sang	Blutregen
Bleu du ciel	Blaues Himmelslicht, Himmelsbläue
Braves vents d'ouest (terme de marine)	Brave Westwinde
Brise	Brise
Turbulence de l'air	Böigkeit ("Bockigkeit")
Force ascensionnelle	Auftrieb
Calibrage	Kalibrierung, Eichung
Calme	Kalme, Windstille
Capuchon (pileus dans l'Atlas)	Kappe
Bassin de réception	Einzugsgebiet
Ciel clair, Définition d'un jour de,	Heiterer Tag
Changements ou Variations climatériques	Klimaänderung
Pluie torrentielle	Wolkenbruch
Nebulosité	Bewölkung
Nuages	Wolken
Col	Sattel (zwischen zwei Antizyklonen)
Front froid	Kaltfront
Vague froide	Kältewelle
Boussole, compas	Kompass
Conduction	Leitung
Couronne	Korona, Hof
Rayons crépusculaires	Dämmerungstrahlen
Choix de courbes	Kurvenanpassen
Air humide	Feuchte Luft
Aube	Dämmerung
Jour	Tag
Débâcle	Beginn des Eisgangs (Aufgang der Flüsse)
Densité	Dichtigkeit
Dépression	Depression
Désert	Wüste
Desséchement	Austrocknung
Déviation	Abweichung, Ablenkung
Rosée	Tau
Diathermansie	Diathermansie, Wärmedurchlässigkeit
Diffraction	Diffraktion
Diurne	Täglich
Pot-au-noir	Doldrums, Stillen, Kalmengürtel
Bruine	Sprühregen
Gouttes	Tropfen
Sécheresse	Dürre
Série (ou période) sèche	Trockenperiode
Durée de l'Insolation	Sonnenscheindauer
Brune (obscurité)	(Die Zeit vom Ende der bürgerlichen Dämmerung bis zur vollen Dunkelheit)
Poussière	Staub

ENGLISH	DANISH	DUTCH
Dust-devil	Støvhvirvel	Zandhoos
Dynamic cooling	Dynamisk Afkøling	Dynamische afkoeling
Earth currents	Jordstrømme	Aardstroomen
Earthquake	Jordskælv	Aardbeving
Eddy	(1) Strømskær (2) Hvirvel	Draaikolk
Equation of time	Tidsækvation	Tijdvereffening
Equatorial air	AEkvatorial Luft	Equatoriale lucht
Equinox	Jævndøgn	Dag en nacht evening
Error	Fejl	Fout
Evaporation	Fordampning	Verdamping
Expansion	Udvidelse	Uitzetting
Exposure	Opstilling	Opstelling, blootstelling
Exsiccation	Udtørring	Uitdroging
Extremes	Ekstremer	Uitersten
Eye of storm	Stormens Øje	Oog van den storm
Eye of wind	Vindøje	Hoek waaruit de wind waait
Falling time (of barometer)	Barometrets Træghed	Valtijd (van den Barometer)
Fiducial temperature	Referens Temperatur	Standaardtemperatuur herleid voor breedte
Floe	Isflage	Bank van drijfijs, ijsbank
Flow-off	Afstrømning	Afvoer
Fog	Taage	Mist
Fog bow	Taagebue, Hvid Regnbue	Mistboog
Forecast	Vejrforudsigelse	Verwachting
Frazil ice	—	(Zwevend ijs)
Freeze, Freezing	Fryse, Frysning	Bevriezen, vriezende
Frequency	Hyppighed, Frekvens	Frequentie (talrijkheid, veelvuldigheid)
Friction	Gnidning, Friktion	Wrijving
Front	Front	Front
Frost	Frost	Vorst
Funnel cloud	Skytap	Ikkestaart
Further outlook	Vejrforudsigelse paa lang Sigt	Verdere vooruitzichten
Gale	Stormende Kuling	Storm
Gale warning	Stormvarsel	Stormwaarschuwingen
General inference	Vejrberetning	Algemeen overzicht
Glacier breeze	Gletschervind	(Gletscher-bries)
Glazed frost	Islag, Isslag	IJzel
Grass temperature	Temperatur i Græsset	Temperatuur op het grasveld
Gravity	Tyngde	Zwaartekracht
Great circle	Storcirkel	Groote cirkel
Green flash	Den grønne Straale	Groene straal
Ground frost	—	Nachtvorst
Ground, State of	Jordoverfladens Tilstand	Grondtoestand
Gust	Vindstød, Vindkast	Windstoot

—continued.

FRENCH	GERMAN
Tempête de sable	Staubwirbel, Sandhose
Refroidissement dynamique	Dynamische Abkühlung
Courants telluriques	Erdströme
Tremblement de terre	Erdbeben
Tourbillon	Wirbel
Equation du temps	Zeitgleichung
Air équatorial	Äquatorialluft
Equinoxe	Äquinoktien, Tag- und Nachtgleiche
Erreur	Fehler
Evaporation	Verdunstung
Détente	Ausdehnung
Exposition	Aufstellung
Desséchement	Austrocknung
Extrêmes	Extreme
Œil de la Tempête	Auge des Sturms
Lit du vent (marine)	(Richtung, aus der der Wind weht)
Inertie	Fallzeit (des Barometers)
—	Die Temperatur, bei der die Able sungen eines in mb. eingeteilten Baro meters in einer bestimmten Breite keiner Korrektion bedürfen
Floe	Eisfeld
Débit	Abfluss
Brouillard	Nebel
Arc en ciel blanc	Nebelregenbogen
Prévision	Vorhersage
(Intraduisible en francais—Sorte de bouillie de glace)	Siggeis
Gel, Congélation	Frieren
Fréquence	Häufigkeit
Frottement	Reibung
Front	Front
Gelée	Frost
Entonnoir de la trombe	Trichter, Schlauch, Rüssel-Wolke
Prévision à assez longue échéance	Voraussichtliche Weiterentwicklung der Wetterlage
Coup de vent	Sturm
Avertissement de tempête	Sturmwarnung
Prévision du type de temps	Allgemeine Wetterlage
Brise de glacier	Gletscherwind
Verglas	Glatteis
Température du sol gazonné	Temperatur am Erdboden
Gravité	Schwere
Grand cercle, orthodromie	Grosser Kreis
Rayon vert	Grüner Strahl
Sol gelé	Bodenfrost
Etat du sol	Zustand des Bodens
Rafale	Windstoss

English	Danish	Dutch
Hail	Hagl	Hagel
Halo	Ring, Maanegaard, Solgaard, Halo	Halo (kring)
Haze	Dis	Nevel
Heat	Varme	Warmte, hitte
High	Højtryk	Hoogedrukgebied
Hoar-frost	Rimfrost	Ruige vorst
Horse latitudes	Heste-Bredder	Stiltegordels
Humidity	Fugtighed	Vochtigheid
Hurricane	Orkan	Orkaan
Hydrometer	Hydrometer Areometer	Vochtweger
Ice	Is	IJs
Iceberg	Isfjeld, Isbjerg	IJsberg
Iceblink	Isblink	IJsblinker
Ice sheet	Isdække	IJslaag
Increment	Tilvækst	Vermeerdering, toeneming
Index correction	Nulpunktskorrektion	Index-correctie
Indian summer	Indiansk Sommer	Nazomer
Isopycnic	Isopycne	Isopyknen
Katabatic	Fald (vind)	Dalend
Kite	Drage	Vlieger
Labile	(1) i ustabil Ligevægt	Labiel, wankelbaar
Lag	Indstillingstid	Achterblijven
Land and sea breezes	Land og Havbris (-vind)	Land en zeewind
Lapse	Lodret Temperatur-Gradient	Verval, verloop
Latitude	Bredde	Breedte
Level	Vandstand, Niveau	Waterpas, vlak, niveau
Lightning	Lyn	Bliksem, weerlicht
Line-squall	Bygelinie	Bui
Liquid	Vædske	Vloeibaar
Local time	Lokal Tid, Stedtid	Plaatselijke tijd
Longitude	Længde	Lengte
Looming	Ragen op i Taagen	Opdoemen
Low	Lavtryk	Laag, depressie, minimum
Lunar	Maane-	Maans-
Mackerel sky	Himmel med Makrelskyer	Schaapjeswolken
Mares' tails	Kattehaler	Paardestaarten (windveeren)
Mercury	Kviksølv, Kvægsølv	Kwik

—continued.

FRENCH	GERMAN
Grêle	Hagel
Halo	Halo
Brume sèche	Dunst
Chaleur	Wärme
Anticyclone	Hoch, Hochdruckgebiet
Gelée blanche	Rauhreif
Zone des calmes tropicaux	Rossbreiten
Humidité	Feuchtigkeit
Ouragan	Hurrikan
Hydromètre	Hydrometer
Glace	Eis
Iceberg	Eisberg
Reflet éblouissant de la glace	Eisblink
Couche de glace	Eisschild
Différentielle	Inkrement
Correction instrumentale	Index-Korrektion, Instrumental-Korrektion
—	Indianer-Sommer, in Deutschland gleichbedeutend mit Altweibersommer
Isopycniques	Isopyknen
Catabatique	Katabatisch
Cerf-volant	Drachen
Equilibre instable	Labil
Retard	Nachhinken, Trägheit
Brise de terre et brise de mer	Land- und Seewinde (brisen)
Décroissance de la température avec la hauteur	Abnahme, Abfall
Latitude	Breite
Niveau	Ebene, Höhenlage, Niveau
Foudre, éclair	Blitz
Ligne de grain	Böe (mit breiter Front)
Liquide	Flüssigkeit
Heure locale	Ortszeit
Longitude	Länge
Mirage, déplacement de l'horizon	—
Dépression	Tief, Tiefdruckgebiet
Lunaire	Lunar
Ciel moutonné	(Ein mit ci-cu oder a-cu undul bedeckter Himmel)
Cirrus en queue de cheval	Federwolke (Cirrus), Windbaum
Mercure	Quecksilber

English	Danish	Dutch
Mirage	Spejling	Luchtspiegeling
Mist	Let Taage	Nevel
Monsoon	Monsun	Moesson
Month	Maaned	Maand
Moon	Maane	Maan
Mountain breeze	Bjergvind	Bergwind
Night sky, Light of	Nattehimlens Lys	Nachtelijken hemel, licht van den
Normal law of errors	Typiske Fejllov	Foutenwet
Observer	Observator	Waarnemer
Oscillation	Svingning	Schommeling
Overcast day	Overtrukket, Graavejrsdag	Betrokken dag
Pack ice	Pakis	Pakijs
Pallium	—	(Pallium)
Paranthelia	Bisole	Bijtegenzon
Paraselenae	Bimaaner	Bijmaan
Parhelion	Bisol	Bijzon
Passing shower	Vandrende Byger	Losse bui
Percolation	Nedsiven	Doorsikkering
Persistence	Uforanderlighed	Aanhouden
Personal equation	Personlig Fejl	Persoonlijke fout
Phenomenon	Fænomen	Verschijnsel
Pilot balloon	Pilot Ballon	Loodsballon
Pitot tube	Pitot Rør	Pitotbuis
Pluviometer	Regnmaaler	Regenmeter
Pocky cloud	—	(Mammato-cumulus)
Polar air	Polarluft	Poollucht
Precipitation	Nedbør	Neerslag
Pressure	Tryk	Druk
Probability	Sandsynlighed	Waarschijnlijkheid
Probable error	Sandsynlig Fejl	Waarschijnlijke fout
Prognostics	Vejrregler, Vejrtegn	Verwachtingen
Pumping	Pumpning	Pompen
Purple light	Purpurlys	Purpurlicht
Radiation	Straaling	Straling
Rain	Regn	Regen
Rain, Artificial	Kunstig Regn	Regen, kunstmatige
Rain-band	Regnbaand	Regenband
Rainbow	Regnbue	Regenboog
Rain day	Regndag	Regendag
Raindrops	Regndraaber	Regendruppels
Rainfall	Nedbør	Regenval
Rain-gauge	Regnmaaler	Regenmeter
Rain-making	Kunstig Fremstilling af Regn	Regenmaken, regenverwekken

—continued.

FRENCH	GERMAN
Mirage	Luftspiegelung, Fata Morgana
Brume	Nebel
Mousson	Monsun
Mois	Monat
Lune	Mond
Brise de montagne	Bergwind
Lumière du ciel nocturne	Licht des Nachthimmels
Courbe en cloche ou Courbe de Gauss	Fehlergesetz
Observateur	Beobachter
Oscillation	Oszillation, Schwankung
Jour couvert (completement couvert)	Trüber Tag
Pack ice	Packeis
Pallium	(Eine gleichemässige, graue Wolkendecke, aus der gewöhnlich Regen fällt)
Paranthélie	Nebengegensonne
Parasélène	Nebenmond
Parhélie	Nebensonne
Averse passagère	Schauer
Percolation	Filtrierung, Durchsickerung
Persistance	Persistenz, Beständigkeit
Equation personnelle	Persönliche Gleichung
Phénomène	Phänomen
Ballon-pilote	Pilotballon
Tube de Pitot	Pitot-Röhre
Pluviomètre	Pluviometer, Regenmesser
Nuage en poche, Nuage en sac	(Mammato Cumulus)
Air polaire	Polarluft
Précipitation	Niederschlag
Pression	Druck
Probabilité	Wahrscheinlichkeit
Erreur probable	Wahrscheinlicher Fehler
Pronostics	Prognose, Vorhersage
Pistonnage	Pumpen (beim Barometer)
Lueurs pourpres	Purpurlicht
Radiation	Strahlung
Pluie	Regen
Pluie artificielle	Künstlicher Regen
Bande de la pluie (dans le spectre)	Regenbande (im Spektrum)
Arc en ciel	Regenbogen
Jour de pluie	Regentag
Gouttes de pluie	Regentropfen
Chute de pluie	Regenfall, Niederschlag
Pluviomètre	Regenmesser
Pluie artificielle	Regenmachen

ENGLISH	DANISH	DUTCH
Rain shadow	Læ	(Regen schaduw, beschutting)
Rain spell	Regnperiode	Regen periode
Recurvature of storm	Afbøjning af Stormbane	Terugloopen van den storm
Reduction	Reduktion	Herleiding
Reflection	Reflektion	Terugkaatsing
Refraction	Refraktion	Breking, refractie
Residual	(1) Rest- (2) Afvigelse	Achterblijvend, overblijvend
Reversal	Vindomslag med Højden	Omkeering
Revolving storm	Hvirvelstorm	Wervelstorm
Ridge	(1) Ryg (2) Kile	Rug
Rime	Rim	Rijp
Roaring Forties	De brølende Vinde paa 40°	Westenwind
Roll cumulus	Skypølser	Rol-cumulus
Salinity	Saltholdighed	Zoutgehalte
Sand pillar	Sandsøjle	Zandpilaar
Sastrugi	—	Sastrugi
Saturation	Mætning	Verzadiging
Scotch mist	—	(Bergnevel)
Screen, Stevenson	Stevensons Termometerhus	Stevenson's hut
Scud	Drivsky, Stormsky	Flarden, rafels
Sea breeze	Søbris, Havbris	Zeewind
Sea disturbance	Søgang	Zeegang
Sea level	Havets Overflade	Zeeniveau
Seasons	Aarstider	Jaargetijden
Secular trend	Sekulær Gang	Seculaire gang
Seisms	Jordrystelser	Seismen, aardbevingen
Serein	Regn fra en klar Himmel	Helder
Shade temperature	Temperatur i Skyggen	Temperatuur in de schaduw
Shower	Byge	Stortbui
Silver thaw	Rimslag	Ruige vorst
Site	Beliggenhed	Ligging
Sleet	Slud	Natte sneeuw
Slide rule, Pilot balloon	Pilot Ballon Regnestok	Rekenschuif of rekenliniaal (voor loods-ballon)
Sling thermometer	Slyngtermometer	Slingerthermometer
Snow	Sne	Sneeuw
Snow drift	Snefog, Sneknog	Sneeuwjacht
Snow line	Snegrænse	Sneeuwgrens
Snow lying	Snedække	Sneeuwbedekking
Snow rollers	—	(Sneeuwrollen)
Soft hail	Hagl, Snehagl	Losse hagel
Solarisation	Direkte Solstraaling	Solarisatie
Solstice	Solhverv	Zonnestilstand
Sounding balloon	Ballon sonde	Registreerballon
Spring	Foraar	Lente

—continued.

FRENCH	GERMAN
Région abritée de la pluie	Regenschatten
Série de pluie	Regenperiode
Courbure de la trajectoire d'un cyclone	Umbiegen der Sturmbahn
Réduction	Reduktion
Réflexion	Reflektion
Réfraction	Refraktion, Brechung
Résiduel	Abweichung
Inversion dans la direction du vent, renversement du vent	Umkehrend
Tempête tournante	Drehsturm
Crête de haute pression ou dorsale	Rücken (beim Hoch)
Givre	Rauhreif
—	Brave Westwinde
Cumulus en rouleaux	Roll-Kumulus
Salinité	Salzgehalt
Trombe de sable	Staubsäule
Sastrugi	Sastrugi
Saturation	Sättigung
—	(Dicker Bergnebel mit Nieselregen)
Abri	Hütte, Stevenson
Diablotin, Nuage coureur, " Scud "	Fractonimbus
Brise de mer	Seebrise
Agitation de la mer	Seegang
Niveau de la mer	Meeresniveau
Saisons	Jahreszeiten
Variations séculaires	Säkularschwankung
Seismes	Seismische Bewegungen
Serein	Tau
Température sous abri	Schattentemperatur
Averse	Schauer
—	Reif
Exposition	Lage
Neige et pluie mêlées (pas de terme special en français)	Schnee und Regen gemischt (Schlackenwetter)
Règle à calcul pour le dépouillement des sondages aérologiques	Rechenschieber für Auswertung von Pilotballonbeobachtungen
Thermomètre-fronde	Schleuderthermometer
Neige	Schnee
Chasse-neige	Schneetreiben
Limite des neiges perpetuelles	Schneegrenze
Couverture de neige	Schneelage
Rouleaux de neige	Schneeroller
Grésil	Graupel
Solarisation	Solarisation
Solstice	Solstitium, Sonnenwende
Ballon-sonde	Sondierballon
Printemps	Frühling

English	Danish	Dutch
Squall	Byge	Windvlaag
Squall line	Bygelinie	Buienlijn
Standard	Norm	Standaard, normaal
Standard deviation	Middelfejl	Middelbare fout
Standard time	Standard Tid	Standaard tijd
State of the sky	Skydække	Bewolking, hemelbedekking
Storm	Uvejr	Storm
Storm cone	Kegle til Stormvarsel	Stormkegel
Subsidence	Nedsynken	Bezwijken, ineenzakken
Summer	Sommer	Zomer
Sun-dial	(1) Solskive (2) Solur	Zonnewijzer
Sun pillar	Sol-Søjle	Zuil boven de zon
Sunrise, sunset	Solopgang, Solnedgang	Zonsopgang, ondergang
Sunrise and sunset colours	Morgenrøden Aftenrøden	Morgenrood, avonrood (schemeringskleuren)
Sunshine	Solskin	Zonneschijn
Sunspot number	Solpletantal	Zonnevlekken getal
Supersaturation	Overmætning	Overzadiging
Surface of discontinuity	Diskontinuitetsflade	Discontinuiteitsoppervlak
Surface of subsidence	Subsidensflade	Vlak van geringsten weerstand
Surge	—	Drukgolf
Swell	Dønning	Deining
Tension of vapour	Damptryk	Spanning van den damp
Terrestrial magnetism	Jordmagnetisme	Aardmagnetisme
Thaw	Tø	Dauw
Thunder	Torden	Donder
Thundercloud	Tordensky	Donderwolk, onweerswolk
Thunderstorm	Tordenvejr, Tordenbyge	Onweer
Tide, Influence on winds	—	Getij, invloed op wind
Time	Tid	Tijd
Trace (of rainfall)	Spor	Spoor (regen)
Trade winds	Passat	Passaatwinden
Trajectory	Bane	Baan
Transparency	Gennemsightighed	Doorzichtigheid
Tremor	Skælv	Tremor (siddering, trilling)
Tropic	(1) Troperne (2) Vendekreds	Keerkring
Trough	Udløber af lavt Lufttryk	Dal, trog
Twilight	Tusmørke	Schemering
Twilight arch	Jordskygge	Schemering boog
Typhoon	Tyfon	Typhoon
Units	Enheder	Eenheden
Upper air	Højere Luftlag	Bovenlucht, hoogere luchtlagen
Valley breeze	Dalvind	Dalwind
Vapour pressure	Damptryk	Dampdruk

—continued.

FRENCH	GERMAN
Grain	Böe
Ligne de grain	Böenlinie
Standard, Etalon	Standard, Normal
Ecart moyen	Mittlere Abweichung
Temps legal	Normalzeit
Etat du ciel	Himmelszustand (Menge der Bewölkung)
Tempête	Sturm
Cône de Tempête	Sturmkegel
Subsidence	Absinken
Eté	Sommer
Cadran solaire	Sonnentägig
Colonne solaire	Sonnensäule
Lever, coucher du soleil	Sonnenaufgang, Sonnenuntergang
Couleurs du levant, du couchant	Dämmerungsfarben
Insolation	Sonnenschein
Nombres des taches solaires	Sonnenfleckenzahl
Sursaturation	Übersättigung
Surface de discontinuité	Diskontinuitätsfläche
Surface de subsidence	Abgleitfläche
Variation générale	Allgemeines Ansteigen des Luftdrucks
Houle	Schwall, Dünung
Tension de Vapeur	Dampfdruck
Magnétisme terrestre	Erdmagnetismus
Dégel	Tau
Tonnerre	Donner
Nuage d'orage	Gewitterwolke
Orage avec tonnerre	Gewittersturm
Marée, Influence sur les vents	Flut, Einfluss auf Winde
Temps (durée)	Zeit
Traces de pluie	Spur, Unmessbarer Niederschlag
Vents alizés	Passatwinde
Trajectoire	Trajektorie, Luftbahn
Transparence	Transparenz, Durchlässigkeit
Vibration	Beben, Zittern
Tropique	Wendekreis
Creux	Troglinie (der Depression)
Crépuscule	Dämmerung (Zwielicht)
Arc crépusculaire	Dämmerungsbogen
Typhon	Taifun
Unités	Einheiten
Haute atmosphère	Obere Luftschichten, Hohe (höhere) Atmosphäre
Brise de vallée	Talwind
Pression de vapeur	Dampfdruck

English	Danish	Dutch
Veering	Vinden drejer til højre	Ruimend
Velocity	Hastighed	Snelheid
Vernier	Nonius	Nonius
Visibility	(1) Synsvidde (2) Sigtbarhed	Zicht
Water	Vand	Water
Watershed	Vandskel	Waterscheiding
Waterspout	Skypumpe	Waterhoos
Water vapour	Vanddamp	Waterdamp
Wave motion	Bølgebevægelse	Golfbeweging
Waves	(1) Bølger (2) Sø	Golven
Weather	Vejr	Weer
Weather maxim	Vejrregel	Weerregel
Wedge	Kile	Wig
Weighting	Tillægge Vægt	Afwegen
Wet bulb	Vaadt Termometer	Natte bol
Wet day	—	Natte dag, regendag
Wet fog	vaad Taage	Natte mist
Whirlwind	Hvirvelvind	Dwarrelwind, wervelwind
Wind	Vind	Wind
Wind vane	Vindfløj	Windvaan
Winter	Vinter	Winter
Wireless telegraphy	Radiotelegrafi, Traadløs Telegrafi	Draadlooze Telegraphie
Year	Aar	Jaar
Zero	(1) Nul (2) Nulpunkt	Nul
Zodiac	Dyrekredsen	Dierenriem
Zone of silence	Tavshedszone	Stiltezone
Zone time	Zonetid	Zone-tijd

—continued.

French	German
Mouvement dextrogyre Virement où virage	Ausschiessen (des Windes)
Vitesse	Geschwindigkeit
Vernier	Nonius
Visibilité	Sicht
Eau	Wasser
Versant	Wasserscheide
Trombe marine	Wasserhose
Vapeur d'eau	Wasserdampf
Mouvement en vague	Wellenbewegung
Ondes	Wellen
Temps (météorologique)	Wetter
Proverbe météorologique	Wetterregel, Wetterspruch, Volkswetterregel, Bauernregel
Coin de haute pression	Keil (Hochdruckkeil)
Pesant	Gewicht
Thermomètre mouillé	Feuchtes Thermometer
Jour humide	Regentag
Brouillard humide	Nässender Nebel
Tourbillon de vent	Wirbelwind
Vent	Wind
Girouette	Windfahne
Hiver	Winter
Télégraphie sans fil	Drahtlose Telegraphie
Année	Jahr
Zéro	Null, Nullpunkt
Zodiaque	Zodiakus, Tierkreis
Zone de silence	Zone des Schweigens
Temps du fuseau	Zonenzeit

LIST OF

The following pages give the equivalents in various languages of a number of the terms languages, and these have been omitted from the lists. The complete lists of translations

English	Italian	Norwegian
Absorption (atmospheric)	Assorbimento (atmosferico)	Absorpsjon (Luftens)
Accumulated temperature	Temperatura accumulata	Temperaturoverskudd
Accuracy	Accuratezza	Nøiaktighet
Actinic rays	Raggi attinici	Aktiniske stråler
Afterglow	Tramonto purpureo (del sole)	Efterglød
Air	Aria	Luft
Air-meter	Misuratore di aria	Vindhastighetsmåler, Anemometer
Air pockets	Tasche di aria	Lufthuller
Air trajectory	Traiettoria dell'aria	Lufttrajektor, Luftmasses [bane
Altimeter	Altimetro	Høidemåler
Altitude	Altitudine	(1) Høide (2) Høidevinkel
Anabatic	Anabatico	Anabatisk
Anemogram	Anemogramma	Anemogram
Anemometer	Anemometro	Vindhastighetsmåler, Anemometer
Anemoscope	Anemoscopio	Anemoskop
Anthelion	Antelio	Motsol
Anticyclone	Anticiclone	Anticyklon
Antitrades	Contro alisei	Antipassat
Anvil cloud	Nube a incudine	Amboltsky
Aqueous vapour	Vapor acqueo	Vanndamp
Arid	Arido	Arid, Ørken-
Atmosphere	Atmosfera	Atmosfære
Atmospheric pollution	Polluzzione atmosferica	Forurensning av luften
Atmospheric pressure	Pressione atmosferica	Lufttrykk
Atmospherics	Atmosferici	Luftelektriske forstyrrelser
Attached thermometer	Termometro unito al Barometro	Barometertemometer
Audibility	Audibilità	Hørevidde
Aurora	Aurora	Polarlys, Nordlys, Sydlys
Autumn	Autunno	Høst
Avalanche wind	Vento a valanga	Skred-vind
Average	Media	Middel
Backing	Salto di vento	Venstredreiende
Ball lightning	Fulmine globulare	Kulelyn
Balloon	Pallone	Ballong
Bearing	Azimut	Peiling
Beaufort notation	Indicazione di Beaufort	Beauforts værkode
Beaufort scale of wind force	Scala di Beaufort della forza del vento	Beauforts vindskala
Black-bulb thermometer	Termometro a bulbo annerito	Sortkuletermometer

EQUIVALENTS.

defined in the Glossary. Many of the words were found to be practically identical in all
are available for reference in the Meteorological Office Library.

PORTUGUESE	SPANISH	SWEDISH
Absórção atmosférica	Absorción atmosférica	Absorption (Atmosfärens)
Temperatura acumulada	Temperatura acumulada	Värmesumma
Exatidão	Precisión	Nogrannhet
Raios actinicos	Rayos actínicos	Fotografiskt verksamt ljus
Fenómenos ópticos durante o crepusculo	Resplandor montañero (2ª fase)	Efterglöd
Ar	Aire	Luft
Aspirador graduado	Anemómetro de mano	Känslig vindmätare
Poços aereos	Pozos de aire	Luftgropar
Trajectória do ar	Trayectoria del aire	Luftpartikelbana
Altimetro	Altímetro	Höjdmätare
Altitude	Angulo de altura	Höjdvinkel
Anabatico	Anabático	Anabatisk
Anemodiagrama	Anemograma	Vindregistrering
Anemometro	Anemómetro	Anemometer, vindmätare
Anemoscopio	Anemoscopio	Anemoskop, vindfana-flöjel
Antélio	Antihelio	Motsol. Antheli
Anticiclone	Anticiclón	Anticyklon. Högtryck
Contra-monção	Contraalisio	Antipassad
Nuvem em forma de bigorna	Nube en yunque	Städ-moln
Vapor aquoso	Vapor acuoso	Vattenånga
Árido	Arido	Arid. öken-
Atmosféra	Atmósfera	Luftkrets. Atmosfär
Polução atmosférica	Impureza atmosférica	Luftens förorening
Pressão atmosférica	Presión atmosférica	Lufttryck
Atmosféricos	Atmosféricos	Atmosfäriska störningar. "Luftis"
Termómetro adjunto	Termómetro unido	Termometern på barometern
Audibilidade	Audibilidad	Hörbarhet
Aurora	Aurora	Norrsken, Sydsken, Polarsken
Outono	Otoño	Höst
Rajãda de vento	Viento del alud	Fallvind vid snöskred
Média	Promedio	Medeltal
De sentido retrógrado	Rolada a la izquierda	Motsolsvridning
Relampago esférico	Rayo en bola	Klotblixt
Balão	Globo	Ballong
Rumo	Rumbo naútico	Bäring
Notação Beaufort	Notación de Beaufort	Beauforts beteckningar
Escala Beaufort, da força do vento	Escala de Beaufort	Beauforts vindskala
Termómetro de reservatório negro	Termómetro de bola negra	Svartkuletermometer

English	Italian	Norwegian
Blizzard	Blizzard (vento con nevischio)	(1) Blizzard (2) Snekave, Snestorm
Blood-rain	Pioggia di sangue	Blodregn
Blue of the sky	Bleu del cielo	Himlens blå farve
Brave West Winds	Brava vento di ovest	Nordlige vestenvindsbelte
Breeze	Brezza	Bris*
Bumpiness	Turbolenza dell'aria	Hiving
Buoyancy	Leggerezza	Opdrift
Calibration	Calibrazione	Kalibrering
Calm	Calma	Vindstille
Cap	Cappa	Hette, Skykappe
Catchment area	Area di presa	Bekken
Clear sky, Day of	Giorno di cielo chiaro (sereno)	Klar dag
Climatic changes	Cambiamenti di clima	Klimaendringer
Cloud-burst	Spiraglio fra le Nubi	Skybrudd
Cloudiness	Annuvolamento	Skydekke
Clouds	Nube	Skyer
Col	Col (regione di media pressione)	Sadel
Cold front	Fronte fredda	Kaldfront
Cold wave	Onda fredda	Kuldebølge
Compass	Bussola	Kompass
Conduction	Conduzione	Ledning
Corona	Corona	Korona, Krans
Crepuscular rays	Raggi crepuscolari	Tusmørkestråler
Curve fitting	Curva idonea	Utjevning ved kurve
Damp air	Aria umida	Klam luft
Dawn	Alba	Daggry
Day	Giorno	(1) Dag (2) Døgn
Debacle	Disgelo	Isgang
Density	Densità	Tetthet
Depression	Depressione	Lavtrykk, Lavtrykksområde
Desert	Deserto	Ørken
Desiccation	Desiccazione	Uttørring
Deviation	Deviazione	Deviasjon
Dew	Rugiada	Dugg
Diathermancy	Diatermano	Diatermansi, Gjennemstrålelighet for varme
Diffraction	Diffrazzione	Diffraksjon, bøining
Diurnal	Diurno	Daglig
Doldrums	Zona di calma equatoriale	Doldrum, Ekvatoriale stillebelter
Drizzle	Spruzzatore	Yr, Duskregn
Drops	Goccia	Dråper
Drought	Siccità	Tørke
Dry spell	Periodo di siccità	Tørkeperiode
Duration of sunshine	Durata dello splendore del sole	Varighet av solskinn
Dusk	Crepuscolo	Tusmørke, Skumring
Dust	Pulviscolo	Støv

* Light breeze, svak vind; strong breeze, liten kuling.

—*continued.*

PORTUGUESE	SPANISH	SWEDISH
" Blizzard "	Ventisca	Blizzard
Chuva de sangue	Lluvia de sangre	Blodregn
Azul do ceu	Azul del cielo	Himmelens blåa färg
Ventos fortes de W	Vientos generales del oeste	——
Brisa	Brisa	Bris
Agitação	Meneo	Gropighet, byighet
Carga de flutuação	Boyanza	Fri lyftkraft
Calibração	Calibración	Kalibrering, pröfning
Calma	Calma	Lugnväder. Blekstillt
Lenticular, barrete	Toca	Molnhätta
Area de captação	Cuenca	Flodområde
Dia de ceu limpo	Día despejado	Dag med klar himmel
Variações climatéricas ou climáticas	Cambios climáticos	Klimatändringar
Bátega de água	Turbión	Skyfall
Nebulosidade	Nubosidad	Molnighet
Nuvens	Nubes	Moln
Sela, garganta	Collado	Sadel
Frente fria	Frente frio	Kallfront
Vaga de frio	Ola de frio	Köldvåg
Bussola	Compás de bitácora	Kompass
Condução	Conducción	Ledning, värmeledning
Corôa	Corona	Krans
Raios crepusculares	Rayos crepusculares	Skymningsstrålar
Curva ou linha representativa	Adaptación gráfica	Anpassning af en kurva
Ar humido	Aire húmedo	Fuktig luft
Aurora	Aurora	Gryning
Dia	Día	Dygn
Desgêlo	Gran deshielo	Islossning
Densidade	Densidad	Täthet
Depressão	Depresión	Minimum, lågtryck
Deserto	Desierto	Öken
Secúra	Desecación	Uttorkning
Desvio	Desviación	Afvikelse
Orvalho	Rocío	Dagg
Diatermicidade	Diatermancia	Diatermansi
Difração	Difracción	Diffraktion, böjning
Diurno	Diurno	Daglig
Regiões equatoriais de calmas	Zona de calmas ecuatoriales	Ekvatoriala kalmerna
Chuvisco	Llovizna	Dugg. Duggregn
Gôtas	Gotas	Droppar
Séca	Sequía	Torka
Periodo sêco	Periodo seco	Torr period
Duração do brilho do sol	Horas de insolación	Antal solskenstimmar
Crepúsculo	Anochecer	Skymning (Astronomisk)
Poeira	Polvo	Stoft

ENGLISH	ITALIAN	NORWEGIAN
Dust-devil	Vento vorticoso (in regione sabbiosa e secca)	Støvhvirvel
Dynamic cooling	Raffreddamento dinamico	Dynamisk avkjøling
Earth currents	Corrente terrestre	Jordstrømmer
Earthquake	Terremoto	Jordskjelv
Eddy	Piccolo vortice	Bakevje turbulent
Equation of time	Equazione del tempo	Tidsjevning
Equatorial air	Aria equatoriale	Tropeluft
Equinox	Equinozio	Jevndøgn
Error	Errore	Feil
Evaporation	Evaporazione	Fordunstning
Expansion	Espansione	Utvidelse
Exposure	Esposizione	Eksponering, opstilling
Exsiccation	Essicazione	Uttørring
Extremes	Estremi	Ekstremer
Eye of storm	Occhio della tempesta	Stormøie
Eye of wind	Occhio del vento	Vindøie
Falling time (of barometer)	Tempo di discesa del barometro	Barometrets falletid
Fiducial temperature	Temperatura fiduciale	Barometrets referenstemperatur
Floe	Mare ghiacciato	Isflak
Flow-off	Deflusso	Avløp
Fog	Nebbia	Tåke
Fog bow	Arcobaleno bianco	Tåkebue, Hvit regnbue
Forecast	Previsione	Værvarsel
Frazil ice	Ghiaccio in aghetti o piastrine	—
Freeze, Freezing	Gelare, congelamento	Frost
Frequency	Frequenza	Frekvens, Hyppighet
Friction	Frizione	Friksjon
Front	Fronte	Front
Frost	Brina	Frost
Funnel cloud	Nube a imbuto	Skypumpe
Further outlook	Previsione a lunga scadenza	Langtidsvarsel
Gale	Vento fresco	Sterk kuling*
Gale warning	Avviso di vento fresco	Kulingvarsel, Stormvarsel
General inference	Inferenza generale	Væroversikt
Glacier breeze	Brezza glaciale	Brevind
Glazed frost	Gelicidio	Isslag
Grass temperature	Temperatura dell'erba	Temperatur i gresset
Gravity	Gravità	Tyngdekraft
Great circle	Circolo massimo	Storcirkel
Green flash	Raggio verde	Den grønne stråle
Ground frost	Rugiada sul terreno	—
Ground, State of	Terreno (superficie della terra), stato del . . .	Markens tilstand
Gust	Colpo di vento	Rosse, Vindkast, Vindstøt

* Beaufort force 8; force 7, stiv kuling; force 9, liten storm.

—continued.

PORTUGUESE	SPANISH	SWEDISH
Turbilhão de poeira	Tolvanera	Damm-hvirfvel
Resfriamento dinamico	Enfriamiento dinámico	Dynamisk afkylning
Correntes teluricas	Corrientes telúricas	Jordströmmar
Tremor de terra	Temblor de tierra	Jordskalf. Jordbäfning
Remoinho	Remolino	Hvirfvel
Equação do tempo	Ecuación de tiempo	Tidsekvation
Ar equatorial	Aire ecuatorial	Ekvatorial-luft
Equinoxio	Equinoccio	Dagjämning
Erro	Error	Fel
Evaporação	Evaporación	Avdunstning
Expansão	Dilatación	Utvidgning
Exposição	Instalación	Utställning
Dissecação, Exsicação	Exsecación	Uttorkning
Extremas	Extremas	Extremer
Olho da tempestade	Ojo de la tempestad	Stormens öga
Ponto irradiante	Filo del viento	Mot vinden
Morosidade do barómetro	Inercia del barómetro	Inställningstid
Temperatura fiducial	Temperatura compensadora	Temperatur, då barometern visar rätt
Blocos de gêlo flutuantes	Témpano	Isflak
Area de inundação	Caudal	Afrinning
Nevoeiro	Niebla	Dimma
Arco de nevoeiro	Arco de la niebla	Dimregnbåge
Previsão	Predicción	Väderleksförutsägelse
Gêlo frazil	Chispas de hielo	Tallriksis
Geáda, glacial	Helar, Helada	Frysa. Fryspunkt
Freqùência	Frecuencia	Frekvens
Fricção	Rozamiento	Friktion
Frente	Frente	Front
Geáda	Escarcha	Frost
Nuvem em funil	Nube en embudo	Skorstensmoln
Previsão prolongada	Indicación ulterior	Utsikter för i öfvermorgon
Vento forte	Temporal	Hård vind eller storm
Aviso de vento forte	Aviso de temporal	Stormvarning
Inferencia ou conclusão geral	Inferencia general	Sammanfattning
Brisa glaciárica	Brisa de glaciar	Jökelvind
Geáda vidrada ou prateáda	Lluvia helada	Isbark
Temperatúra da relva	Temperatura junto al suelo	Grästemperatur
Gravidáde	Gravedad	Tyngdkraft
Circulo maximo	Círculo máximo	Storcirkel
Raio verde	Rayo verde	Gröna strålen
Geáda no terreno	Helada	Frost med skador
Estado do terreno	Estado del terreno	Markens tillstånd
Rajáda	Ráfaga, Racha	By

English	Italian	Norwegian
Hail	Grandine	Hagl
Halo	Alone	Halo, Ring, Værgard :— (1) Solgard (2) Månegard
Haze	Nebbia (secca), caligine	Ølrøk, Moe
Heat	Calore	Varme
High	Alto	Høitrykk, Høitrykksområde
Hoar-frost	Brina	(1) Rim (2) Tåkerim
Horse latitudes	Latitudine delle calme	Hestebredder
Humidity	Umidità	Fuktighet
Hurricane	Uragano	Orkan
Hydrometer	Idrometro	Areometer
Ice	Ghiaccio	Is
Iceberg	Iceberg (montagna di ghiaccio)	Isfjell, Isberg
Iceblink	Macchia luminosa nel cielo sopra il ghiaccio	Isblink
Ice sheet	Coperta di ghiaccio (lenzuolo)	Innlandsis
Increment	Incremento	Tilvekst
Index correction	Indice delle correzzioni	Nullpunktskorreksjon
Indian summer	Estate indiana	Indian summer
Isopycnic	Superfici di uguale densità	Isopyknisk
Katabatic	Katabatico	Fall(vind)
Kite	Cervo-volante	Drage
Labile	In equilibrio instabile	Labil
Lag	Pigro	Innstillingstid
Land and sea breezes	Brezze di terra e di mare	Solgangsvind :— (1) Landbris, (2) Sjøbris
Lapse	Decremento della temperatura con l'altezza	Vertikal temperaturgradient
Latitude	Latitudine	Bredde
Level	Livello	Nivå
Lightning	Lampo	Lyn, Kornmo*
Line-squall	Linea della tempesta	Linjebyge
Liquid	Liquido	Væske
Local time	Tempo locale	Lokaltid
Longitude	Longitudine	Lengde
Looming	Ingrandimento apparente	Forstørrelse ved tåke
Low	Profondo	Lavtrykk, Lavtrykksområde
Lunar	Lunare	Måne-
Mackerel sky	Cielo con nubi ondulate	Makrellskyhimmel
Mares' tails	Code di cavallo (nube)	Meiskyer, Revehaler
Mercury	Mercurio	Kvikksølv

* Distant lightning.

—*continued.*

Portuguese	Spanish	Swedish
Saraiva	Granizo	Hagel
Halo	Halo	Halo
Cerração	Calina, Calima	Disa
Calôr	Calor	Värme
Altúra	Alta	Högtryck
Geáda branca	Escarcha	Rimfrost
Regiões de calma	Zona de calmas tropicales	Rossbredderna
Humidade	Humedad	Fuktighet
Furacão	Huracán	Orkan
Hidrómetro	Hidrodensímetro	Areometer
Gêlo	Hielo	Is.
" Iceberg "	" Iceberg." Montaña flotante de hielo	Isberg
" Iceberg "	Resplandor del hielo	Isblink
Lençol de gêlo	Sábana de hielo	Ismassa
Acrescimo	Incremento	Inkrement
Correcção do index	Correción de índice	Indexkorrektion
Verão de S. Martinho	Veranillo de San Martin, Veranillo del membrillo	Indiansommar
De igual densidade	Isopícnica	Isodens
Catabatico	Catabático	Katabatisk
Papagaio	Cometa	Drake
Lábil (instavel)	Lábil	Labil
Atraso ou demora	Retardo	Eftersläpning
Brisas da terra e do mar	Brisas de tierra y de mar. (Terral y virazón)	Land-och sjöbris
Deminuição da temperatura com a altura	Degradación de temperatura	Vertikalgradient
Latitude	Latitud	Latitud. Bredd
Nivel	Nivel	Vågrät. Nivå
Relampago, raio	Relámpago	Blixt
Linha de borrasca, ou frente fria duma depressão	Linea de turbonada	Linjeby
Liquido	Líquido	Vätska
Hora local	Hora local	Ortstid
Longitude	Longitud	Longitud. Längd
Amplificação aparente	Espectros de calina, Espejismo de calina	Hägring
Baixo	Baja	Lågtryck
Lunar	Lunar	Mån-
Céu cinzento	Cielo aborregado	Makrilmoln
Caudas de cavalo	Rabos de gallo, colas de gato	Hästsvansar
Mercurio	Mercurio	Kvicksilfver

English	Italian	Norwegian
Mirage	Miraggio	Luftspeiling, Hildring
Mist	Nebbia	Tåkedis
Monsoon	Monsone	Monsun
Month	Mese	Måned
Moon	Luna	Måne
Mountain breeze	Brezza di montagna	Fjellvind
Night sky, Light of	Luminosità del cielo di notte	Nattehimlens lys
Normal law of errors	Legge normale degli errori	Feilloven
Observer	Osservatore	Observatør, iakttager
Oscillation	Oscillazzione	Oscillasjon, Svingning
Overcast day	Giorno caliginoso	Overskyet dag
Pack ice	Ghiaccio ammonticchiato	Pakkis
Pallium	Pallium (nube)	Jevnt skylag
Paranthelia	Parantelio	Motsol
Paraselanae	Paraselenio	Bimåner
Parhelion	Parelio	Bisol
Passing shower	Pioggia di breve durata	Vandrende byger, Vandrende skurer
Percolation	Percolazione	Nedsiving
Persistence	Persistenza	Vedvaren
Personal equation	Equazione personale	Personlig feil
Phenomenon	Fenomeno	Fenomen, foreteelse
Pilot balloon	Pallone pilota	Pilotballong
Pitot tube	Tubo di Pitot	Pitotrør
Pluviometer	Pluviometro	Pluviometer, Regnmåler
Pocky cloud	Nube a tasca	Mammato-
Polar air	Aria polare	Polarluft
Precipitation	Precipitazione	Nedbør
Pressure	Pressione	Trykk, Lufttrykk
Probability	Probabilità	Sannsynlighet
Probable error	Errore probabile	Sannsynlig feil
Prognostics	Prognostici	Værmerker, Værregler
Pumping	Instabilità (barometro)	Pumpning
Purple light	Luce purpurea	Purpurlys
Radiation	Radiazione	Stråling
Rain	Pioggia	Regn
Rain, Artificial	Pioggia artificiale	Kunstig regn
Rain-band	Banda della pioggia	Regnbånd
Rainbow	Arcobaleno	Regnbue
Rain day	Giorno di pioggia	Dag med nedbør $>$0.2 mm.
Raindrops	Gocce di pioggia	Regndråper
Rainfall	Caduta di pioggia	Nedbør
Rain-gauge	Pluviometro	Regnmåler
Rain-making	Pioggia artificiale	Regnmakeri

—continued.

Portuguese	Spanish	Swedish
Miragem	Espejismo	Hägring
Névoa, nebrina	Neblina	Disa
Monção	Monzón	Monsun
Mês	Mes	Månad
Lua	Luna	Måne
Brisa da montanha	Brisa de montaña	Berg-och dalvind
Luz do céu á noite	Claridad del cielo nocturno	Natthimlens ljus
Lei normal dos erros	Ley normal de los errores	Gauss' fellag
Observador	Observador	Observatör
Oscilação	Oscilación	Svängning. Variation
Dia enevoado	Día cubierto	Mulen dag
Pacote de gêlo	Banco de hielos a la deriva	Packis
" Pallium "	Palio. (Pallium)	Regnmolnstäcke
Parantélio	Paranthelios	Motbisol. Parantheli
Paraselena	Paraselenes	Bimåne
Parhélio	Parhelio	Bisol. Parheli
Aguaceiro passageiro	Chubascos pasajeros	Övergående skur
Filtração	Filtración	Perkolation
Persistencia	Persistencia	Persistens. " Erhaltungstendenz "
Equação pessoal	Ecuación personal	Personlig ekvation
Fenómeno	Fenómeno	Fenomen
Balão piloto	Globo piloto	Pilotballong
Tubo de Pitot	Tubo de Pitot	Pitotrör
Pluviómetro	Pluviómetro	Regnmätare
Nuvem bexigosa	Nubes abolsadas	Mammato-
Ar polar	Aire polar	Polarluft
Precipitação	Precipitación	Nederbörd
Pressão	Presión	Tryck. Lufttryck
Probabilidade	Probabilidad	Sannolikhet
Error provavel	Error probable	Sannolikt fel
Prognosticos	Pronósticos	Väderlekstecken
Oscilação	Tembleteo	Pumpning
Luz purpúrea	Luz purpúrea	Purpursken
Radiação	Radiación	Strålning
Chuva	Lluvia	Regn
Chuva artificial	Lluvia artificial	Konstgjordt regn
Risca de chuva	Banda de absorción de la lluvia	Regnband
Arco-íris	Arco iris	Regnbåge
Dia de chuva	Día de lluvia	Nederbördsdag
Pingos de chuva	Gotas de lluvia	Regndroppar
Chuva caída	Precipitación	Nederbörd
Pluviómetro	Pluviómetro	Nederbördsmätare
Chuva artificial	Pluvificación	Regnmakeri

ENGLISH	ITALIAN	NORWEGIAN
Rain shadow	Area di poca pioggia	Le for nedbør
Rain-spell	Lungo periodo di pioggia	Regnværsperiode
Recurvature of storm	Deviazione della tempesta	Tilbakebøining av tropisk stormbane
Reduction	Riduzione	Reduksjon
Reflection	Riflessione	Refleksjon, Speiling
Refraction	Rifrazione	Refraksjon, Brytning
Residual	Residuo	Avvikelse fra utjevnet verdi
Reversal	Rovesciamento (del vento)	Vindomslag med høiden
Revolving storm	Ciclone tropicale	Hvirvelstorm
Ridge	Sommità	Kile, Rygg
Rime	Nebbia gelata	(1) Tåkerim (2) Rim
Roaring Forties	—	Sydlige vestenvindsbelte, De brave vestenvinde
Roll cumulus	Roll-cumulus	Skyruller
Salinity	Salinità	Saltgehalt, Saltholdighet
Sand pillar	—	Sandhvirvel
Sastrugi	Ondulazioni sulla neve	Skavler
Saturation	Saturazione	Metning
Scotch mist	Precipitazione da nebbia fine	Tåkeyr
Screen, Stevenson	Capanna (meteorologica di Stevenson)	Stevensons bur
Scud	Fracto-nimbo	—
Sea breeze	Brezza di mare	Sjøbris
Sea disturbance	Burrasca marina	Sjøgang
Sea level	Livello del mare	Havsnivå
Seasons	Stagione	Årstider
Secular trend	Ciclo secolare	Sekulær endring
Seisms	Sismo	Jordrystelser
Serein	Sereno (pioggia con cielo)	Regn fra klar himmel
Shade temperature	Temperatura all'ombra	Temperatur i skyggen
Shower	Rovescio	Skur, byge
Silver thaw	Galaverna	Rimslag
Site	Luogo	Beliggenhet
Sleet	Pioggia gelata	Sludd
Slide rule, Pilot balloon	Regolo calcolatore per palloni piloti	Regnestav for pilotballonger
Sling thermometer	Termometro a fionda	Slyngetermometer
Snow	Neve	Sne
Snow drift	Neve gelata ammonticchiata	(1) Snefokk, Snedrev (2) Snedrive
Snow line	Limite delle nevi (perpetue)	Snegrense
Snow iying	—	Snedekke
Snow rollers	Cilindri di neve	—
Soft hail	Grandine molle	Hagl*
Solarisation	Insolazione	Eksponering for sollys
Solstice	Solstizzio	Solhverv
Sounding balloon	Pallone sonda	Registrerballong
Spring	Primavera	Vår

* Kornsne is used for granular snow.

Portuguese	Spanish	Swedish
Area protegida das chuvas	Sequía orográfica	Regnskugga
Período chuvoso	Periodo lluvioso	Regnperiod
Encurvamento da tempestade	Incurvación de la tempestad	Stormens riktningsändring
Reducção	Reducción	Reduktion
Reflexão	Reflexión	Reflektion. Återkastning
Refracção	Refracción	Refraktion. Brytning
Residual, restante	Desviación	Residu
Reversão	Reversión	Vindomkastning med höjden
Ciclone, furacão	Ciclón, tifón, huracán, baguío	Hvirfvelstorm
Crista	Loma	Rygg af högt lufttryck
Neváda	Cenceñada (Niebla helada)	Dimfrost
—	Ponientes duros australes	—
Cumulus em forma de rôlo	Rollo-cumulos, ó cumulos en rollo	Vals-Cumulus
Salinidade	Salinidad	Salthalt
Coluna de areia	Tolvanera	Sandstod
" Sastrugi "	" Sastrugi "	Skaflor
Saturação	Saturación	Mättning
Nebrina da Escocia	Neblina escocesa	Regndimma
Abrigo Stevenson	Garita de Stevenson	Stevenson's bur
Fracto-nimbus	Correos	Molnflagor
Brisa do mar	Virazón	Sjöbris
Perturbação do mar	Estado del mar	Sjögång
Nivel do mar	Nivel del mar	Havsytan
Estações	Estaciones del año	Årstider
Variação secular	Tendencia secular	Sekulärvariation
Sismo	Sismos	Seismer
Sereno	Sereno, relente	Regn från klar himmel
Temperatura á sombra	Temperatura a la sombra	Temperatur i skuggan
Aguaceiro	Chubasco	Skur
Degêlo prateado	Escarcha plateada	Glattis. Silfverdagg
Situação	Situación	Förläggning
Geáda miuda	Aguanieve	Snöblandadt regn
Régua de cálculo para balões pilotos	Regla de cálculo para globos pilotos	Räknesticka för ballong-viseringar
Termómetro funda	Termómetro honda	Slungtermometer
Neve	Nieve	Snö
Neve amontoada	Ventisquero y ventisca	Drifsnö
Linha de neve	Límite de las nieves perpétuas	Snögräns
Neve jacente	La nieve cubre el suelo	Snötäcke
Rolos de neve	Rollos de nieve	Snöbultar
Graniso	Nieve granulada	Trindsnö
Exposição ao sol	Insolación	Utsättning för solljuset
Solsticio	Solsticio	Solstånd
Balão sonda	Globo sonda	Ballon-sonde
Primavéra	Primavera	Vår

English	Italian	Norwegian
Squall	Tempesta	Vindbyge, Byge
Squall line	Fronte della tempesta	Bygelinje
Standard	Di ugual misura, campione	Standard
Standard deviation	Deviazione tipo	Middelfeil
Standard time	Tempo medio locale	Normaltid
State of the sky	Stato del cielo	Skydekke
Storm	Burrasca, temporale	(1) Uvær, (2) Storm
Storm cone	Segnale di tempesta	Stormvarselskjegle
Subsidence	Subsidenza	Subsidens, Nedsynkning
Summer	Estate	Sommer
Sun-dial	Orologio solare	Solur
Sun pillar	Colonna solare	Solsøile
Sunrise, sunset	Sorgere del sole, tramonto del sole	Solopgang, Solnedgang
Sunrise and sunset colours	Colori del sorgere e del tramonto del sole	Morgenrøden, Aftenrøden
Sunshine	Splendore del sole	Solskinn
Sunspot number	Numero delle macchie solari	Solflekktall
Supersaturation	Soprasaturazione	Overmetning
Surface of discontinuity	Superficie di discontinuità	Diskontinuitetsflate
Surface of subsidence	Superficie di subsidenza	Subsidensflate
Surge	Cambiamento di pressione	Utstrakt trykkendring
Swell	Onde (di mare) persistenti	Dønning
Tension of vapour	Tensione del vapore	Vanndampens trykk
Terrestrial magnetism	Magnetismo terrestre	Jordmagnetisme
Thaw	Liquefazione	Tø
Thunder	Tuono	Torden
Thundercloud	Nube da tuoni	Tordensky
Thunderstorm	Temporale	(1) Tordenvær (2) Tordenbyge
Tide, Influence on winds	Marea, influenza dei venti	Tidevannets innflydelse på vinden
Time	Tempo	Tid
Trace (of rainfall)	Traccia (della pioggia) (piccola quantita)	Spor (av nedbør)
Trade winds	Venti alisei	Passat
Trajectory	Traiettoria	Trajektor, Bane
Transparency	Trasparenza	Gjennemsiktighet
Tremor	Tremito	Jordskjelv
Tropic	Tropico	(1) Vendekrets (2) Troperne
Trough	—	Lavtrykksrenne
Twilight	Crepuscolo	Tusmørke, Skumring
Twilight arch	Arco crepuscolare	Jordskygge
Typhoon	Tifone	Tyfon
Units	Unità	Enheter
Upper air	Aria superiore	Høiere luftlag
Valley breeze	Brezza di valle	Dalvind
Vapour pressure	Tensione del vapore	Vanndampens trykk

—continued.

Portuguese	Spanish	Swedish
Borrasca	Turbonada	Stormby. Stormil
Linha de borrásca ou frente fria duma depressão	Linea de turbonada	Bylinje
Padrão	Patrón, tipo, norma, modelo	Etalon
Desvio da normal	Desviación tipo	Medelafvikelse
Hora normal	Hora civil	Normaltid. Gemensam tid
Estado do céu	Nubosidad	Himmelens utseende
Tempestade	Tempestad, temporal, borrasca	Storm
Cone, aviso de tempestáde	Señales de tempestad	Stormvarningskon
Abatimento	Subsidencia	Efterströmning
Verão	Verano	Sommar
Relojio de sol	Cuadrante solar	Solvisare. Solur
Coluna solar	Columna solar*	Ljuspelare
Nascer do sol e pôr do sol	Orto, ocaso	Soluppgång. Solnedgång
Colorações ao nascer e pôr do sol	Coloraciones del orto y ocaso	Skymningsfärger
Brilho do sol	Horas de sol	Solsken
Número de manchas solares	Números de Wolf	Solfläckstal
Sobressaturação	Sobresaturación	Öfvermättning
Superficie de descontinuidade	Superficie de discontinuidad	Diskontinuitetsyta
Superficie de abatimento	Superficie de subsidencia	Subsidensyta
—	Variación de conjunto	Allmän tryckstegring
—	Mar de leva, Mar sordo, Mar tendida	Dyning
Tensão do vapor	Tensión del vapor	Ångtryck
Magnetismo terrestre	Magnetismo terrestre	Jordmagnetism
Degêlo	Deshielo, fusión	Dagg
Trovão	Trueno	Åska
Nuvem de trovoáda	Nube tormentosa, nubarrón	Åskmoln
Trovoáda	Tormenta	Åskväder
Mare, influencia sobre os ventos	Marea, influencia sobre los vientos	Tidvattnets inflytande på vinden
Hora	Hora (Tiempo)	Tid
Vestigios de chuva	Lluvia inapreciable	Ngt (pronounced något)
Ventos regulares	Vientos alisios	Passader
Tragectória	Trayectoria	Trajectorie
Transparencia	Transparencia	Genomskinlighet
Tremor	Temblor de tierra	Jordstötar
Trópico	Trópico	Vändkrets. Tropik
Linha de baixa pressão	Vaguada	Tråg
Crepúsculo	Crepúsculo	Skymning
Arco crepuscular	Arco crepuscular	Skymningsbåge
Tufão	Tifón o baguío	Tyfon
Unidades	Unidades	Enheter
Camada superior do ar	Atmósfera superior	Högre atmosfären
Briza do vale	Brisa de valle	Dalvind
Tensão de vapor	Tensión del vapor	Ångtryck

* Also obelisco luminoso

English	Italian	Norwegian
Veering	Rotazione	Høiredreiende
Velocity	Velocità	Hastighet
Vernier	Verniero	Nonius
Visibility	Visibilità	(1) Synsvidde (2) Siktbarhet
Water	Acqua	Vann
Watershed	Linea di displuvio	Vannskille
Waterspout	Tromba marina	Skypumpe
Water Vapour	Vapore di acqua	Vanndamp
Wave-motion	Moto ondoso	Bølgebevegelse
Waves	Onde	Bølger
Weather	Tempo (meteorologico)	Vær
Weather Maxim	Aforismi sul tempo	Værmerke, Værregel
Wedge	Cuneo	Kile, Rygg
Weighting	Pesata	Tildele vekt
Wet Bulb	Bulbo bagnato	Vått termometer
Wet Day	Giorno umido	Dag med nedbør $>$ 1.0 mm.
Wet Fog	Nebbia umida	Våt tåke
Whirlwind	Turbine	Hvirvelvind
Wind	Vento	Vind
Wind Vane	Anemoscopio	Vindfløi
Winter	Inverno	Vinter
Wireless Telegraphy	Telegrafia senza fili	Radiotelegrafi
Year	Anno	År
Zero	Zero	(1) Null (2) Nullpunkt
Zodiac	Zodiaco	Dyrekretsen
Zone of Silence	Zona del silenzio	Taushetssone
Zone Time	Fuso orario	Sonetid

—continued.

PORTUGUESE	SPANISH	SWEDISH
Sentido directo	Rolada a la derecha	Medsolsvridning
Velocidade	Velocidad	Hastighet
Nónio	Nonio	Nonie
Visibilidade	Visibilidad	Siktbarhet, synvidd
Agua	Agua	Vatten
Aguas vertentes	Divisoria	Vattendelare
Tromba de agua	Tromba marina, manga	Skydrag
Vapor de agua	Vapor acuoso	Vattenånga
Movimento ondulatorio	Movimiento ondulatorio	Vågrörelse
Ondas	Ondas, olas	Vågor
Tempo	Tiempo	Väder. Väderlek
Maximas ou aforismos	Refrán meteorológico	Väderleksregel
Cunha	Cuña	Ås
Peso	Ponderación	Förse med vikter
Reservatório molhado	Termómetro húmedo	Våta kulan
Dia humido	Día de lluvia	Regndag
Nevoeiro humido	Niebla húmeda	Vätande dimma
Remoínho	Torbellino	Hvirfvelvind
Vento	Viento	Vind
Catavento	Veleta	Vindfana
Inverno	Invierno	Vinter
Telegrafía sem fios	Radiotelegrafía	Trådlös telegrafi. Radio
Ano	Año	År
Zéro	Cero	Noll
Zodíaco	Zodiaco	Djurkrets
Zona de silencio	Zona de silencio	Tyst zon
Fusos horários	Hora del huso	Zontid

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