# METEOROLOGY.

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FROM THE ENCYCLOPÆDIA BRITANNICA.

BY

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# INTRODUCTION.

The little Essay which follows appeared originally as an article in the new edition of the Encyclopædia Britannica. The editors of that work being desirous of publishing it separately, have obligingly afforded me an opportunity of revising it during its re-impression, an opportunity of which, however, I have only so far availed myself as to correct some few errors of slight importance—to insert, here and there, in the form of notes and brief additions to the text, some notices of recent speculations or observations not involving large additions, and to explain a little more at large certain points which seemed to require further elucidation. This has been more especially the case in respect of the theory of the annual and diurnal fluctuations of the barometer, a point of a very delicate nature, and on which the views of meteorologists are so far from being in harmony with each other, or with nature, that M. Dove in one of his most recent publications instances the cases of M. Lamont, who attributes these phenomena to an electric attraction exerted by the sun, of Mr. Broun who seeks their origin in the sun's magnetism, and of M. Henry who looks to the resistance of the ether as their cause. To have extended the Encyclopædic article into a systematic, or anything like a complete treatise, would have required more time and labour than I have at my disposal.

Where anything beyond mere numerical corrections and slight alteration of expressions has been introduced, the interpolations have been distinguished from the original text, if in an entire paragraph, by the addition of an italic letter to the number of the paragraph as, for instance, in Art. (77, *a*), or if in the form of a note or of an insertion in the text of a paragraph already numbered, by placing the new matter between brackets thus [ ] or by express mention.

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# METEOROLOGY.

(1.) **Meteorology**, which, in its ancient and etymological sense, included all the appearances of the heavens, as well astronomical as atmospheric, is at present restricted in its meaning to the description and explanation of those phenomena which group themselves under the heads of the weather, of the seasons, and of climate —phenomena which, scientifically regarded, are referable almost entirely to the agency of those laws which govern the ever-varying affections of the atmosphere of our globe in its relations to heat, moisture, and electricity, and the movements which the changes of those relations, brought about by astronomical or other causes, impress upon its parts.

(2.) Were it not for this last-mentioned class of relations, those, namely, which depend on the mobility of our atmosphere, and the consequent perpetual local interchange of its parts more or less heated, and more or less moist, *inter se*, the problems presented by meteorology would be of a very simple nature. Whatever be the temperature of the interior of our globe (and there is every reason to believe it very high), it has been amply demonstrated, that the escape of its internal heat into space through its surface, for many ages past and to come, may be regarded as uniform, and so excessively slow as to be quite inappretiable as a cause of any portion of the temperature prevalent on the surface, still more so of any variation in that element. Local conflagrations and volcanoes (whatever influence geologists may ascribe to the latter in earlier states of our planet) are absolutely insignificant at present for the supply of warmth, so that it is to the sun alone that we have to look as the ultimate source of heat, and therefore, also, in all probability, of electrical excitement. Supposing, then, no lateral communication or transfer between the columns of air incumbent on adjacent parts of the earth's surface, the totality of atmospheric and climatic change in any given locality would be limited to periodical and perfectly regular fluctuations of temperature depending on the direct heating power of the sun at its various altitudes above the horizon during the day and its withdrawal during the night, and to the alternate generation and condensation of vapour equally periodic and regular, immediately consequent on such fluctuations, over those parts of the surface occupied by water. No rain would ever fall on, or cloud form over, any part of the land, which would be perfectly arid, and dependent for its temperature, at any spot, on the greater or less aptitude of its materials at that spot for absorbing and retaining the sun's rays. It is needless to add that, under such circumstances, the ocean only would possess the conditions indispensable to animal or vegetable life.

(3.) The mobility of the air, while it destroys this simplicity of sequence, and substitutes for it the variety and complexity of phenomena we actually observe, lands us, while seeking for their explanation, among mechanical difficulties of a very high order. If there be one part of dynamical science more abstruse and unapproachable than another, it is the doctrine of the propagation of motion in fluids, and especially in elastic fluids like the air, even when the amount and application of the original acting forces are known and calculable. But in this case, the acting forces consist in local dilatations of parts of the atmosphere by the sun's heat during the day, and contractions by cold during the night—in the permanent difference of temperature in the equatorial and polar regions—in the evaporation of moisture in some parts, and its precipitation in rain in others, which act directly as motive forces displacing air, and indirectly by carrying heat in a latent form from one region to another. And as if the problems arising out of these considerations alone were not sufficiently complex and intractable, the occupation of one part of the surface of our globe by land and another by sea; differing as they do in their relations to heat, in their evaporation of moisture, and in their resistance to the motion of bodies of air passing over them; the irregular form of the continents, and the existence on them of mountain chains which confine, obstruct, and divert the free courses of aerial currents—all concur to fill the subject of meteorology with difficulties utterly insurmountable if attacked by those methods of calculation which have proved so signally successful in many other branches of science.

(4.) And yet it is these very difficulties, and this excessive complication, which, by forcing us to abandon the *deductive* mode of philosophizing from sheer inadequacy of methods, throws us on the opposite, or *inductive* course of inquiry in the very attitude most favourable to success. For it is not because the general principles of dynamics are *inapplicable* to the subject that we are deterred from resorting to them as our sole dependence, but because we neither possess data sufficiently wide and precise to afford ground for their application, nor command enough of them, as instruments, to grapple with such data in all their particularity if we had them. In our assurance of their *general applicability*, we possess an invaluable clue, which precludes all groping in the dark for causes, and which serves at every step to direct the course our induction ought to take, and the forms in which it is desirable that our acquirements should be invested so as to be most available for constructing a complete theory. We come to the subject, in short, as we have every reason to believe, with a clear apprehension of all the principal efficient causes, and a pretty distinct conception of their *direct* action. It is the number and simultaneous operation of their derivative causes, the immense influence and complication of their *indirect* actions, which constitute the difficulty of this branch of physics. But, on the other hand, our knowledge of these causes throws the whole burden of the inquiry on the discovery of subordinate or derivative laws, and never leaves us at a loss (as in so many other departments of physical research) for the interpretation of those laws when discovered, or for the best and most philosophical way of expressing them in terms conveying their true theoretical import.

(5.) And hence arises one of the most marked peculiarities of this our science, viz., that while in respect of the general explanation of its phenomena it may be said to be nearly complete, inasmuch as there are few of its more important facts and broad features which cannot be rationally and satisfactorily accounted for, and referred to the recognized operations of physical agents, yet when we would follow out the results of their actions in "number, weight, and measure," and as exhibited in specified time and place, theory affords us little or no assistance. Meteorology, in short, in all that concerns numerical valuation, is pre-eminently a science of detail, and one in which all the subordinate laws which are susceptible of numerical statement have to be made out by laborious and continued observation carried on in every region of the globe. The results of such observation, accumulated in masses, and discussed by the application of those powerful and refined processes of calculation which modern invention has devised, become cleared of accidental error, freed from the influence of transient and purely local causes of irregularity, and presented in the form of mean or average conclusions, each expressing some general fact or law of progressive change. Thus, while on the one hand *deductive* theory, based on our knowledge of the acting causes and the circumstances under which they act, pursues their operation clearly to a certain extent, and less and less distinctly as it becomes lost in their entanglement; it is yet enabled to point out the directions where light is to be looked for, the lines of inquiry which *inductive* observation ought to pursue, and the form of the results which it ought to aim at securing.

(6.) The course we shall follow in the present essay will be in accordance with this general view of the subject. We shall first pass in review the agents concerned, and the laws which regulate their mutual reactions. We shall then apply our knowledge of these laws to the general explanation of the phenomena of meteorology in their order of importance and natural sequence, and finally afford as complete a view as a mere sketch like the present will allow of those subordinate laws of periodic fluctuation which meteorologists are agreed upon, a knowledge of which, as modified by geographical situation, constitutes the science of climatology; as well as of the combined system of observation and calculation by which this knowledge may be most availably obtained and extended.

## OF THE SUN AS A SOURCE OF HEAT, AND OF THE MEASURE OF ITS DIRECT ACTION. ACTINOMETRY.

(7.) The absolute uniformity of the sun's emission of heat is open to considerable doubt. From some recent inquiries by Professor Wolf, it would appear subject to a periodical increase and diminution connected with the abundance and paucity of spots on its disc, a connection surmised by the late Sir William Herschel. That the appearance of such spots is periodical, has been shewn by Professor Schwabe. The period assigned by Professor Wolf is 11·11 years from minimum to minimum, or almost exactly nine periods to each century, commencing at the beginning of the century itself. [That originally proposed by Professor Schwabe, and still, we believe, adhered to by General Sabine, is ten years.] The last year (1856) has been remarkable for an almost total absence of spots—a fact in perfect agreement with this law. As the planet Jupiter, the largest in our system, revolves about the sun in nearly the former time (11·9 y.), it would almost seem as if these singular appearances stood in some connection with electric or magnetic reactions between the sun and planets, the comparatively small discordance of periods being due perhaps to the action of the other planets.*

* While in the act of revising this sheet, we observe in the Royal Society notices for March 12, 1857, a letter from Professor Wolf announcing his discovery of an *annual sub-period* of the spots—a fact strongly corroborative of the view taken in the

(8.) Independent, however, of any such cause of inequality, the amount of solar heat momentarily received by the earth is subject to a regular annual fluctuation to the extent of one-fifteenth of its mean amount, due to the eccentricity of the earth's orbit—the heat received *in perihelio* (or on the 1st of January) being to that *in aphelio* (July 2d) as 16 to 15. As the sun is vertical over the southern tropic about the former epoch, and over the northern about the latter, it would seem at first sight that the southern hemisphere would receive per annum a larger supply of heat; but the unequal angular velocity of the earth in its orbit, which varies in the same precise ratio, effects an exact compensation in this respect by giving a *shorter* duration to a *hotter* summer in the southern hemisphere, and a *longer* to a *cooler* one in the northern.

(9.) The *general* dependence of climate on geographical situation, the high temperature observed at the equator, and the extreme cold at the poles, the annual variations of temperature which accompany the changes of season, as well as the diurnal alternations of heat and cold, are all such obvious consequences of those astronomical arrangements, in consequence of which the sun, at any geographical station attains a greater or less meridian altitude, and continues a longer or a

text. [In September 1857 appeared a memoir by the same distinguished meteorologist assigning distinct periodical amounts of fluctuation to each of the principal planets.—(*Added to the Note January* 1861.)]

shorter time above the horizon, as to need no lengthened explanation. The same sunbeam which, at a vertical incidence, acts on a surface equal to its own sectional area, when incident obliquely on the earth (including its atmosphere), is spread over a surface larger in the inverse proportion of radius to the sine of the obliquity. It needs little consideration, then, to perceive that at the poles, where the sun is below the horizon for half the year, and where during the other half it never attains a greater altitude than 23½° and that only for a short time, its effective warming power on a given horizontal surface must be very far inferior to that which it exercises in the equatorial regions, where its meridional altitude never falls short of 66½°, and where the days and nights are always nearly twelve hours in duration; nor that in intermediate latitudes the increase of its altitude, and the length of the day as it advances along the ecliptic from the winter to the summer solstice, should bring with it that accession of general temperature which we observe.

(10.) This effect of obliquity of incidence is, however, enhanced by another cause. The sun's heat is partially absorbed in passing through the atmosphere, and *that* the more, the greater the mass of air it has to penetrate, or the more obliquely it traverses it. Professor Forbes, reasoning from observations made by himself and M. Kämtz on the Faulhorn in Switzerland, as compared with others at Brienz, 6844 feet lower in level, concludes that 46 per cent of a vertical sunbeam is absorbed in traversing a *cloudless* atmosphere before reaching the sea level. A series of observations made in Paris by M. Pouillet (in 1837-38) at different zenith distances of the sun, gives only 24 per cent. 'One-third is probably not too low an estimate. The remaining two-thirds only (or less if the incidence be oblique) are directly effective in heating the earth's surface. The absorbed portion is employed in heating the air throughout its whole extent, and though not ineffective in maintaining the general temperature, acts to that end in a very different manner, as being more immediately transferable from one region to another by the action of the wind.

(11.) From experiments made at the Cape of Good Hope from December 23, 1836, to January 9, 1837, by the writer of this essay, it results that the direct heating effect of a vertical sun at the sea level is such as would suffice to melt 0.00754 in. per minute in thickness, from a sheet of ice exposed perpendicularly to its rays. M. Pouillet's conclusions, reduced to a similar form of expression, give 0.00703 in. A mean of the two determinations, 0.007285 in. per minute, may therefore be pretty confidently stated as the measure of the sun's vertical heating power at the sea level in a perfectly cloudless sky. If visible cloud or haziness, even very trifling, be present, the effect is diminished. In a clouded state of the sky nearly the whole of the solar heat is expended in heating the air, and evaporating the clouds.

(12.) Supposing, however, the sky clear, and all the rays of heat equally absorbable (which, however, is not probable), the melting effect per minute of *oblique* sunshine for a zenith distance $= z$ not exceeding 80° on a sheet of ice perpendicularly exposed to it, would be expressed by 0.01093 in. $(\frac{4}{5})^{\sec. z}$, and on a sheet *laid horizontally*, by the same function multiplied by cos. $z$. This latter effect is the measure of the direct power of sunshine to heat the general surface of the region on which it is incident (abstraction made of the specific nature of that surface).*

(13.) *Actinometry.*—The direct heating power of the sun's rays may be measured in two different ways—statically and dynamically. The statical method consists in equilibrating the heating power of sunshine on some body (as a blackened thermometer) with some external cooling influence which is itself measurable or which we have reason to believe invariable. It has been usual to suppose this accomplished by simply noting the degree marked by such a blackened thermometer in the sun (exposed till it ceases to rise), in excess of that marked by a similar one in the shade. This is much as if a man should measure his strength by the depth to which he could thrust a pole into the ground, in the absence of any knowledge of its sharpness, or the resistance of the soil. The cooling influences (conduction and radiation) are dependent for their effects on local and temporary circumstances too

* A table, in which the calorific efficacy of a vertical sun is represented by .750, and which gives its diminution for oblique incidences for every fifth degree of altitude, will be found in the article on CLIMATE, Encyclopædia Britannica, vol. vi. p. 776.

numerous and too variable to estimate. The measure itself requires to be measured. The objection is palliated but not removed, by enclosing the thermometer in an exhausted glass tube, which eliminates conduction by cutting off the contact of air, and by other methods designed to deaden, or equalize external influences. It is however, insuperable in principle.

(14.) The dynamical method consists in ascertaining the amount of physical change of a nature susceptible of definite measurement, effected on some object by a given sectional area of sunbeam in a given time, such for instance as the dilatation of a liquid, the melting of ice, or the raising of the temperature of a given quantity of water a certain number of degrees. The first attempts at obtaining such a measure, so far as we are aware, were made by the writer of this article in a tour through Sicily in 1824. A glass vessel full of inked water was exposed alternately 5 minutes in sunshine and in shade, the change of temperature being noted by a very delicate thermometer immersed in the liquid, and the solar effect per minute measured by the difference of the minutely changes observed to take place in sunshine and in shade. A similar method was employed in the experiments at the Cape of Good Hope, cited in art. 11; the sun, nearly vertical, being allowed to shine directly on a cylindrical vessel of water. M. Pouillet's "pyroheliometer" is constructed on this principle—a cylindrical body of water of large diameter in proportion to its height, being inclosed in a metallic vessel of that form *with a glass face*, which is exposed perpendicularly to the sun. In the "actinometer"* a blue liquid (ammonio-sulphate of copper) is enclosed in a glass cylinder, one end of which is closed by a silver screw working in a tight collar, to admit of a small change of capacity when the liquid becomes too much dilated by heat, while the other end is soldered on to a thermometer tube, by which the liquid measures its own dilatation, the cylindrical portion acting as the bulb of the thermometer. The actual temperature of the liquid (on which its dilatability depends) is ascertained by an interior thermometer occupying the axis of the cylinder, and whose stem penetrates the axis of the adjusting screw, and is read off along its exterior prolongation. This instrument being several times alternately exposed for one minute in the sun and shade, and the changes of volume in each case read off on the scale, the differences or sums of the mean changes, according as the action has been in the same or in a contrary direction, gives the dilatation produced by the sunshine alone (freed from the disturbing influences), corresponding to the actual temperature of the liquid, which being reduced by an appropriate table to give the temperature acquired, affords a measure of the effect of a given sectional area of sunbeam in heating a definite volume of liquid. Finally, the result is reduced to "actines," or units of solar radiation, each actine denoting that amount of

* First used in the field by the author in 1826, in Cantal, on the Puy de Dome, and at Montpellier, but without the internal thermometer.

radiation which would suffice to melt one millionth part of a metre from the thickness of a sheet of ice perpendicularly exposed, in one minute, supposing it wholly absorbed. For the details of the description, the tables to be used for reducing the observations, and the general management of the instrument, the reader is referred to the "Manual of Scientific Enquiry," published by the Board of Admiralty, which contains, moreover, practical directions for making and registering every description of meteorological observation. The portability and facility of use and reduction of this instrument, as well as the consistent results it affords, leave nothing to desire, and afford a perfect measure of solar radiation.

## Of the Nature and Constitution of the Atmosphere. Its Pressure, Mass, and Extent.

(15.) We live under what may not improperly be called an ocean of air, which covers the sea and land, and extends far beyond the summits of the highest mountains. Like the sea, this ocean has its currents, which are winds, its waves of vast extent and magnitude, not visible indeed to the eye, but capable of being made so to the intellect by means of the barometer, and its tides due to the action of the sun and moon. But here the analogy ceases. The air is a permanent gas, incapable of being reduced to the liquid state by any degree of cold or pressure yet applied. As such it is highly and perfectly elastic; condensible by pressure when confined, into any fraction, however minute, of its ordinary volume, and dilating itself, when relieved, so as to fill any space, however large. Its elastic force, like that of all gases, is in the direct proportion of its density, its temperature continuing unaltered, but increases, if the temperature be raised at the uniform rate of $\frac{1}{273}$, or 0.00366 of its amount, for every degree centigrade (or 5-9ths of this quantity = 0.002033 for every degree of Fahrenheit's thermometer) of additional heat, and diminishes at the same rate if cooled.

(16.) As the air reposes on the earth, and the whole weight is distributed over the whole globe, each portion (suppose a square inch) of its surface supports the weight of the column of air vertically above it, to whatever height it may extend, and therefore, by the law of reaction, presses upward that column with a force equal to its weight. Hence it follows, that the pressure per square inch, which equilibrates, and therefore measures the elasticity of the air at the earth's surface, must be equal to the weight of such a column. This the barometer enables us to ascertain, at any instant and at any place, by balancing it against that of a column of mercury just sufficient in height to counteract it. It is subject to extensive fluctuations, but observation has shewn that the mean or average length of such a column in the latitude of Paris, and at the level of the sea, may be taken at 0.760 met. French measure (29.922 in.), the mercury being of the density which it has at the temperature of melting ice, which is 13.596 times that of distilled water at its maximum. If the temperature of the mercury be 62° Fahr., which is the standard temperature of the English metrical system, the dilatation of mercury for 1° Fahr. being almost precisely 1-10,000th of its volume, the corresponding length of the mercurial column is 30.012 in., which is so nearly 30 in. that it is customary for English meteorologists to consider 30 inches as the mean or standard height of the barometer. In all meteorological reductions and discussions, however, wherever the term "*barometric pressure*" is used, it expresses the length of a column of mercury *at the temperature* 0° C. *or* 32° *Fahr.* which balances the aerial pressure.

(17.) The weight of such a column of mercury having a square inch for its base is 14.7304 lbs. avoird., which is therefore the weight of atmosphere incumbent on each square inch of the earth's surface, supposed a perfect sphere. Hence, from the known diameter of the earth (7926 miles), we calculate the total weight of an atmosphere so uniformly covering it at 11.67085 (about $11\frac{2}{3}$) trillions of pounds; so that, making allowance for the space occupied by the land above the sea-level, we may take $11 \times 10^{18}$ lbs. as an approximate value, which is about 1-1,200,000th part of the mass of the earth itself. Of this, about $99\frac{1}{2}$ per cent has been ascertained to consist of a mixture of oxygen and nitrogen gases in the proportion of 21 : 79 in volume, or about 23 : 77 in weight. An atomic compound of these gases in the proportion of 2 atoms of nitrogen to 1 of oxygen, would give a ratio of 20 : 80 in volume, Some chemists, therefore, have considered the air as such a compound, and not a mere mixture. But, besides that the deviation of the ratios from each other is beyond the limit of error which chemical analysis tolerates, M. Regnault (Chem. i. 144) has adduced arguments which must be considered decisive against such a conclusion. Still the near approach to an atomic proportion is remarkable. Of the remaining 0·5 per cent, about 0.05 consists of carbonic acid, and 0.45, on an average, of aqueous vapour.

(18.) The specific gravity of dry atmospheric air is to that of mercury (at 32° Fahr., and 0.76 m. pressure), as 1 : 10513½, and a cubic foot of such air weighs 1.29056 oz., so that were the air of that uniform density from the surface upwards, in order to exert the same pressure, it would require to be 26214 feet, or a trifle less than five miles in altitude. This is what is understood by the *height of a homogeneous atmosphere.*

(19.) Such, however, is not the real constitution of the atmosphere. There are mountains higher than this, which yet are covered with perpetual snow, and have clouds above them; and if we consider that each stratum of air, as we ascend from the earth's surface, bears only the weight of those above it, and being therefore less and less pressed, occupies a larger and larger volume in proportion to its weight, we shall perceive that (supposing air infinitely divisible and expansible), there would be no assignable limit to the height of the atmosphere. Theory demonstrates, that *supposing the temperature uniform* throughout, the density would decrease in geometrical progression as the altitude increases in arithmetical, and assigns for the relation between them the following equation (in which P, $p$, represent the densities (measured by the barometric pressures), at the sea level and at the height $h$, and H the height of a homogeneous atmosphere), viz.

$$h = H\,(\text{Log. } P - \text{Log. } p),$$

the logarithms being hyperbolic; or if $h$ and H be expressed in feet, and the hyperbolic reduced to common or tabular logarithms,

$$h = 60309 \times (\text{Log. } P - \text{Log. } p).$$

At the height, then, of 60,000 feet in round numbers, or about $11\frac{1}{2}$ miles, the density of the air on this supposition would be one tenth of that at the sea-level; at 23 miles, one hundredth; at $33\frac{1}{2}$, one thousandth, and so on. At an altitude of 103 miles, the density would be reduced to the thousand-millionth part of its superficial amount. Actually (for reasons which will presently appear), the decrease is still more rapid.

(20.) The question, whether or not there be any absolute limit to the atmosphere, has been considered to depend on the view we may take of the intimate constitution of matter. If it consist of ultimate, finite atoms, a limit must at all events occur where the gravity of one atom to the general mass of the earth exceeds the repulsive power exerted on it by the air below it, a question which defies calculation, since we know nothing of the law of force with which the particles of air repel each other, the usual opinion that it is inversely as their distance being quite untenable. If, on the other hand, matter be infinitely divisible, it has been argued by Doctor Wollaston that the celestial spaces must be full of attenuated air, and that the sun, planets, and satellites, standing in communication with this general reservoir, would each in the course of ages, have drawn to itself such a share, that equal densities in their vicinity should correspond to equal forces of gravitation. Calculating on this datum, the sun's atmosphere should have the density of the earth's at the sea level, at about $4\frac{1}{2}$ times *its own radius* above its surface, and Jupiter at about $\frac{8}{11}$. At these distances from the respective luminaries, the rays of light should suffer a deviation by refraction, equal to twice our horizontal refraction, or more than a degree, a result directly refuted by observation, which indicates no refraction whatever. This argument, however, takes no account of the effect of centrifugal force. Apart from all considerations of molecular repulsion, it is certain that at about 26,000 miles' distance from the earth's equatorial surface, the centrifugal force would equal gravity, and beyond that distance would exceed it; so that were there no physical cause producing a positive and definite limit, all the air beyond that level must be flirted off into space; and there being no pressure, other air would rise from below to replace it, and share the same fate, so that the whole atmosphere would be drained away, to form a ring like that of Saturn. In fact, however, the excessive tenuity which must, under any hypothesis, be ascribed to the interplanetary air (to express which in fractional parts of its density at the earth's surface would require the denominator to consist of at least 1370 figures), dispenses with giving such reasonings any serious discussion. If, indeed, there were the least ground for believing that atmospheric air could be liquefied by a cold of – 120° Fahrenheit, the existence of a limit at a very moderate height would follow as a matter of course, as will presently appear. Supposing the law of dilatability to hold good rigorously for all temperatures, the elasticity of air at – 273° centigrade would be *nil*. But we have no means of producing this degree of cold, and therefore no experimental examination of the case is possible; and we must therefore be content with the assurance, that at no elevation which can ever be attained by man, or in which life could be supported, does the law in question suffer any impeachment; and that at 80 or 90 miles above the earth's surface a vacuum exists, inconceivably more perfect than any which we can produce with our air pumps. At 45 miles the air is already rarified about 25,000 times, at which elevation it would seem, from the duration of twilight, that some feeble reflexion of light still subsists.

(21.) According to Dalton's views respecting the mixture of gases, two or more bodies of this nature mixed together exert no elastic force on each other mutually, though they obstruct and impede each other's free movement. Each *tends* to diffuse itself among the others, and to arrange itself as if the others had no existence, and if left long enough undisturbed would do so. In consequence of this property in a mixed atmosphere, if perfectly quiescent, each gas would constitute a separate and distinct atmosphere, arranged according to the above laws of equilibrium, and each sustaining its quota of the total pressure in the exact proportion of its own volume present in the mixture at the point where the pressure is estimated. But these volumes would be proportionally different at different elevations, the density of the oxygen atmosphere decreasing in a more rapid geometrical progression than that of the nitrogen, and that of the carbonic acid than either. But owing to the obstruction each offers to the free permeation of the others, and to the extreme mobility and continued agitation of the air, the state of equilibrium is never even approached; and experiment has shewn that air collected at all elevations above the surface in balloon ascents (in one instance by Gay Lussac, in his memorable ascent in 1804, at the height of 22,896 feet), contains these two elements in precisely the same proportions. With the carbonic acid, the case is somewhat different, that gas being subject to local variations consequent on its peculiar uses in the economy of animal and vegetable life; but the differences are so trifling, that for meteorological purposes they may be altogether neglected, and the atmosphere (at least its gaseous portion) regarded as one homogeneous gas.

## Of the Decrement of Temperature on Ascending into the Atmosphere, and on the Barometric Measurement of Heights.

(22.) All who have ascended high mountains and all aëronauts are agreed on the fact of a decrease of temperature, which is conspicuously evident from the existence of perpetual snow on elevated summits even in the hottest regions. Respecting the rate of this decrease and its law, much uncertainty still prevails. We possess, it is true, a great accumulation of observations of mountain temperature, both barometrically and trigonometrically determined by De Saussure, Cordier, Raymond, Humboldt, Colonel Sykes, Eschmann, Boblaye, and many others, on the Alps, Pyrenees, Etna, Teneriffe, the Andes and Himalayas, and in Greece; but the results are only loosely accordant, and appear to indicate that the rate of decrease depends in some considerable degree on the season of the year and the local situation of the place of observation. If we assemble the most accordant, and especially those cases where the heights ascended have been considerable, and trigonometrically determined, we find an average decrement of 1° of Fahrenheit's thermometer for every 100 yards of ascent, or 1° Cent. for every 180 yards. The most unexceptionable mode of determining this important element would no doubt be by balloon ascents; but as the heights in such ascents are necessarily determined barometrically, they involve in their calculation (as will presently be shewn) the very element in question, and the results deduced from such ascents seem generally to indicate a materially slower rate of decrease. Thus we find, indeed, from Gay Lussac's voyage, as calculated from a decrease of 72·5° Fahr. in ascending 22,896 feet, a decrement of 1° in 316 feet, agreeing pretty well with the average above stated. But on the other hand, a mean of four ascents by Mr. Green and Mr. Rush in the Nassau balloon in 1838 and 1850, to altitudes between 19,185 and 20,352 feet, gives 485 feet, and a similar mean of four ascents by Mr. Welsh in the autumn of 1852 from London, under the direction of the committee of the Kew Observatory, one of which was to the height of 22,930 feet, and in which all the observations were conducted with scrupulous precision, and the reductions very scientifically made, afford the result of 386 feet. As a general average deduced, then, from balloon ascents, 400 feet per degree of Fahrenheit would seem to be preferable to 300.

(23.) For the cause, or rather causes, of the general fact of the decrement in question, we have not far to seek. There are several, all probably more or less efficient.

The first is, that in receding from the earth's surface, we are quitting the proximity of a heated body; approaching a region where no such body exists; and interposing more and more of a medium obstructive of heat. If we put any confidence in the theories of Fourrier and Pouillet, the temperature of the interplanetary spaces is probably not higher than −226° Fahr. Consequently, a thermometer exposed at a height where, practically speaking, there is no air, ought at all events not to stand above an arithmetical mean between this and the temperature of the earth's surface below it, that is, − 72° at the equator, and − 113° at the poles, taking 82° Fahr. and 0° Fahr. as the mean temperatures at those places. Between these two latitudes and levels, then, it would mark, of course, every intermediate degree.

Again, secondly, As the earth's surface receives on the average (art. 10) twice as much solar heat as the air, it is, generally speaking, habitually warmer, and warms the air by contact communication. The heat so imparted is entirely, in the first instance, diffused through the lower strata, only that radiated off going to heat the upper.

Thirdly and lastly, there exists a powerful cause, first pointed out by Leslie, of quite a distinct nature, which will need a little more explanation.

(24.) Suppose the atmosphere of equal temperature throughout and at rest. Now let any mass of air at the surface receive an impulse upwards by some external force (not by heating it). It will rise, and in so doing, displace quiescent air above it, which will descend to fill its place, and this process will continue till the upward impulse is extinguished by friction and resistance. In rising, air expands, but as the descending air contracts, *pari passu*, the whole disturbed space, when quiet is restored, will be occupied by air as before, and the total pressure will be unaltered. But as regards the distribution of *sensible* heat, a great change will have taken place. The air which has expanded in ascending has absorbed caloric, and grown colder, while that which has contracted in descending has given out just as much, and become hotter. The total heat and the total mass remain unchanged, but the equilibrium of temperature is destroyed. The lower strata have become warmer than the upper: the density adjusts itself accordingly; and the undisturbed column superincumbent on both is supported as before. Precisely the same consequence will result from forcing down by mechanical means (not by cooling) any mass of air from a higher to a lower level. The descending air in condensing becomes heated, while that which ascends to replace it is cooled by its own expansion.

(25.) Now this is no imaginary case. It will be shewn hereafter (art. 52) that when aqueous vapour ascends by its levity, it drags air up with it; not by heating it, but by mere mechanical impulse; and thus we see that the mere fact of a circulation of air in the atmosphere, *in so far as that circulation is due to the generation and condensation of vapour, or even to the downward mechanical impulse of the fall of rain or snow*, must of necessity cause a deficiency of *sensible* heat in the higher as compared with the lower regions.*

* If instead of being urged upwards by external impulse, a body of air dilated by heat, ascend in consequence of such dilatation, it will rise until its expansion reduces it to the temperature of the surrounding air; but it cannot do so without depressing other air to a lower level, which thus becomes heated, so that in this case also the equilibrium of sensible heat is subverted, though in a somewhat different way.

(26.) As regards the law followed by this decrement little decisive can be said. A uniform rate of decrease, such as that described in art. (26.) as a physical law co-extensive with the atmosphere, is not probable, though for heights below 15,000 or 20,000 feet it is perhaps as exact as any which can be briefly stated in words. Assumed as a basis of calculation, it leads to the following very remarkable relation between the height ($x$) in yards, and the ratio of barometric pressures $\left(\varpi = \frac{P}{p}\right)$ at the higher and lower levels, viz.—

$$\varpi = \left(\frac{X}{a}\right)^{5.584}$$

when $a = 180$ yards $\times (273 + T)$, T being the reading of the centigrade thermometer at the lower station, and X the *depression* of the upper station *below* the height $a$ (reckoned from the lower station), $(X = a - x)$, which must be considered a limit to the atmosphere, or rather as a limit beyond which the formula is uninterpretable, or physically speaking, absurd. Nevertheless, within the limits above specified it affords results not very remote from the truth. Thus it gives for Gay Lussac's ascent, calculated on his own data (in which $T = 30°.8$ C. and $\varpi = 0{\cdot}42966$), a height of 7678 yards, differing only 46 yards from that assigned by himself. *Meteorologists in general, we apprehend, are hardly aware how completely the law of equable decrease is subversive of the received notion of a diminution of pressure in geometric progression upwards from the sea level.* This our formula above renders very apparent.

(27.) The law of decrement of temperature is a subject to which great interest is attached, and around which a vast amount of laborious research has accumulated, with a result not unusual in such cases—a great deal of thought and calculation wasted, and no very positive conclusion arrived at. The fact is, the problem has been attacked in the wrong direction. Speculation has been busy in assigning hypothetical laws, either simply tentative, or resting on no solid foundation of physical consideration, to exhibit the relation of the temperature to the height *directly:* to verify which supposes a series of heights and temperatures corresponding to each other to be given by direct observation, the whole series being *comparable.* Now we possess not, and never can possess, any such series; and it is therefore purely and simply groping in the dark to assemble a mass of miscellaneous observation from all quarters, in all climates and seasons, in which insulated decrements of temperature are concluded from mountain ascents; and put them together with the expectation that any intelligible result should emerge. We pass, therefore, without discussion, the theory of M. Biot (Kämtz, ii. 130) which assigns a decrement in geometrical progression for heights in arithmetical, and which sets out with the assumption that the whole heat of the air at any place is due to the extinction of heat radiated or conducted immediately from the earth at that place; or that of Lambert, followed by Baron Zach and Mr. Atkinson, in which it is assumed (on a mere general impression that the decrement decreases with the height), that equal decrements of temperature shall correspond to *uniformly increasing increments* of altitude. In fact, no law of decrement, which would not make the density *increase* upwards, would be incompatible with the equilibrium of the strata; and for heights under 10,000 feet almost any law and rate which satisfies this condition, and represents the temperatures at the highest and lowest levels correctly, will do so at the intermediate ones. The great defect of all such hypotheses is, that they cannot be fairly tested unless we possessed a scale of heights, trigonometrically determined, up to 20,000 or 30,000 feet, all in one geographical situation, and readily accessible from the sea level. Balloon ascents, indeed, amply satisfy the latter requirement—but as the heights must be concluded barometrically, they fail to afford what this mode of looking at the subject absolutely requires. A most valuable piece of positive information *is*, however, afforded by a balloon ascent, viz., that in a given very limited locality, out of the reach of surface inequalities and up-turned currents of heated air; on a given day, and with every facility for obtaining simultaneous observations on the surrounding region, a *definite relation, depending on no hypothesis, but absolutely given by observation, prevails between the temperature and pressure*, as read off at as many different instants, throughout the ascent, as the observer pleases—which relation is capable of being exhibited to the eye with all its capricious incidents by graphical projection in a curve, and of being freed, by a mode of treating such projections which has elsewhere (*Mem. Ast. Soc.* v.) been largely exemplified by the writer of these pages, from the greater part of the errors arising from casual influences or imperfect observation. In the view of the subject we are about to take (which it is something astonishing should have been overlooked by all who have treated of it), this information is all that is necessary for a rigorously exact determination of the heights of the several points of observation themselves, and of the law of decrement which actually subsisted *at the time and place.* By the comparison of such laws at different times and places, it will then be seen whether they are such as really to admit of any uniform or general expression.

(28.) To shew this, let $p$ be the barometric pressure, $t$ the temperature (centigrade), and $\delta$ the density of the air at any altitude, $x$, and P, T, $\Delta$, those at the sea level; $h$ the height of a homogeneous atmosphere at the temperature 0° C. and H at temperature T. Now if $k = 0.00366$, we shall have by what was shewn in art. (15),

$$p = \frac{\delta\,(1+k\,t)}{\Delta\,(1+k\,\mathrm{T})}\mathrm{P}; \qquad (1)$$

and since the differential of the pressure ($d\,p$) is the weight of the column $d\,x$, whose density is $\delta$,

$$d\,p = -\,\delta.\,dx; \qquad (2.)$$

Dividing, then, equation (2) by (1), and observing that

$$\frac{\mathrm{P}}{\Delta\,(1+k\,\mathrm{T})} = h,$$

we shall have

$$-\frac{dp}{p}=\frac{d\,x}{h\,(1+kt)}\,; \qquad (3)$$

If $t$ be known in functions of $x$, this equation gives at once the relation between the altitude $x$ and the barometric pressure $p$; and this is the mode in which the analysis of this question has always been conducted. But if put under the form

$$d\left(\frac{x}{h}\right)=-\frac{(1+kt)\,dp}{p},\ \text{or}\ \frac{x}{h}=\int-\frac{(1+kt)\,dp}{p}\,; \qquad (4)$$

it becomes available for a different mode of procedure. If the law of temperature, as depending on the *pressure*, be analytically expressible, or if $t$ be an explicit function of $p$, we have $x$ given at once by integration. But what makes this way of putting the matter peculiarly valuable is, that if this be not the case, but $t$ only given *numerically* by the registered observations of the thermometer, and the reading-off of a graphical projection of them as above described; the integral in question *may be obtained graphically* with quite sufficient precision (practically speaking), and in an infinitely shorter time, than by any system of calculation; so that the determination of the altitudes in balloon ascents is made to depend *on no hypothesis whatever*, but to result purely and absolutely from the series of observed temperatures and pressures in the ascent and descent.

(29.) We have been able to collect no more than nine balloon ascents to sufficient altitudes (which should not be less than 10,000 feet), in which a series of corresponding readings of the two instruments have been taken consecutively enough for discussion, viz., those of Gay Lussac (art. 22), of Messrs. Green and Rush in 1838 and 1850 (19,185, 20,352, 19,904, 19,440 feet), and of Mr. Welsh in 1852 (19,510, 19,100, 12,640, and 22,930 feet), these latter leaving nothing to desire in point of instrumental appliances and scientific precision in their use. Plate I. exhibits the graphical projection of the observations registered in each of these ascents, the dots being the points laid down: the continuous curve lines swept among them *liberâ manû*, without reference to any theory, but that one condition without which no general speculation on the subject is possible, viz., that their curvature shall be, generally speaking, similar in character, and have its concavity throughout towards the same side: and the dotted lines analogous curves in which this condition is not adhered to, but in which the most essential peculiarities of each ascent are brought into evidence. Each set of dots is referred to the curve to which it belongs by a light connecting line. The readings-off of these curves are stated in cols. 2, 3 .... 10 of the following table, and are set down *just as they were read from the actual projections used, without any subsequent equalization of differences or correction whatever.*

| 1 $p$ = pressure in inches. $p$ = | 2 Gay Lussac. Sept. 17, 1804. $t$ = | 3 Rush, Sept. 4, 1838. $t$ = | 4 Rush, Sept. 10, 1838. $t$ = | 5 Rush, June 22, 1850. $t$ = | 6 Rush, June 29, 1850. $t$ = | 7 Welsh, Aug. 17, 1852. $t$ = | 8 Welsh, Aug. 26, 1852. $t$ = | 9 Welsh, Oct. 21, 1852. $t$ = | 10 Welsh, Nov. 10, 1852. $t$ = | 11 Mean of the foregoing $t$ = | 12 Values of $t$ calculated from Eqn. Art. 34. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 30.5 | 82°.3 : | 66°.4 : | 60°.0 | 73°.2 | 64°.0 : | 73°.0 : : | 66°.5 : : | 57°.9 : | 47°.1 : : | 65°.6 | |
| 30 | 81.8 | 66.0 | 59.8 | 72.6 | 63.4 | 72.0 : | 65.4 : | 57.6 | 46.7 : | 65.0 | 65.0 |
| 29 | 79.7 | 65.0 | 59.1 | 71.0 | 62.6 | 69.8 | 63.3 | 56.3 | 45.6 | 63.6 | |
| 28 | 77.7 | 63.8 | 57.8 | 69.5 | 61.5 | 67.4 | 61.1 | 55.0 | 44.1 | 62.0 | 62.5 |
| 27 | 75.4 | 62.6 | 56.4 | 68.0 | 60.0 | 64.9 | 58.8 | 53.5 | 42.4 | 60.2 | |
| 26 | 73.0 | 61.5 | 54.7 | 66.2 | 58.3 | 62.4 | 56.2 : | 51.3 | 40.5 | 58.2 | |
| 25 | 70.6 | 60.0 | 52.6 | 64.4 | 56.6 | 59.5 | 53.3 : | 49.4 | 38.4 | 56.1 | 56.3 |
| 24 | 67.8 | 58.3 | 50.2 | 62.3 | 54.7 | 56.4 | 50.5 : | 47.0 | 36.2 | 53.7 | |
| 23 | 64.7 | 56.4 | 47.1 | 60.0 | 52.5 | 53.0 | 47.6 : | 44.2 | 33.9 | 51.0 | 51.0 |
| 22 | 61.6 | 54.3 | 43.8 | 57.6 | 50.0 | 49.0 | 44.4 | 40.6 | 31.3 | 48.1 | |
| 21 | 58.0 | 52.0 | 40.4 | 54.8 | 47.3 | 44.8 | 41.0 | 36.7 | 28.7 | 44.9 | |
| 20 | 54.4 | 49.1 | 36.7 | 51.7 | 44.4 | 40.4 | 37.4 | 32.5 | 25.6 | 41.4 | 41.0 |
| 19 | 50.2 | 45.9 | 33.4 | 48.6 | 41.3 | 35.7 | 33.7 | 27.6 | 22.1 | 37.6 | |
| 18 | 46.0 | 42.6 | 29.5 | 45.4 | 37.7 | 30.8 | 29.6 | 22.6 | 18.4 | 33.6 | 33.0 |
| 17 | 41.0 | 38.5 | 25.4 | 41.5 | 33.3 | 25.5 | 25.0 | 17.6 : | 13.8 | 29.1 | |
| 16 | 35.8 | 33.5 | 21.0 | 37.7 | 28.3 | 19.9 | 19.9 | 12.0 : | 9.4 | 24.2 : | |
| 15 | 30.0 | 28.0 | 16.4 | 33.5 | 23.2 | 14.0 | 14.9 | 6.4 : : | +4.2 | 19.0 : | 19.0 |
| 14 | 23.5 | 21.9 : | 11.0 : | 29.0 : | 17.2 : | 8.0 : | 9.6 : | +0.5 : : | −1.5 | 13.2 : | |
| 13 | 16.7 | 15.4 : : | 5.4 : : | 24.0 : : | 11.3 : : | 1.4 : : | 4.0 : : | −5.5 : : | −7.8 | 7.8 : : | 7.0 |

Col. 11 contains the means of all the readings in the other columns, and from these a curve (the last of the plate referred to) is laid down which exhibits an average form of the curve, and embodies all the other results. That this proceeding is legitimate will appear from the following consideration:—Suppose $t$ the temperature (or ordinate of any one of the curves) corresponding to the pressure $p$ (the abscissa), and suppose any general relation such as $t = \alpha . \varphi(p) + \beta \psi(p) +$ &c. to subsist, $\alpha$, $\beta$, &c. being parameters peculiar to each curve. Then if there be several such curves in which (corresponding to *the same pressure*) $\alpha$, $\beta$, $\alpha'$, $\beta'$, $\alpha''$, $\beta''$, &c. are the parameters, and $t$, $t'$, $t''$, &c. the ordinates, since $t = \alpha \varphi + \beta \psi +$ &c., $t' = \alpha' \varphi + \beta' \psi +$ &c., we have

$$\frac{t + t + \&c.}{n} = \frac{a + a' + \&c.}{n} \varphi + \frac{\beta + \beta' + \&c.}{n} \psi + \&c.,$$

which shews that a similar relation subsists between the *means* of the temperatures and the pressures, provided *mean* values of the parameters are used.

(30.) This essential point premised, we may now observe that the course of all the curves is evidently systematic; that the tendency to fluctuate in one direction in the early part of their course, as marked by the dotted curves in some of them, is contradicted by a similar tendency in the opposite direction in others, and that they agree in speaking a language to the eye which we have to interpret into a formula. Thus a good deal depends on the view we may take of the nature of heat itself and of temperature. Is there an absolute zero? And if so, does matter occupy space in virtue of the presence of heat? If we reply in the affirmative to both these questions, and suppose moreover, empty space absolutely devoid of heat, we must take the extreme lowest thermometer reading, as $t = -\infty$ corresponding to $p = 0$. In that case the speculative prolongation of our curve would give it a vertical asymptote at $p = 0$, and as its aspect so prolonged bears some general resemblance to a logarithmic curve, we will give that curve a trial. Taking, then, $\log. p = \alpha + \beta t,$* (5), we have $\frac{dp}{p} = \beta dt$, and by equation (4) art. (28), $x = h \int - \beta dt \,(1 + kt)$

$$= \beta h \left\{ (\mathrm{T}-t) + k\frac{\mathrm{T}^2 - t^2}{2} \right\} = \beta h \,(\mathrm{T}-t)\left\{ 1 + k.\frac{\mathrm{T}+t}{2} \right\}; \quad (6)$$

But by equation (5) we have $\log. \mathrm{P} = \alpha + \beta \mathrm{T}$, whence we get $\beta\,(\mathrm{T} - t) = \log. \mathrm{P} - \log. p$; substituting which in (6) it becomes

$$x = h\,.\log.\left(\frac{\mathrm{P}}{p}\right)\left\{1 + k.\frac{\mathrm{T}+t}{2}\right\}; \quad (7)$$

(31.) This is the formula given by Laplace in the tenth book of the *Mécanique Céleste*, abstraction made of two factors in his expression for $x$, viz.

$$\left(1 + 0{\cdot}00228 \cdot \log. \frac{\mathrm{P}}{p}\right)$$

which takes into account the diminution of gravity in receding from the centre of the earth, and

$$(1 + 0{\cdot}00265) \cdot \cos. 2\,\lambda$$

$\lambda$ being the latitude of the place; which expresses the

* $t$ here expresses centigrade degrees, the same *form* applying equally to either mode of expression.

influence of the centrifugal force arising from the earth's rotation. The value of *h*, if the logarithms used are the common tabular ones, may be taken at 60,309 British feet; if hyperbolic, at 26,254 feet. This is the formula (including these factors) now universally adopted for computing heights from barometric observation. Its reduction to numbers is facilitated by tables which are given in the "Annuaire" of the French Board of Longitude, in Galbraith's Barometric Tables (Edin. 1833), and in that very useful collection by Arnold Guyot, published by the Smithsonian Institution, U. S. (Washington, 1852), to which, as containing almost every table a meteorologist can require, we once for all refer our readers. From this formula it appears that, according to the best estimate we can form of the temperature at great elevations, the extreme rarefaction specified in art. (19) as existing at 103 miles, on the supposition there made, would really be found about 11 miles lower, or at about 1-85th part of the earth's diameter above its surface.

(32.) Laplace's investigation of this formula is based on an assumption (avowedly introduced by him for the sole purpose of simplifying his analysis) of a variation of temperature with altitude which amounts to supposing equal decrements of temperature to correspond to increments of height, *decreasing* progressively in arithmetical progression. This is in fact the law of decrement which would result from our equation (6). It is therefore precisely the reverse of that of Lambert, Zach, and Atkinson, and, we may add, not in accordance with the general impression among meteorologists (in which, however, we do not participate), that the decrease is *slower* the higher we ascend. It is somewhat singular that Laplace does not appear to have noticed the logarithmic relation (5) which his hypothesis implies between the temperature and pressure; and still more so (and we are surprised that the remark should not have occurred either to Laplace himself, or to any of those who have used his formula) that his expression *is identical with that which would result from assigning to the whole atmosphere a uniform temperature, the mean of those actually observed at the higher and lower levels.*

(33.) When we come to examine our curve of decrement more particularly, however, it becomes evident that it is *not* a logarithmic curve, but a most undeniable parabola. The errors in the former case are systematic, and far beyond bearable limits. Supposing the curves to agree at the 15th and 30th inch of $p$, the errors are at 13, 17, 20, 23, 27, and 30.5 inches respectively $+ 2{\cdot}2°$, $- 1{\cdot}8°$, $- 3{\cdot}3°$, $- 4{\cdot}2°$, $- 2{\cdot}2°$, and $+ 1{\cdot}2°$. The logarithmic curve, therefore, is not in satisfactory accordance with the average course of nature as collected from these observations.

(34.) If we take for Fahrenheit's scale $\alpha = - 87°$, $\beta = + 9{\cdot}0667$, and $\gamma = - 0{\cdot}1333$, or for the centigrade $\alpha = - 66{\cdot}1111$, $\beta = + 5{\cdot}0370$, and $\gamma = - 0{\cdot}0741$, we shall find the numbers in col. 11 to be perfectly well represented by the equation $t = \alpha + \beta\ p + \gamma p^2$, substituting which in equation (4), integrating from P and T to $p$ and $t$, eliminating $\gamma$ by the equation

$$\mathrm{T} - t = \beta\,(\mathrm{P} - p) + \gamma\,(\mathrm{P}^2 - p^2),$$

taking 60,309 ft. for the value of $h$ (as adapted for the use of *common* logarithms), putting for $k$ its value 0.00366, and *using the centigrade values* of $\alpha$ *and* $\beta$, we shall find

$$x=h\left\{(1+0{\cdot}00366\,\alpha)\log.\frac{P}{p}+0{\cdot}000795\left\{(T-t)+\beta\,(P-p)\right\}\right\};\ (10)$$

(35.) To apply this formula to any proposed ascent, the readings of the instruments having been graphically projected, two extreme and one intermediate pair of corresponding values of $t$ and $p$ are to be fixed upon, and thence by resolving the three simple equations of the form $\alpha+p.\beta+p^2.\gamma=t$ which these afford, the values of $\alpha$ and $\beta$ are obtained, which may then be substituted in (10), and the value of $x$ determined. As an example, we shall take Mr. Welsh's ascent of Nov. 10, which gives $P=29{\cdot}972$, $p=12{\cdot}240$; $T=46^\circ{\cdot}7$ F. $=8^\circ{\cdot}16$ C.; $t=-11^\circ{\cdot}3$ F. $=-24^\circ{\cdot}06$ C.; $\alpha=-94^\circ{\cdot}804$ F. $=-70^\circ{\cdot}44$ C.; and $\beta=+8^\circ{\cdot}4848$ F. $=+4^\circ{\cdot}7136$ C., and executing the calculation we obtain $x=22983$ feet, which, corrected (by the factors in art. 31) for latitude and decrease of gravity, finally gives $x=23027$ feet, being 97 feet in excess of the height assigned by Mr. Welsh from Laplace's formula; by which it appears that, whatever be the objections to which the law of temperature implied in that formula may be liable, it may still be used with tolerable safety even for such altitudes.

(36.) If $p=0$, or so nearly such as would be the case in ascending some 25 or 30 miles, $t=\alpha$, which is therefore the temperature a thermometer would mark exposed to the total joint radiation of the earth and air from beneath, and to that into space from above. If then we call S the temperature of space *beyond the influence of terrestrial radiation*, we have, at least approximately, $\alpha = \frac{1}{2}$ (T + S). Now we have seen that in our mean curve $\alpha = -87°$ F. and T = + 65° F., and that in Mr. Welsh's last ascent $\alpha = -95$, T = +49. Both agree in giving S = −239° F. Hence we may conclude generally, that taking for S this value, $\alpha$ may be at once assumed as $= \frac{T}{2} - 119\frac{1}{2}°$ F. At the equator, then, the limiting temperature of the atmosphere would average − 77½° F., and at the poles about − 119½° F., with a range of temperature from the surface of 161½° in the former case, and 119½° in the latter.

### Of Land and Water as Recipients and Communicants of Heat.

(37.) Of the solar heat which actually reaches the surface of the globe, that which falls on water penetrates it to some moderate depth and is absorbed internally, while that which is incident on land is wholly absorbed superficially, or within a very minute thickness. Water, moreover, is eminently a non-conductor of heat, so that once received into its substance it is only diffusable by agitation; and since this, however violent at the surface of the ocean, diminishes rapidly with the depth, the ultimate communication of heat downwards to any considerable depth being a very slow process. By far the greater portion of the daily supply of heat to water, then, may be said to float within a moderate depth of the surface, forming a kind of reservoir of heat. On the other hand, water is a *good radiant*, and as such is continually, both day and night, giving off radiant caloric, which is absorbed in traversing the air, and thereby tends to raise the temperature of the latter medium. It is a property of caloric radiant from bodies heated below incandescence to be eminently absorbable by transparent media. Hence it is most probable that much of the heat so radiated off is detained in the lower strata of the air. Meanwhile a balance is struck in the water itself of the quantities received and parted with, by the preponderance of one or the other of which it gains or loses in average temperature on the 24 hours. Thus, in the warm season, when days are long and nights short, the general temperature of the sea is slowly rising above its annual average, and *vice versa* in the opposite season. Below a certain depth, however, the temperature of the ocean would appear to be determined by other causes, and to be very little dependent on its superficial amount or fluctuations. It results from the observations of Kotzebue, Beechy, and Sir James C. Ross, as a general fact ascertained by thermometric soundings, that the deep sea water below a certain level, determined by the latitude, is of invariable temperature throughout the globe, and that a very low one; the calculations of Lenz, founded on Kotzebue's results, giving 36° F., and those of Ross 39°·5 (which last is the temperature at which pure water attains its maximum of density). The depth at which the fixed temperature is attained is about 7200 feet at the equator, diminishing to lat. 56° on either side of that line, where it attains the surface, and the sea (superficial currents apart) is of equal temperature at all depths. Thence, again, the upper surface of this uniform substratum descends, and at 70° of latitude has already attained a depth of 4500 feet. Thus the ocean is divided into three great regions; two polar basins in which the surface temperature is below 39°, and one medial zone above it, attaining 8° at the equator, and at the poles of course the freezing point of sea water. It is within these respective regions only, then, that superficial currents can act as transporters of *meteorological* temperature.

(38.) The habitudes of dry land with relation to incident heat are very different. There is no mobility of parts, and the communication of heat downwards is therefore entirely a process of conduction. But what is most influential, is the fact that the absorption is performed strictly *on* the exposed surface, which therefore in the instant of absorption fixes upon itself within a very minute depth all the heat which, falling on water, would in the same instant be disseminated through many feet or yards of its substance. The mere superficial film, then, becomes much more heated, and, since it is a law of radiation that its intensity increases rapidly with the temperature of the radiant surface, it radiates out on the very instant a much larger fraction of the total incident heat than in the case of water, besides imparting to the air by contact-communication a proportionally greater amount. In water the absorbed heat is for the most part withdrawn from the radiant action, enveloped and husbanded. In dry land it is instantly and wholly exposed to such action in its most intense form. It is no uncommon thing in dry and light (*i.e.* badly conducting) soils, in hot climates, to find a superficial temperature of 120°, 140° F., and even more. We have ourselves observed it at 159° F. at the Cape of Good Hope. In the arid regions of Australia, Captain Sturt reports that a lucifer match dropped on the ground takes fire. The surface water of the equatorial seas is scarcely ever known to range higher than 85° in the day and a degree or two lower in the night.

(39.) That portion of the heat which enters the soil is conducted downwards, and so long as the surface is gaining in temperature, a wave of heat is continuously propagated downwards into the earth. When the surface, however, by the decline of the sun, begins to lose heat, this ceases, and (the radiation still continuing) what may be called a wave of cold (less comparative heat) begins to be propagated, and so on alternately during the day and night. These waves as they run on spread forwards *and backwards*, and so by degrees neutralize and destroy each other. Thus the diurnal fluctuations of temperature beneath the surface grow continually less as the depth increases; the rate of diminution depending on the "conductility" of the soil.

In ordinary soils the difference between the diurnal and nocturnal extremes becomes imperceptible at four feet below the surface. (Quetelet, *Mem. Acad. Brux.*, 1836.) In like manner, the general increase of heat due to the summer season, and of cold during winter, are propagated in similar but larger and feebler annual waves, which in their turn neutralize each other at more considerable depths, and become imperceptible at 40 or 50 feet. Professor Forbes has shewn in an elaborate memoir on this subject (*Trans. R. S. Edin.*, xvi.) that at depths varying from 57 to 99 feet, according to the nature of the soil, the annual variation does not exceed 0°.01 C.

(40.) The absorption of incident heat *as solar heat*, and its radiation outwards *as terrestrial heat* (*i. e.* heat of a much more absorbable nature) by the solid surface, depends very much on the nature of its substance; but if the ground be covered with vegetation, *the whole* of the *incident heat* is returned back either by radiation or contact-communication to the air; and the soil receives no heat where so covered, otherwise than circuitously through the medium of heated air. All these causes acting together produce a vast difference as respects the temperature *of the air* in regions of the globe covered by the ocean and those occupied by dry land. In the former its fluctuations, both diurnal and annual, are confined within very much narrower limits than in the latter; and this contrast, which theory indicates, is confirmed by universal observation, as the expression of the distinction between an *insular* and a *continental* climate, or that of a small island remote from all other land and of the central regions of an extensive continent. If there be one general feature in meteorology more prominent than another it is the uniformity of temperature over great bodies of water, as compared to that under similar exposures to the direct sun on land.

(41.) *Terrestrial Radiation.*—The theory of radiant heat promulgated by Prevost, which all experimental inquiry into the subject has tended to confirm, lays it down as a principle, that a mutual interchange of heat is continually taking place between all bodies freely exposed to view of each other, the hotter radiating more than the colder in the ratio of some function increasing with the temperature. The experiments of Dulong and Petit on the radiation of bodies in vacuo, have shewn that this function, within the limits of their experiments, is of the exponential form, or in other words, that the force of radiation in vacuo increases in geometrical progression as the excess of temperature of the radiant body above that of its envelope increases in arithmetical.* Hence, when a hot body is placed in presence of bodies, some colder some hotter than itself, an equilibrium will rapidly be established, in which its momentary gains and losses of heat to and fro among them all will balance each other, and its temperature will thenceforward be unchanged.

(42.) Such will be the case if the body be com-

* There must be some natural limit to such a law. Radiation in absolute vacuity *cannot be infinite.*

pletely surrounded or enclosed by others. But if only partially so, if there be an opening out into perfectly free space, through which rays of heat can escape, and from which none are returned, heat will constantly flow out from such a system, and the body will be maintained at a temperature lower than that of such partial envelope, and the more so the larger the *angular area* of the opening.

(43.) If it were certain that the vacuum, or ætherial medium in which the planets move, and which conveys light, had absolutely *no temperature* of its own capable of being imparted to matter, and if the air were perfectly transcalescent and incapable of radiation from its own particles, or from those of impurities floating in it, a thermometer placed a very small distance from the ground, with an unobstructed view of the sky, would receive from the hemisphere above it no heat but that radiated from the stars and moon; or (putting the moon out of the question, as it is almost certain that no portion of her heat escapes absorption in the air), none bearing a greater ratio to that it would receive from the sun, than the light of a starlight night to direct sunshine, which cannot exceed that of 1 to 100,000,000. It may therefore be regarded as *nil.*

(44.) The mean temperature of the earth remaining unchanged, it necessarily follows that it emits by radiation *from* and *through* the surface of its atmosphere, on an average, the exact amount of heat it receives from the sun, *i.e.*, as much as would melt 0·01093 in. in thickness of ice per minute over the area of one of its great circles, or one-fourth of this thickness (0·00273 in.) over its whole surface (art. 11, 12), which is equivalent to 135-960ths of that quantity, or 0·000374 in. depth of water per minute (or 1-40th in. per hour), condensed from its dew point. Taking this as the measure of the total average radiation, one-third of it, or 1-120th in., may be taken as radiated off from the atmosphere without ever reaching the earth, and the remaining two-thirds (1-60th in.), may be considered as got rid of by radiation, direct or indirect, from the surface of the earth. In complete absence of any means of estimating the ratio of these portions, we may suppose the latter to be one-half of 1-60th or 1-120th in. Let us now consider the manner in which this part of the process takes place, supposing a clear sky to prevail.

(45.) Conduction through the soil is a very slow process, radiation a very rapid one. So soon, then, as the sun has sunk so low as not to counteract the earth's radiation, the immediate surface begins to part with its heat, at first, of course, slowly, but as night advances, more rapidly, and at length much faster than it can percolate from the interior to supply the waste. The surface, therefore, becomes greatly chilled, and a wave of cold (to use the mode of expression adopted in art. 39), is propagated downwards, neutralizing and destroying the heat-wave rising to meet it—a process which goes on leisurely, and takes its own time. Meanwhile the chilled surface now borrows heat from the air also, to supply its waste, 1st, by contact-communication; 2d, by downward radiation; *and, 3d, by* *condensation of vapour when the temperature of the surface-air is reduced to the dew point*, and thus attains that state of equilibrium which the circumstances admit of. The process is in fact in every respect the converse of that described (art. 38), by which heat penetrates the soil, the immediate surface exhibiting in both cases the most sudden and violent effect of the acting causes.

(46.) The most consecutive series of experiments and observations we possess on terrestrial radiation, are those of Dr. Wells, Professor Daniell, Captain Sabine, and more recently Mr. Glaisher, the author of a very elaborate memoir on the subject (*Phil. Trans.*, 1847). Our limits will only permit us to mention some of the more prominent results obtained. The maximum of terrestrial radiation takes place when a perfect calm and cloudless sky prevail during a long night, in a level country. Under these circumstances, there is nothing to disturb the air immediately resting on the soil, so as to replace the air cooled by contact with the chilled surface by warmer air from above; and if a series of thermometers be exposed at various heights above the surface, that which is just not in contact will be found to mark several degrees lower than the general temperature of the air, and the others at greater altitudes, will stand progressively higher, up to about 10 or 12 feet, the difference, however, above 4 feet being very trifling.

(47.) The depression of the thermometer exposed to radiation in contact with any horizontal surface is greater as the radiating power of the substance of which that surface consists is greater, and as its power of conducting heat is less. The greatest depression observed by Mr. Glaisher below a thermometer freely suspended at 12 feet above the ground, was no less than 28°.5 Fahr.! the lower thermometer being placed on raw cotton wool on long grass. The relative depressing powers of this and other supporting substances, assigned by him from a mean of all his observations, are given below; long grass being taken as a standard.

| | | | |
|---|---|---|---|
| Hare Skin | 1316 | Charcoal Powder | 776 |
| Rabbit Skin | 1240 | Jet-black Lambs' Wool | 741 |
| Raw White Wool | 1222 | Sheet Zinc | 681 |
| Flax | 1186 | White Tin | 667 |
| Raw Silk | 1107 | Snow | 657 |
| Unwrought White Cotton Wool | 1085 | Sheet-Iron | 642 |
| Long Grass | 1000 | Paper | 614 |
| Lamp-black Powder | 961 | Slate | 573 |
| Flannel | 871 | Garden Mould | 472 |
| Glass | 864 | River Sand | 454 |
| Sheet Copper | 839 | Stone | 390 |
| Coloured Lambs' Wool | 832 | Brick | 372 |
| Whiting-powder | 827 | Gravel | 288 |

(48.) When a thermometer is exposed with its bulb in the focus of a concave silver hemisphere* or paraboloid, highly polished both internally and externally, and deep enough, when exposed with the concavity upwards, to cut off from the thermometer all view of the earth, and as it were to continue the sky beneath it, it can only receive heat by condensation and radiation

* The figure is absolutely of no importance. A paraboloid is generally used, for no reason that we can perceive but to increase the cost.

from the air, and from the condensation of moisture. A thermometer so exposed under a clear sky, and shaded from direct sunshine, always marks several degrees below the temperature of the air, and its depression affords a rude measure (of the statical kind, and open to all the objections to which that kind of measure is open.—See art. 13) of the facility for the escape of heat by radiation afforded under the circumstances of exposure. As compared with exposure on any of the supporting substances above enumerated, the depressing power of such a reflector by Mr. Glaisher's experiments appears to be 888, that of long grass being 1000, which is almost identical with that of the glass of which the bulb is formed. If the axis of such a reflector be directed to a cloud, or to any terrestrial object, the thermometer immediately rises, even should that object be the summit of a snow-covered mountain (as we had ourselves occasion to observe on April 18, 1824, from the roof of the observatory at Turin, the snowy range of the Alps affording an excellent object for trial). If directed to a cloud, the height of the cloud is not indifferent—Mr. Glaisher's observations clearly shewing that the higher the cloud the greater the radiation upward, whether estimated by the reflector, or by the depression of a thermometer laid on grass. Thus in nights uniformly and totally cloudy, the mean height of the clouds being respectively 1900, 2800, and 3700 feet (which his peculiar situation enabled him to ascertain), the depressions were found to average $1^\circ{\cdot}6$, $2^\circ{\cdot}5$, $3^\circ{\cdot}9$, clearly indicating the lower temperature of the higher clouds.

(49.) As an instance of the effect of terrestrial radiation applied to a practical purpose, may be mentioned the manufacture of ice in the East Indies. The process, as described by Mr. Williams (*Phil. Tr.*, vol. lxxxiii. p. 56), practised in Benares on an immense scale, consists in exposing shallow porous earthen pans on straw in a level area divided into compartments four or five feet square. The pans are filled in the afternoon; and the temperature being much reduced by evaporation before night, the freezing process is completed by radiation at night. In this way Mr. Williams has often seen ice $1\frac{1}{4}$ inch in thickness produced in December, January, and February, the thermometer at $5\frac{1}{2}$ feet above the ground, marking from 41° to 46° Fahr. In a night of 12 hours, it may be remarked, the mean emission of heat from the earth's surface, taken as two-thirds of the total mean radiation, would suffice for the conversion of $480 \times 0{\cdot}00273$ or $1{\cdot}31$ in. into ice (art. 44). So that there can be no necessity to recur to other causes than radiation (as has been done by some) for a full account of the effect observed.

(50.) *Of the evaporation and condensation of water, and the dilatation of air, as elements of power in Meteorological Dynamics.*—Water, freely exposed to the air, evaporates at all temperatures, even *when in the state of snow or ice.* The rapidity of evaporation is, however, much increased by warmth. Thus, in a calm atmosphere, under the ordinary pressure, Dalton found that when, from a certain surface, the evaporation from boiling water proceeded at the rate of 40 grs. per minute, it was 20 grs. at a temperature of 180° Fahr., 13 grs. at 164°, 10 grs. at 152° and so on. *Cœteris paribus*, in dry air the rapidity of evaporation is proportional to the elastic force with which the generated vapour tends to escape from the evaporating surface; *i. e.*, to the tension of vapour due to the temperature of that surface. If the air be already moist, evaporation is proportionally retarded, the force of escape being the difference between the elastic tensions of the generated vapour and of that already existing in the air. Under a low atmospheric pressure, also, it is far more rapid than under a high one, owing to the comparative absence of obstruction to the diffusion of vapour by the aerial particles—vapour being subject to the same laws of diffusion and non-reciprocity of pressure as other gases, and indeed, *while maintained in the vaporous state*, to all the other laws of gaseous statics and dynamics. Owing to the same reason, evaporation is accelerated by wind blowing over the evaporating surface, which removes the generated vapour as fast as it is produced, and dispenses with the slower process of diffusion upwards. *Cœteris paribus*, moreover, the amount of water evaporated is proportional to the surface exposed to air. It is much greater, therefore, from rough and porous solid substances kept wetted (as, for instance, from moist soil or from vegetation wetted by rain), than from the surface of water itself; and from the latter, when agitated by winds or dashed in spray, than when tranquil.

(51.) Evaporation never takes place without the abstraction of heat from the evaporating surface. Every grain of water evaporated carries off with it sufficient heat to raise 960 grains, 1° Fahr., to supply which, that quantity of the residual water must have been cooled 1°. This heat, however, is *latent*, *i.e.*, does not appear as *temperature* in the vapour produced, which is no warmer than the surface from which it emanates. On condensation, however, the absorbed heat is given out again; and thus aqueous vapour becomes an agent in the transfer of heat, in its latent state, from one part of the globe, or from one region of the atmosphere to another, just as a moving body transfers the impetus which created its velocity to the place where it encounters an obstacle.

(52.) Vapour introduced into the air acts as a moving power in two distinct ways. 1*st*, By a simple addition of volume. The tension of the vapour is added to the elastic force of the air, according to Dalton's law, and increases by the same amount the total power of the mixture to support pressure. Were the specific gravity of vapour the same with that of air, the effect of its introduction would be simply one of distension. It would tend to relieve itself by lateral diffusion, or removal of obstructing air; and if prevented from so doing, would simply heave up the incumbent aerial column in struggling to diffuse itself, and so increase its total vertical altitude. 2*d*, But a far more efficacious motive power originates in the less specific gravity of the vapour of water than of air of the same temperature (0·6235 : 1). It is the lightest of all known "vapours," and, with exception of hydrogen and ammonia, the lightest of gases. In consequence, as soon as generated, it tends to rise in the air by its buoyancy, and in so doing, carries up with it much of the air with which it is intermixed, disengaging itself no doubt from it, in its upward progress, to become entangled, however, with fresh particles, which again it carries upward, to abandon them for others. In this way, not only is its upward diffusion far more rapid than its horizontal, but in its struggle upwards it tends to produce an ascensional movement in the air itself, and thus (as we shall presently see) to act as a powerful agent in the production of wind.

(53.) Whenever vapour comes in contact with any body, or arrives at any locality whose temperature is lower than that due to its tension, a portion of it condenses into water, or, it may be, into ice. In so doing it gives out again its latent heat, which is communicated to the condensing body, raising its temperature, or else is disseminated throughout the region, together with the condensed particles. If the condensation be into water, the heat thus reappearing as temperature is precisely the same in amount as that taken up in evaporating the same quantity of vapour from water, or 960° Fahr.; if into ice, the additional amount of 135°, which is that which becomes latent on the conversion of ice into water is set free. If the condensation takes place at the surface of the earth the result is dew or hoar-frost, according as the surface is above or below the freezing-point; if aloft in the air, the result is a cloud of mist, or, if abundant, rain, snow, or hail. But in every case the condensation of vapour is accompanied with a mitigation of cold *at the point where it actually takes place.* The same is true of the freezing of water, however contrary to ordinary notions. Were it not for this, our winters would be intolerable.

(54.) It is clear, moreover, that the generation of vapour, under any extensive region, *more rapidly than it is carried off* by diffusion or otherwise, must be attended with an increase of barometric pressure, since the total weight of the atmosphere vertically over any region must be supported by the total area of surface, and equally so that its condensation, *provided the condensed water be abstracted from the atmosphere,* must lead to a diminution of pressure. The contrary will happen if the vapour generated be carried off as fast as produced by such a general upheaving of the aerial strata over any region as shall subvert their equilibrium, and cause them to overflow, upwards and laterally. In such a case, since air also will be carried off bodily from the region, and be replaced by vapour, the mean specific gravity of the whole aerial column, and its total weight, will be diminished, and the barometric pressure lowered. This takes place on a most extensive scale over the intertropical seas. The temperature of the surface water in them is habitually very elevated (from 78° at the tropics to 83° at the equator), and varies very little by the vicissitudes of season, or the alternation of day and night. A steady and copious evaporation is therefore continually going on. Vapour, carrying with it air, is constantly thrown up beyond the levels of equilibrium, where it flows over and spreads itself out over the upper regions of higher latitudes. The immediate consequence is a habitual deficiency of barometric pressure at the sea-level on the equatorial, as compared with that on the extra-tropical seas. In a voyage to the Cape of Good Hope in 1833-4, the writer of these pages found this decrease from the tropics to the equator, on either side, to amount to 0·24 in. He was not at the time aware that the fact had before been noticed by Schouw and Humboldt.

(55.) The dilatation of the air itself by heat, whether communicated to it from the earth, or radiated directly into it from the sun, acts in a somewhat different manner. Air is dilated only by about one-tenth of its volume by 50° Fahr. increase of temperature, so that unless locally and violently heated, its effect in producing bodily uprushing currents is comparatively less than that of the introduction of vapour into its mass. When heated over large tracts, it acts rather by increased elasticity to upheave the superincumbent strata, and, by bulging them upwards, to destroy their equilibrium, and cause the upper atmosphere to flow over on less heated regions. The general effect, how ever, is similar; and as the sun cannot generate vapour without at the same time heating the air, it is impossible to separate their dynamical effects. Whether the air go forth from its place *proprio motu*, or be jostled out of it by the introduction of a lighter medium, the local relief of pressure is equally produced.

(56.) *Of the winds.*—Among the proximate agents in meteorology, the winds hold the first place. To their agency is owing the subversion of what Humboldt has termed the *solar climate* of the world (or that which would exist were the atmosphere motionless), and the production of its *real climate.* This they effect in two ways, viz., 1st, *Directly*, by transferring into regions remote from their origin the heated air and aqueous vapour (charged with latent heat) which the sun's direct action generates; and, 2dly, *Indirectly*, by causing currents in the ocean, which convey to one locality the surface water heated in another. In both ways they effect a constant circulation, both of heat and moisture, the two great elements of climate, which cannot therefore be understood till we know something of the habitual force and direction of these great aerial movements, considered on an extensive scale.

(57.) A very small difference of atmospheric pressures, as a moving power, suffices to generate a considerable wind. Calculating from a formula given by D. Bernouilli to express the velocity of a gas issuing through an orifice in a vessel in which it is compressed, into surrounding air of less elasticity, it appears that, to generate in atmospheric air, velocities of efflux equal respectively to 10, 20, 30; 60, 90, 120; and 150 feet per second (or of 7, 14, 21; 41, 61, 82; and 92 miles per hour), would require corresponding effective differences of pressure of 0·006 in., 0·010 in., 0·016 in., 0·06 in., 0·14 in., 0·25 in., and 0·41 in. These may be taken as the velocities of wind in a gentle air; a light breeze; a good sailing breeze; a gale; a great storm; a tempest; and a hurricane producing universal desolation, sweeping away buildings, and tearing up trees. The corresponding pressures of the wind per square foot on a plane surface, perpendicularly opposed to it, are respectively in pounds 0·2, 0·9, 1·9; 7·5, 16·7, 30·7; 37·9. It must be borne in mind, however, that for such pressures to produce the velocities ascribed to them, they must be supposed to act unmitigated by any graduation, which is never the case in nature, the transition from a higher to a lower pressure at stations remote from each other being always extremely gradual, so that barometric elevations and depressions to a much larger extent may and do exist without giving rise to great winds. It is only when sensible differences subsist between the pressures at places near each other that violent phenomena arise.

(58.) We have seen that the immediate effect of the application of heat to any region is to generate an ascensional movement in the incumbent atmosphere, a bodily overflowing of its material above, and a relief of barometrical pressure below. The air of the cooler surrounding region not being so relieved (but rather the contrary, owing to the increase of weight poured on it from above), will be driven in by the difference of hydrostatic pressures so arising, and thus originate two distinct winds, an upper one setting *outward* from the heated region, a lower *inward*. If the region heated be a limited one, these currents will radiate from and to it as a centre; if a linear tract, or a whole zone of the globe, such as the generally heated intertropical region, they will assume the character of two sheets of air setting inwards on both sides below, uniting and flowing vertically upwards along the medial line, and again separating aloft, and taking on a reversed movement.

(59.) In this account of the production of wind, however, no account is taken of the earth's rotation on its axis, which modifies all the phenomena, and gives their peculiar character to all the great aerial currents which prevail over the globe. The first clear perception and announcement of this cause, as affording an explanation of the trade winds (otherwise inexplicable), is due to Hadley (*Phil. Tr.*, 1735), and affords a beautiful demonstration of that great astronomical principle as a physical fact. To form a right estimate of its importance, it is only necessary to observe, that of all the winds which occur over the whole earth, one-half at least, more probably two-thirds, of the average momentum is nothing else than force given out by the globe in its rotation in the trade currents, and in the act of reabsorption or resumption by it from the anti-trades.

(60.) Since the earth revolves on an axis passing through its poles from west to east, each point in its surface has a rotatory velocity eastward proportional to the radius of its circle of latitude, and any body of air relatively quiescent on that point will have the same. Conceive now such a body to be urged by any impulse in the direction of a meridian towards the equator. Since such impulse communicates to it no increase of easterly velocity it will find itself, at each point of its progress, continually more and more deficient in this element of movement, and will lag behind the swifter surface below it, or drag upon it with a relative westerly tendency. In other words, it will no longer be a direct north or south wind, but, relatively to the surface over which it is moving, will assume continually more and more the character of a north-easterly or south-easterly one, according as it approaches the equator from the north or south.

(61.) Meanwhile, however, the earth is continually acting on the air by friction, and communicating to it rotatory velocity. As it approaches the equator, in whose vicinity the diurnal circles increase more slowly, the relative westerly tendency is continually less and less reinforced by the cause which produced it, and the counteraction arising from friction acquires energy, till, on arriving near the equator, the wind loses its easterly character altogether; while the northern and southern currents here meeting and opposing, mutually destroy each other, producing a calm; and become deflected upwards to form an ascensional current replacing the air abstracted. The result, then, is the formation of two great tropical belts, in the northern of which a north-easterly, and in the southern a south-easterly wind prevails, while the winds in the equatorial belt which separates them, are comparatively feeble and free from any steady prevalence of easterly character. This is the general description of the trade winds as actually observed.

(62.) A precisely contrary set of re-actions takes place on the upheaved or displaced equatorial air. In flowing over to regain its level, it commences its course relatively in a meridional direction, but really with the full amount of easterly velocity which the earth's equator has; and since this, as it proceeds north or southwards, is in excess of what would suffice to keep it on the same meridian, it continually deviates to the eastward; and when it again returns to the earth in its circulation, which it does on both sides beyond the tropics, it does so with a powerful westward tendency, and the more, as in its course it has been less under the influence of surface friction, owing to the elevated region in which it has travelled. It thus restores to the mass of the earth the momentum abstracted by it in the former phase of the cycle. We have here the origin of the S.W. and westerly gales, so prevalent in our latitudes, and of the almost universally westerly winds in the northern and southern extra-tropical seas. The existence of an upper current, opposite in direction to the under, is a matter of frequent observation, as shewn by the courses of a lower and higher stratum of clouds.

(63.) Were the whole globe covered with water, and the sun always in the equinoctial, the system of the trades and anti-trades (for so the compensating westerly winds may conveniently be designated) would be perfectly symmetrical about the equator, as their medial line. Two causes tend to derange this symmetry, viz. —1*st*, The movement of the sun in declination, which carries it alternately away from the equator to 23½° on either side; and 2*d*, The existence and peculiar form of the continents.

(64.) Suppose the sun at the northern tropic. At that time, the region beneath the southern being 47° from the circle of vertical sunshine, will be receiving little more than half its maximum of solar heat (art. 12), and the circle of 47° latitude will be receiving as much heat as the equator itself, or more, the days being longer. If this state of things were permanent, the neutral line would shift from the equator to the northern tropic, carrying the whole system of the trades with it. But the sun approaches the tropic gradually, and does not remain there, but returns to the equator; and as, moreover, the general temperature of the ocean follows very slowly the action of its rays (art. 40), these effects cannot be fully wrought out, or nearly so, and the utmost that could arise would be a very moderate northerly transfer of the medial line, and with it, of the inner and outer limits of the trades; and as the reverse effects will of course arise when the sun gets into south declination, the result altogether will issue in a periodical annual oscillation of the wind system to and fro on either side the equator; the maximum excursions falling later in the year than the precise epochs of the solstice, on the general principle that CUMULATIVE

EFFECTS NECESSARILY ATTAIN THEIR MAXIMUM LATER IN POINT OF TIME THAN THEIR CAUSES.

(65.) This is very nearly an accurate account of the real state of things in the Pacific Ocean, whose vast extent brings it within the general scope of our hypothesis, and in which the north-eastern trade extends from about 2° to 23° north latitude, in its mean situation, and the south-eastern from about 3° to 21° south latitude. Between them lies an equatorial belt of about 5° in breadth, of such habitual calm as to have given a name to the ocean itself. The annual oscillation is confined within very moderate limits.

(66.) In the Atlantic the disturbing influence of the continents is very sensibly felt. The great mass of Africa, and especially of its sandy and burning deserts, lies considerably north of the equator. These become intensely heated, and their temperature *follows the sun* much more closely than that of the sea. There can be no doubt that the medial line of the trades crosses Africa considerably to the north of the equator, nor that the annual oscillation of the northern trades at least is very great, and the influence extends to the neighbouring Atlantic. In this ocean the equatorial limit of the north-east trade shifts with the season from 5° 15′ to 11° N. lat., and that of the south from about 2° to 3° 15′ N., so that the medial line lies always a little north of the equator.

(67.) It is in the Indian seas, however, and especially in the vicinity of the great Asiatic continent, that the disturbing influence of the land is most clearly exhibited, issuing in a complete reversal of the north-east trade during a considerable portion of the year, and the production of monsoons, *i. e.*, of winds which blow half the year in one, and the other half in the contrary direction. When the sun is south of the equinoctial, it being the cold season in those continental regions, the regular trade winds prevail throughout those seas, and what is called the north-east monsoon is in fact no other than the undisturbed north-east trade wind. But where the sun has north latitude, and especially about the northern solstice, it is vertical over a very large region of Arabia, Hindostan, Bengal, Burmah, and Cochin, which become, of course, intensely heated. Under these circumstances, besides the permanent line of maximum temperature in the equatorial sea, there is developed another more intense and less regular line of the same nature, under or near the northern tropic, towards which, and not towards the equator, a large proportion of the intermediate air is drawn. Receiving thence a *northern* impulse, and that impulse carrying it into a region of less rotatory velocity than that which it has left, it assumes a relative south-west direction, and is called the south-west monsoon. Meanwhile, south of the equator, the south-east trade continues to prevail from May to October over all that part of the Indian Ocean which is not skirted with large tracts of land to the south; but where this is the case, as in the Java seas, as far as New Guinea, which are skirted to the south by the great Australian continent, we have again a double maximum, and the phenomenon of a

N.W. monsoon taking the place of the S.E. trade. Those who would wish to pursue this subject into details, are referred to Dove's Meteorological Researches, Kämtz's Meteorology, and Horsburgh's India Directory, and more especially to the wind-charts published by the Board of Trade. The setting in of the monsoon is generally accompanied by deluges of rain and thunder-storms of excessive violence.

(68.) *Sea and land winds.*—The uniformity of temperature over a surface of sea, compared with that over land, gives rise to winds alternately setting to and from the land, at those seasons when it is powerfully heated in the day time, while at night its temperature sinks to an equality, or even sometimes below, that of the sea surrounding it. As the hottest and coldest hours of the day are about 2 P.M. and a little before sunrise, the winds in question necessarily attain their greatest power at somewhat later epochs in the day.

(69.) *Dove's law of rotation of the wind.*—It is not, however, merely in the great system of aerial movements which affect the whole atmosphere, that the influence of the earth's rotation is felt. Even very limited local movements are modified by it. It is a remark as old as Lord Bacon (*de Ventis*, 1600), and since confirmed by Mariotte in France, Sturm in Germany, Toaldo in Italy, and many other writers both in Europe and North America, that the wind has a decidedly preponderating tendency to veer round the compass according to the sun's motion, *i.e.*, to pass from N. through N.E., E. S.E., to south, and so on round in the same direction through west to north; that it often makes a complete circuit in that direction, or more than one in succession (occupying sometimes many days in so doing), but that it rarely veers, and very rarely or never makes a complete circuit in the contrary direction. M. Dove in his "*Meteorologische Untersuchungen,*" was the first to shew that this tendency is a direct consequence of the cause above mentioned.

(70.) Suppose at any station in north latitude, after a calm, the air over and around the place, for some considerable distance, to receive an impulse in the direction of a meridian, carrying it towards the equator. The first air which passes over the station, coming from its immediate neighbourhood, has the same rotatory velocity as the station, and therefore passes it as *a north wind.* But the movement continuing, that which arrives subsequently having set out from a continually higher and higher latitude, arrives with continually less and less rotatory velocity, and therefore in its passage over the station, will relatively decline more and more to the east, and pass as a north-east wind. If now the southward movement relax, and at length cease, the relative motion from the east will continue for a while, till destroyed by friction, and the wind will for the moment have become a direct east wind. Now, suppose a contrary impulse given, or that the mass of air begins to travel again northward, the east wind will evidently begin to be deflected towards the north in its direction, and will become a south-east wind. As the northward movement continues, the fresh arrivals will bring with them an excess of rotatory velocity, or a tendency to blow relatively *from the west* and will thus first neutralize the easterly character, changing the wind from SE. to S., and finally overcome it, passing into a south-west wind. If, then, the other oscillation take place, and the mass of air begin again to travel southward, the wind, by the very same reasoning, will gradually change to west, then by NW. to N., and finally come round again to the NE. It is obvious that for a station in south latitude, the conditions being reversed, a contrary law of rotation ought to prevail. Observations in south latitude are in great measure wanting by which to test this theory. In north, as we have seen, it is found conformable to fact.

(71.) In the tropical regions, where the superficial air always flows towards the equator, no such oscillatory movement northwards and southwards, as is above supposed, takes place. Where monsoons exist, there is but one such oscillation annually, and accordingly the wind makes one annual circuit; but in the temperate zones beyond the trades, as casual circumstances determine, equatorial and polar tendencies alternately preponderate, and every oscillatory movement so impressed is thus converted into a circulation in a fixed direction.

(72.) *Cyclones.*—The West Indian seas, those about Mauritius, and the China seas, are infested with *hurricanes*, or storms of wind, of excessive violence, productive of frightful devastation both on land and on sea, and which, in addition to the interest which such scourges must always command, have of late come to possess a peculiar one in the eyes of meteorologists, on account of the remarkable features in their history brought to light by the laborious researches of Professor Redfield, Colonel Reid, and Mr. Piddington. By a collection of the log-books of ships which have encountered such storms, and the comparison of the recorded directions of the wind, at different periods of their progress on land, in regions devastated by them, the following general facts respecting them have been established, viz., 1st, That in any such hurricane, the movement of the air (regarding its whole extent) is vorticose. They are in fact whirlwinds, though often of vast magnitude, the diameters of some of them, which have been already traced, exceeding 500 miles, though for the most part not more than 200 or 300. Hence the name given to them of cyclones. 2d, The centre of the vortex is not fixed, but travels leisurely enough (from 2 to 30 miles per hour), along certain tracts. In the West Indies they are confined to a pretty definite area, their usual course being in a parabolic curve, having some point near Bermuda for its focus—originating in the Gulf of Florida—and running along the coasts of the United States, following generally the course of the Gulf Stream, and sweeping across the Atlantic, occasionally visiting our island. In the southern Indian seas, according to Mr. Piddington (*Sailor's Handbook*), they follow also parabolic curves, the vertices of which often sweep round the isles of Mauritius, Rodriguez, and Bourbon, and whose average focus is a point about 25° S. lat. and 70° E. long. Along the arcs of these parabolas, in both regions, the initial movement of the centre of the storm is westward, so that the movement of the cyclone in its parabolic orbit is contrary to that of the wind in the cyclone itself. 3d, In cyclones which occur in the northern hemisphere, the rotation of the air is invariably in the *contrary* direction of the hands of a watch laid face uppermost  ; in those of the southern hemisphere this rule is reversed and the movement is . 4th, They originate between the tropics, and run outwards from the equator towards the poles. But *on the equator itself they never occur.* 5th, They are announced by a rapid fall of the barometer, the depression being greatest in the centre (sometimes amounting to two inches !) 6th, The wind is most violent in the neighbourhood of the centre of the cyclone, but as the centre itself passes over any spot, a momentary calm is observed, the wind immediately recommencing in the reverse direction to what it had the instant before (a necessary consequence of the vorticose motion).

(73.) A complete account of all these characters is afforded by Hadley's principle, as developed by Dove in his "Law of Rotation," and applied to this specific class of aerial movements by Professor Taylor. Suppose (in the northern hemisphere), that owing to the application of local heat, a tendency in the air over some extensive locality C, to ascend in a vertical column should arise. To supply the place of the air so ascending, an indraught from all the surrounding region will commence. Let the equal lines N*n*, 1-1, 2-2, 3-3, E*e*,

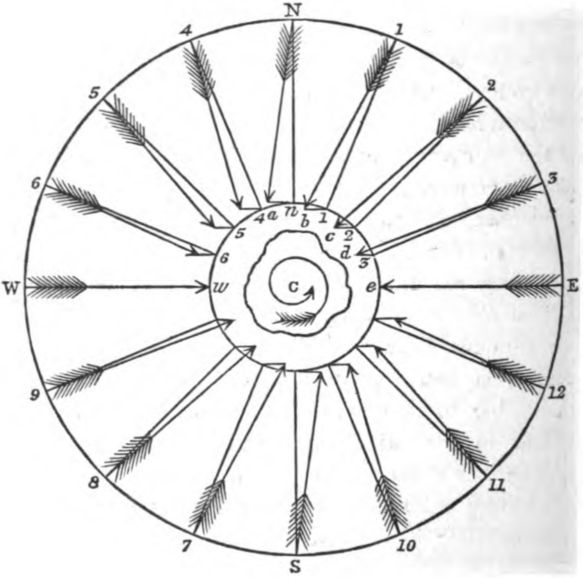


Fig. 1.

&c. (fig. 1) represent the forces and directions of currents drawn in from equidistant points, situated to the N., NNE., NE., ENE., East, &c.; then, were the earth at rest, these currents would all press towards C with equal force, and the lines N*n*, &c., would be terminated by concentric circles, and a mere vertical ascending current without gyration would result. But the earth revolving from W. to E., take to the westward of *n*, *na* to N*n* as the difference of the rotatory velocities at N, *n* to the velocity of the indraught; join N*n*, which will then represent the *relative* force and direction of the current setting in from N; and a similar construction being made at every other point, the system of relative currents will be that represented by the arrows N*a*, 1 *b*, 2 *c*, 3 *d*, E *e*, &c. And it needs but a bare inspection of the figure to perceive that such a system terminating in an ascensional movement over the tract C can be no other than a vortex or spiral eddy in the direction of the internal curved arrow, *i. e.*, in a direction contrary to the motion of the hands of a watch laid face upwards. In the southern hemisphere it will be the reverse, as will appear on drawing the figure.

(74.) It is also obvious that the force of the vortex so arising must be in proportion to the strength of its efficient causes. In high latitudes there is a deficiency of solar heat and aqueous evaporation to produce a sufficiently powerful ascending current. On the other hand, on the equator, with abundant heat, the other efficient cause, viz., a difference of diurnal rotatory velocity, is absent.

## Atmospheric Tides and Waves.

(75.) *Atmospheric waves.*—The atmosphere, like the ocean, has its waves, which are rendered sensible by the increase or diminution of barometric pressure, as the crest or the trough of the wave passes over the place of observation. They are, however, on a much vaster scale than those of the sea, as might be expected, from the greater mobility of the medium, and the extent of surface over which their exciting causes act simultaneously. But they are distinguished from the latter by features of a peculiar kind, which depend on two causes, viz., 1st, the varying density of the air from the earth upwards; and 2d, The fact that the disturbances in which they originate are not (as in the case of the sea-waves) merely superficial, but extend through the whole depth of the atmosphere, and are most powerful at the ground level.

(76.) A very good general notion may be formed of the peculiar modification of waves which depend on a decreasing density of the medium in which they are excited, by pouring into a large glass vessel fluids of different densities which do not mix, and which have different colours. An undulatory movement impressed on such a system disappears very speedily from the surface of the uppermost fluid, but continues long after to agitate the lower strata; and moreover the latter, while possessing the inertia which belongs to their *entire* densities, but the preponderant weight, which corresponds only to their *differences* of density from those above them, are less controlled by gravity in proportion, and their excursions above and below their planes of equilibrium are therefore vastly exaggerated. Again, if there are several such strata, which is easily managed by carefully pouring, one over the other, several fluids (even if *miscible*, provided actual *mixture* be avoided), their undulations are far from maintaining any parallelism or correspondence; and it will be found practicable to propagate in them waves of independent origin, and differing in direction, mutually reacting on each other. The aerial waves are, besides, exaggerated by the elasticity of the medium, the portion thrown up, *ipso facto*, dilating itself, and therefore swelling into a higher convexity than it would assume if inelastic.

(77.) As the attractions of the sun and moon tend to produce an elliptic distortion in the spherical outline of the ocean (whose vertex follows the luminaries), and which thus becomes converted into a great circulating tide-wave, with two maxima and two minima in the luni-solar day; so the heat of the sun producing a far more considerable elevation of the lines of equal density (*which when so elevated cease to be statical level lines*), and a far greater deviation from the figure of dynamical equilibrium in the aerial hemisphere beneath it; while the nightly chill on the other side acts *in a contrary way* on the opposite hemisphere; a similar, but much more considerable circulating wave, or what may be called a *heat-tide*, is generated, following the sun (as all cumulative and periodical effects follow their causes) at a certain interval, but which differs from the sea-tide wave in having only one elevation and one depression, and in having a mean solar day for its period. The *gravitation tide* of the atmosphere, depending on the joint attractions of the sun and moon will give rise to no greater difference of level in the aerial strata than what the same causes produce in the ocean itself, viz., about six feet. Its effect on the barometer therefore, would amount at the maximum to less than 1-130th of an inch.

(77, *a.*) The direct effect of the diurnal heat-tide on the barometer *in an atmosphere free from aqueous vapour* would be even less in amount than this. In fact, the heat-wave itself in such an atmosphere would be one of form, and not of pressure; since each column of the air, though dilated in altitude by the increase of temperature, undergoes no diminution of *weight* by such expansion. The direct effect indeed would be altogether *nil* but for the reaction on the earth's surface arising from the alternate elevation and depression of the centre of gravity of each atmospheric column through a vertical altitude of about 726 feet (taking *exempli gratia*, 20° Fahr. for the difference of day and night temperature, and applying the formula (7) art. 30). But the length of the period in which this oscillation is performed (viz., 24 hours or 86,400 $^{\text{sec.}}$), reduces the motive force of this reaction to an almost infinitesimal equivalent of barometric pressure (less than 1-700,000th of an inch). Equally inappretiable will be the effect of this, as a motive force acting laterally to *thrust* air from the hot hemisphere into the cold. An indirect effect, however, by no means of so very minute an order, results from the elevation of the surface of the atmosphere above the figure of equilibrium on one side, and depression below it on the other. To form some rough estimate of this effect, whose exact calculation would be difficult, we must consider that an elevation of 363 feet on one side, and a similar depression on the other, correspond to a slope of 3″.5 at the common boundary of the two hemispheres, down which the centre of gravity of each aerial column situate on that boundary (being unsupported laterally), tends to glide. The effect of this will be the production of a general movement of air setting outwards from the heated hemisphere, and which, though feeble (as its velocity would, at its maximum, hardly exceed a mile an hour), yet acting over the whole circumference of a great circle of the globe, would transfer a sensible fraction of the whole atmosphere backwards and forwards. Taking the earth's radius at 4000 miles; a bodily extension of the air in one hemisphere of $1\frac{1}{8}$ miles in excess of its amplitude would correspond to a mean diminution of pressure of a hundredth of an inch of mercury (the indirect effect thus being 7000 times greater than the direct!)

(78.) Were the sun constantly vertical over the equator (exactly as in the astronomical theory of the tides), no annual fluctuation of this kind would arise; but as the point of maximum heat oscillates from tropic to tropic, an annual transfer of air from hemisphere to hemisphere takes place, producing a fluctuation analogous to the menstrual inequality of the tides arising from the moon's change of declination—only as there is 365 times more time given for this cause to work out its effect, than in the case of the diurnal heat tide, the extent of the annual variation in the barometric pressure thus produced in the mode above characterized as indirect must be very considerable: and for the same reason, as in the diurnal fluctuation, the wave which causes it is single not double crested.

(79.) It is not with these fluctuations, however, that we are now concerned. They are greatly modified, and not only powerfully exaggerated but essentially altered in their character by the alternate generation and condensation of aqueous vapour, and will therefore more properly be considered under another head. The atmospheric waves here considered are those which originate, not from the general movement of the whole body of the atmosphere, but from internal displacements, the result of winds diverted from their course, or of great local disturbances of temperature, due to a concurrence of circumstances which may be termed casual, forasmuch as we cannot trace their laws. Such waves have been traced by comparing hourly observations of the barometer made by numerous observers, on certain days determined by preconcerted arrangement, in distant places: the progress of the waves, their general direction, their height, and velocity, being concluded from the rise and fall of the barometer as noted in each. Thus, to cite some instances, it has been found that on the 21st of September 1836, by observations made at Markree, Limerick, Halifax, Oxford, London, Brussels, Hanover, Geneva, Turin, Gibraltar, and Cadiz, a wave having a barometric depth of 0·2 in., was ascertained to have passed over the British Isles and the west of Europe, having its crest nearly in the direction NNE. or SSW., and the direction of its progress nearly from WNW. to ESE. The half breadth of this wave, which occupied nearly 26 hours in its passage, extended from Oxford to near Halle in Würtemberg (about 540 miles). Its velocity of advance was about 26 miles per hour. Again, on the 21st of December 1837, a very well defined wave travelled in a direction from 10° north of W. to 10° south of E., at the rate of 18·62 miles per hour. The total depth of this wave from crest to trough was measured by fully ⅞ inch of barometric pressure, so that the level strata must have fluctuated through a vertical height of at least 700 feet. The area over which this wave was traced, is marked by fifteen stations of observation, extending from Markree in Ireland, to Parma in Italy. —(*Brit. Ass. Rep.* 1843.)

(80.) It would appear from the researches of Mr. Birt, that a very remarkable wave of this kind (to which he has given the name of "the great November wave") passes annually over these islands and the adjacent regions (embracing probably the whole of Europe and the seas on its north-west coasts in its range), the crest extending in a direction from NE. to SW., the direction of progress (at right angles to this or) from NW. to SE., the velocity about nineteen miles per hour. Both the breadth and depth of this wave are on a vast scale. The whole wave occupies about fourteen days in its transit, the crest passing over London about the middle of November, so that its total breadth cannot be less than 6000 miles, while the extent of barometric elevation from its trough to its crest seldom falls short of an inch, and occasionally amounts to double that quantity. What is no less remarkable, there is a certain region (in which London is included), over which the rise and fall of the barometer during the transit of the wave exhibit a considerable resemblance, so that a section of it, in the direction of its advance, would be a symmetrical curve, the middle crest being preceded and followed at about five days' interval by two lower ones, and the beginning and the end marked by deep depressions. The researches of M. Le Verrier leave no doubt that the great Crimean storm of the 14th November 1854, of disastrous memory, was part and parcel of this phenomenon.

### ANEMOMETRY.

(81.) The wind, regarded as a meteorological element to be measured and recorded, differs from other elements, inasmuch as it offers two distinct objects of measurement, viz., its direction and velocity; three, indeed, since the quantity of air passing over a given place of observation varies as the velocity and density jointly. This, however, is a nicety into which meteorologists have not yet thought it worth while to go, being content to regard the number of miles travelled over by the wind in a given direction as expressing the material transfer of the air in that direction. In fact, as different and often opposing currents co-exist at different levels, it would be a useless refinement to do so. The direction and velocity, however, are essential features. The former is readily determined by a well-constructed vane, erected high enough to be out of the reach of eddies and either read off on a divided circle to degrees of deviation from the meridional direction, or so mechanically arranged as to register itself at every instant. The velocity may be measured (or self-recorded) in several different ways. As, for instance, first by causing the wind to act perpendicularly (as in Osler's anemometer) against a square foot of surface, so as to drive back a spring of known elasticity, the extent of compression determining the number of pounds which equilibrate the momentum per square foot, and which (like the direction) may be self-recorded at every instant. Secondly, by causing it to drive round the fans of a light vane, presented always perpendicular to its direction, and registering the number of its turns by means of an endless screw and wheelwork, as in Whewell's construction (C. U. Phil. Tr. vi.; improved by Dr. Robinson, Mem. R. I. Acad. xxii.), which has the advantage of giving not merely the momentary velocity, but the total or integral amount of space run over, or the transfer of air per day, per hour, or per minute, as may be required.

(82.) Since the whole of the air in the region surrounding the place of observation participates in the movement so recorded, and must be considered as transferred bodily at each instant with a motion equal and parallel, the particle which was first over the spot will describe a curve whose elementary arc and direction are determined, and may therefore be traced, either by hand or by a self-acting movement in the mechanism of the anemometer on any scale. Suppose (fig. 2) A *p q r* B to be the trace of one day's movement, A S the direction of the meridian, *p*, *q*, *r*, the points attained at stated hours, $t_1$, $t_2$, &c., and let $Q_1$, $Q_2$, $Q_3$, &c. be the angles *p* A P, *q p a*, *r q b*, &c., or the directions of the

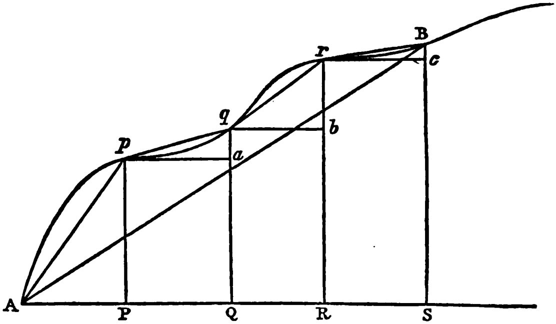


Fig. 2.

wind, reckoned round the compass from the north, eastwards, and $v_1$, $v_2$, &c. its velocities; then since *p* P $= v . \sin. \theta$, $AP = v . \cos. \theta$; if $dt$ be the element of the time, we shall have $AS = \int v dt . \cos. \theta$, and $BS = \int v dt . \sin. \theta$, from $t = 0$ to $t = 24$ h. in strictness and approximately—

$$BS = v_1 . \sin. \theta_1 + v_2 . \sin. \theta_2 + \&c. = A$$

$$AS = v_1 . \cos. \theta_1 + v_2 . \cos. \theta_2 + \&c. = B$$

So that if AB be joined, AB representing the mean movement during the twenty-four hours, if $AB = V$, and $BAS = \varphi$, we shall have

$$V = \sqrt{A^2 + B^2}; \quad \tan. \varphi = \frac{A}{V},$$

whence the mean velocity and direction, during the twenty-four hours, may be calculated from a series of registered numbers, or from the measurement of AB and BS on the self-registered trace.

(83.) AB, BC, CD, DE, &c., represent the mean diurnal movements during a week, month, or year (fig. 3), so, by a similar system of calculation, may the mean

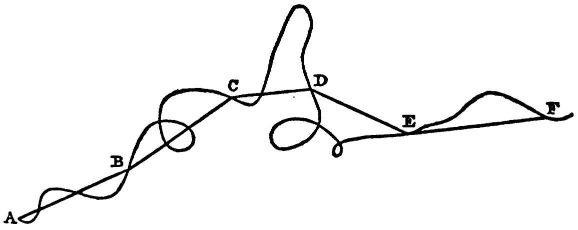


Fig. 3.

weekly, monthly, or annual direction and velocity be computed. Hitherto it has not been possible to obtain the necessary data for any considerable number of stations, the instruments required being both costly and comparatively of recent construction. But no class of observations is calculated to afford more insight into the sequence of meteorological changes: and they cannot be too earnestly recommended to general attention. Meanwhile, in the absence of all information as to the velocity of the wind, it has been the practice to assume *all winds as of equal force*, or rather that the force of winds may be regarded, on the average, as measured by the frequency of their occurrence. The formula given by Lambert for the average direction and force of the wind is founded on this supposition (a most misleading one), and consists in substituting for $v_1$, $v_2$, &c., in the general values of A and B above given, the numbers $n_1$, $n_2$, and in which the winds N., NNE., NE., &c., making angles $\theta_1 = 0$, $\theta_2 = 22^0\frac{1}{2}$, $\theta_3 = 45^0$, &c., supposing the circumference divided into sixteen "points:" or $\theta_1 = 0$, $\theta_2 = 45^0$, &c., if only into eight points. As there exists an abundance of observations in which the direction of the wind, *per vane*, is thus recorded daily, a rude approximation to the desired results can thus be made for a great number of localities. Kämtz and Dove have thus computed the mean annual force and direction, as well as their monthly variations, for a great number of stations in Europe and North America, the general result of which the former has embodied in a synoptic table, as below, viz.—

| | Direction. | Force. |
|---|---|---|
| England | S. 66° W. | 0.198 |
| France and Holland | S. 88 W. | 0.135 |
| Germany | S. 76 W. | 0.177 |
| Denmark | S. 62 W. | 0.170 |
| Sweden | S. 77 W. | 0.228 |
| Eastern Europe | N. 87 W. | 0.167 |
| Northern part of United States | S. 86 W. | 0.182 |

in which the numbers under the column headed Force express the values of V in the formula so modified.

## OF OCEANIC CURRENTS AS DISTRIBUTORS OF HEAT AND MOISTURE.

(84.) The winds act indirectly as distributors of heat and moisture, by producing currents in the ocean. Were there a free communication round the globe, at or about its equator, the continuous action of the trades could not fail to establish a westerly circulation of the equatorial waters with little deviation to the north or south; and were the whole globe covered with water, the compensating SW. and NW. winds beyond the tropics would produce two extra-tropical easterly currents, surrounding the globe, and separated from the equatorial one by zones of still water, a lively picture in short of what is most probably the state of the planet Jupiter (the rotatory velocity of whose equator is 26 times greater than the earth's) as concluded from the appearance of its belts.

(85.) The continent of America, however, which presents an unbroken barrier as far as the 55th degree of south latitude, effectually prevents the equatorial current from making a complete circuit round the globe, its passage round Cape Hoorn being barred by the contrary southern compensating current. Its passage round the Cape of Good Hope, also, is materially impeded, though not prevented, by a similar cause, so that in the Atlantic two vast eddies are formed, in the southern of which the water, deflected along the Brazilian coast till it meets the opposite current at Cape Hoorn, joins that current, and is swept eastward with it. In the northern it is thrown upon the north-east coast of South America, through the Caribbean Sea, obliquely into the hollow of the Gulf of Mexico, where it is suddenly and violently deflected to the north-west, and issues in what is called the Gulf Stream, to which, as a very powerful agent in determining our own climate, we must devote some small space, referring the reader for further details on the subject of currents to works on HYDROGRAPHY, and to the chart of Oceanic Currents by Captain Beechy, in the *Admiralty Manual of Scientific Enquiry*, p. 106.

(86.) The Gulf Stream, where it quits the Gulf of Florida, has a velocity of from three to five miles per hour (varying with the season), a breadth of only a few miles, and a temperature of 83°. Thence it follows the coast of America to about the 36th degree of latitude, where it still possesses a temperature of 76° Fahr., and where it quits the coast about Cape Fear, and encircling the Azores, spreads itself in wide diverging streams over the basin of the Atlantic, between the coasts of America and Spain, forming a vast eddy, overgrown with the "sargasso" or Gulf weed. The main stream, however, continues to run north-westward, directed full towards the British Islands, to about the 46th parallel, in the 40th degree of west longitude, where its force is much weakened by subdivision. The surface water, however, continues to flow onwards in the same direction, and its presence on our western shores is evidenced by the warm vapours the south-west winds waft from above it, and by tropical plants and seeds thrown ashore on the west coast of Ireland, on the Hebrides, and even on Norway. Were the isthmus of Panama broken through, there is no doubt that the whole climate of our islands would undergo a most notable deterioration.

## Of the Precipitation of Vapour, and the Formation of Dew, Fogs, Clouds, and Rain, etc., Hygrometry.

(87.) Air and vapour, according to the views of Deluc (first distinctly announced in a very remarkable paper, *Phil. Tr.* 1792, p. 400), and the theory of the independent elasticity of gases in general, announced by Dalton in 1801, form two distinct and in great measure independent atmospheres; the one permanent in material and constant in quantity—the other in a continual state of destruction and renovation. Were the temperature of all regions of the globe alike, no precipitation of vapour in the form of rain or snow would ever take place. A certain definite amount of vapour once generated and diffused, would remain as a permanent constituent of the atmosphere, and each aerial stratum would exist in a state of habitual exact saturation, so that no further evaporation would take place from a moist surface at whatever level exposed. But owing to the equatorial heat, the polar cold, and the great system of circulation established by the winds, the atmosphere is converted into a great distilling apparatus, and the vapour raised in warmer regions is continually being precipitated in colder, according to laws which we are now to trace.

(88.) The most immediate, though assuredly not the most obvious result of this state of things, is a general fact avouched (like the cold of the higher regions) by all mountain travellers and all aeronauts, viz.—The habitual *hygrometric* or *relative dryness of those regions* IN CLEAR WEATHER. This is shewn by very ordinary but very demonstrative facts. Thus Deluc remarked that the head of his walking stick always fell off in high mountain ascents, from the shrinking of the wood. We have seen that were there never any rain, etc., each stratum of the air would be in an exact state of saturation, and no evaporation would be possible from a moist surface at any level. "But * every act of precipitation, no matter how produced, unsettles this state of things, and withdraws from the total mass of air some portion of its entire amount of vapour. As such precipitations, therefore, are constantly going on in some place or other, the atmosphere, as a mass, though incumbent on a wet and evaporating surface, is necessarily always deficient in moisture; and for the very same reason, every superior stratum is relatively deficient in comparison with that immediately beneath it, from which its supply is derived. In point of ultimate causation, then, there is a constant drain on the aqueous contents of the atmosphere, arising from changes of temperature. This drain extends to all its strata; but while the

* Essays from the Edinburgh and Quarterly Reviews, etc., by the author of this work (London, Longman and Co., 1857), p. 353.

lower renew their losses from a surface hygrometrically *wet*, the upper draw *their* supply from sources more and more deficient in moisture." What the equatorial depression of the barometer at the sea level then is to the system of winds, such is the habitual hygrometric dryness of the air above the clouds to that of rains—at once an indication of a process in progress, and an efficient agent in continuing it. Wherever such relative dryness exists, vapour, by its own expansive *nisus*, is in the act of transfer *in an invisible state* from one atmospheric region to another, and the rapidity of that transfer is proportional, *cæteris paribus*, to the degree of dryness, as the velocity of a river at any point is to the inclination of its surface to the horizon. This by no means supposes a universally prevalent deficiency of vaporous tension. Complete saturation must exist at the points of evaporation and deposition, but at intermediate ones any amount of irregularity may prevail according to local circumstances.

(89.) *Hygrometry.*—To obtain a measure of this important element is the object of *hygrometry*, which consists in determining by instrumental means the absolute quantity of water existing, as vapour, in a given volume (suppose a cubic foot) of air, under any circumstances of temperature and pressure, and thence, from the known specific gravity of vapour, deducing its elastic force or tension. For the ways in which this may be accomplished, and for a description of the instruments used, the reader is referred to the article on HYGROMETRY, in the Encyclopædia Britannica and other similar digests. The method now adopted in preference to all others, as the most simple and convenient in practice, and leading to results which a very severe examination has proved to be quite satisfactory, is the simultaneous observation of the wet and dry thermometer. The formula of reduction, as it results from Dr. Apjohn's elaborate investigations, is as follows:—Let $t$, $t'$ be the respective readings of the *wet* and *dry* thermometers (in degrees Fahrenheit), $h$ the barometric pressure in inches, $f$ the elastic force of saturated vapour at the temperature $t$, and F its elastic force at the "Dew-point," or at that temperature which the air ought to have, so as to be exactly saturated with the quantity of vapour it actually contains. Then will

$$F = f - \frac{t'-t}{80} \cdot \frac{h}{30}; \quad (a) \qquad \text{or, } F = f - \frac{t'-t}{96} \cdot \frac{h}{30}; \quad (b)$$

the equation ($a$) or ($b$) being used according as $t$, the reading of the wet thermometer, is above or below 32°. $f$ is found from a table of the elastic force of saturated vapours (see STEAM) at different temperatures, which will also be found in the *Admiralty Manual of Scientific Enquiry*, p. 321; and F being calculated from the above expression, the dew point may be had from the same table, used reversely, *i.e.*, entering the table with F and finding the corresponding temperature. F known, the weight of water per cubic foot is found by multiplying the weight of a cubic foot of dry air at 30 inches (563·2124 grs.) by the specific gravity of steam for elasticity F, *i.e.*, by F × 0·6235, or by the formula F × 35·166. Copious tables for facilitating the whole process have been published by Mr. Glaisher (*Hygrom. Tables*, Lond. R. and J. E. Taylor. 1847).

(90.) If the temperature of any given space containing vapour be higher than its dew-point, water exposed in it will evaporate. The air it contains is then said to be *relatively* more or less dry, or (in reference to the old chemical theory of solution advanced by Hutton, the language of which being convenient, is retained, though the theory is exploded), under-saturated. If lower, some portion of the vapour will begin to be precipitated, and this precipitate assumes various forms, according to the circumstances under which a sufficiently low temperature is produced.

(91.) I. *Dew.*—When the mass of moist air is simply brought into contact with a cold body, the result is *dew*, which is deposited in minute globules of water on the body, or if the temperature of the latter be below the freezing-point, ice or *hoar-frost.* The nature of these phenomena was, up to a late period, strangely misconceived,—the effect, by a mistake very common in meteorology, being put for the cause, the dew being regarded as *producing* the chill accompanying it, instead of the reverse. Dr. Wells, in his "Essay on Dew"—a little work which deserves to be considered as a model of experimental inquiry—was the first to place in a clear light the true nature of the process. The chief facts to be accounted for are these: —1st. Dew (as distinguished from small rain or the moisture produced by visible fog) is never deposited except on a surface colder than the air. 2d. It is never deposited in cloudy weather; and so strict is its connection with *a clear sky*, that its deposition is immediately suspended whenever any considerable cloud passes the zenith of the place of observation. 3d. It is never *copiously* deposited in a place screened or sheltered from *a clear view of the sky*, even if the screen be of very thin material, such as muslin or paper suspended over it. 4th. It is most copiously deposited on all such bodies as are *good radiants and bad conductors of heat*, such as grass, paper, glass, wool, etc., but little or not at all on *bad radiants*, such as polished metals, which are also *good conductors*. And, lastly, it is never deposited if there be much wind. All these circumstances, as Dr. Wells has shewn, point to the escape of heat from the bodies exposed by *radiation out into space*, or into the upper and colder regions of the air, faster than it can be restored by counter-radiation or by *conduction* from contact with the warm air or with solid substances—wind acting in this respect with great efficacy, by continually renewing the air in contact. Hoar-frost differs only from dew by being frozen in the moment of deposition, and therefore accreting in crystalline spiculæ.

(92.) II. *Mist or Fog.* If a table of vapour tension, or the formula from which such a table is calculated, viz.

$$\text{Tab. Log.}\left(\frac{p}{30}\right) = -0.0085412197.t - 0.0000208109.t^2 + 0.000000058.t^3$$

where $p$ is the elastic force of saturated vapour, corresponding to a temperature of 212°—*t* Fahr. (Biot, *Tr. de Phys.* i. 278), be projected into a curve (fig. 4.), taking *t* for an abscissa, and *p* for an ordinate, it will be found to have the form P D Q convex in every part towards its axis or asymptote A B. Hence, if between any two dew-point temperatures, A M, A N, an arithmetical mean A B be taken, and P Q, the ends of the ordinates joined, B E will express the arithmetical mean of the extreme ordinates, or of the elasticities at

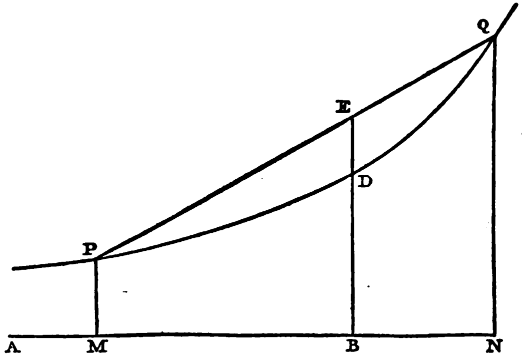

Fig. 4.

the two temperatures, and B D (less than B E) that corresponding to their mean. Hence it is evident, that if two equal volumes of air, saturated at temperatures *t* and *t′* be mixed, since the mixture will have the mean temperature, water must be precipitated, the corresponding vapour tension being less than the mean. The form in which the moisture so precipitated first appears, will necessarily be that of very minutely divided particles, which, however, having the refractive power of water, reflect and refract light as such, and appear therefore as a mist, fog, or cloud of greater or less density and opacity, according to the amount precipitated in a given volume. It is a favourite dogma with many meteorologists, that the particles so precipitated assume the form, not of drops, but of hollow spheres or bubbles. De Saussure states, that he has seen such floating before his eyes in clouds and fogs on the Alps,* and the dusty appearance of the vapour floating over a cup of coffee in the sunshine is adduced in proof. The strongest argument in their favour, however (for there is great room for optical illusion in such matters), is that adduced by Kratzenstein, that the sun striking on a cloud or fog produces no rainbow, which it ought to do were the water collected in spherical *drops*. This argument does not admit of a ready answer; but the difficulty, on the other hand, of conceiving any possible mode in which such bubbles can be formed, disposes us to believe that the extreme minuteness of the globules may be found to afford one, their diameters being probably of an order comparable with the breadths of the luminiferous undulations.†

* [I have never, myself, seen such a phenomenon, and have questioned Alpine excursionists of far more extensive experience than my own, with a like negative reply. *Note added Feb.* 1861.]

† [On the Newtonian doctrine of fits of easy transmission and reflexion, or (which comes to the same thing), on the hypo-

(93.) *Radiation Fogs and River Mists.*—When the air in contact with a radiating surface has been reduced in temperature to the dew-point, and has discharged its superfluous moisture in dew or frost, it remains saturated and at the same time colder than that above it. If the ground be quite level, and the air quite calm, however, little or no mixture will take place, the upper air remaining uppermost, in the absence of any reason for its descent, or for the rise of that beneath. But if the ground slope ever so little towards a valley or hollow basin, the cold air will run downwards, and mixing with the air below, if sufficiently near to saturation, will depress the mean temperature of the mixture below its resultant dew-point, and produce fog. If the low ground be occupied by water or marsh, as the air reposing on it is sure to be saturated, copious precipitation will necessarily result. If dry,

thesis of light consisting in rotating corpuscles with attractive and repulsive poles—there would be no difficulty of the kind. A globule (or a particle of water of any other form) whose greatest linear diameter did not exceed the thickness of that central spot in a soap-bubble which reflects little or no light, would be equally non-reflective, and therefore incapable of forming a rainbow. In the undulatory theory, however, it is the parallelism of the surfaces of the film of which that central spot consists which renders it non-reflective. I suspect, however, that in the case contemplated in the text, that theory, carefully re-examined, would render a somewhat different account of the singular abruptness of transition from the most brilliant reflexion to an almost absolute extinction of the reflected ray, and of the uniformity over large areas of a thin film of the very small remaining fraction of the incident light which it *does* reflect, than that usually given. *Note added Feb.* 1861.]

the mist produced will be less copious, and *may* not even take place at all. In the Weald of Kent, a district abounding in grassy slopes and winding and branching valleys, in the calm clear nights which are there so frequent, beautiful instances of radiation-fog are of perpetual occurrence. Immediately after sunset, in clear weather, dew commences—streams of cold air set downwards, following the lines of shortest descent (very sensible as descending currents), their course being marked with mist, thin and filmy at first, but acquiring density in its downward progress, and by degrees filling the valleys with fog, which, in the morning before sunrise, presents exactly the aspect of a winding lake or river of water, whose surface, perfectly even and horizontal, runs a sharply defined level line round every promontory and into every retreating nook. Descending into such a lake under a full moon, a few yards below its upper surface, *a lunar rainbow is frequently seen* in the mist. We on more than one occasion have resorted to a particular spot well situated for the purpose, to look for one, and have not been disappointed. (Here then, at least, the argument of Kratzenstein for vesicles is inapplicable.) By far the finest lunar rainbow we have ever been fortunate enough to witness (Nov. 12, 1848) was formed in a dense fog, *evidently close at hand*, which, however, was beginning to resolve itself into a fine, light, mizzling rain. On this occasion the exterior or secondary bow was seen.

(94.) It is a matter of ordinary remark, that the spring frosts are severer in hollows and low grounds than on slopes and heights. This is an obvious consequence of what has been said. The cold air flows downwards, and collects in the hollows, being replaced on the heights by the air of a higher stratum, unchilled by radiation.

(95.) A radiation-fog once formed tends to its own increase, by radiating off heat from its own particles, water in the liquid state being a good radiant of caloric.

(96.) When the warm current in the open ocean encounters a shoal, the lower water (of inferior temperature) is thrown up to the surface. The surface-water, therefore, on the shoal is colder than that of the surrounding ocean, and the atmospheres (saturated at the respective temperatures) mingling, produce those fogs which are observed to be prevalent in such localities. The fogs of Newfoundland are a remarkable instance in point. Fogs, too, are produced in the neighbourhood of floating icebergs, on a similar principle. The Arve, in its descent from Chamouni, occasionally presents the appearance of a river of warm water throwing up steam (though, in fact, many degrees colder than the air), from the mixture of the cold air above it with the saturated warmer air of the valley through which it flows (*Obs.* Aug. 1821).

(97.) *Barometric fogs.*—The temperature of a mass of air may be lowered beneath the dew-point, independent of radiation, contact of a cold body, or mixture with colder air, by the simple effect of its own expansion.

This may take place in two ways, viz., 1st, By a rapid and considerable relief of barometric pressure from above; or, 2dly, By its own ascent into a higher region of the atmosphere. The first case takes place when the trough of an atmospheric wave (see *art.* 75) passes rapidly over the place of observation. The fog so produced comes on for the most part suddenly, and without any obvious cause. It is not rolled in from a distance by the wind, nor does a moderate wind dissipate it. It is not confined to the surface of the ground, but extends at once to great altitudes. It does not resolve itself into rain, but disappears, when the atmospheric equilibrium is restored, by the recondensation of the air, and the reappearance of its sensible heat. Such fogs are very common, and are precisely analogous to the cloud produced in the receiver of an air-pump by a rapid partial expansion of the air. They want a name, and that of barometric fogs seems not inappropriate.

(97, *a.*) *Diffusional fogs.*—There is a fog of not very frequent occurrence in our climate, which comes on gradually, in a perfectly calm state of the air, without any sudden or considerable diminution of barometric pressure, and which evidently arises from a gradual increase of humidity in the air, at length attaining the dew-point. Such fogs would seem, not unnaturally, to result from the quiet lateral *diffusion* (see § 21, 52, 87) of vapour as a gas from some neighbouring or slowly approaching mass of vapour-loaded air, *in anticipation* of its bodily arrival as a moist or rainy south-west wind. To such a fog the epithet of "Diffusional" may not improperly be applied.

(98.) III. *Clouds.*—When a body of vapour is generated from any warm evaporating surface, it ascends by its relative levity, losing sensible heat, as well by its own expansion as by its bodily transfer into and intermixture with colder air. Should the supply of vapour, however, not be very copious, and should it find itself, in its ascent, always in a region hygrometrically dry, it by no means follows that it will reach the point of precipitation; but should the reverse of these conditions obtain, viz., a copious and continued supply from below, and a state of vaporous tension already existing aloft approaching saturation, a portion will be precipitated in visible cloud on arriving at a certain level. When this process takes place in a calm state of the air, and the evaporating surface is limited in extent, or irregularly distributed in patches (as over marshy ground, rivers, lakes, &c.), or if any other cause dispose the vapour to rise in columnar bodies of greater or less extent, the summits of these are marked by protuberant masses or piles of cloud, with generally rounded outlines, which appear to repose on flat bases, indicating the "vapour plane," or that level where hygrometric saturation commences. To such clouds, in Howard's *Nomenclature of Clouds*, the names of Cumulus is assigned. They abound in the calm latitudes of the equatorial seas, and form a distinguishing feature in the meteorology of that region.

(99.) That the mere self-expansion of the ascending air is sufficient to cause precipitation of some of its vapour, when abundant, is rendered matter of ocular demonstration in that very striking phenomenon so common at the Cape of Good Hope, where the south or south-easterly wind which sweeps over the Southern Ocean, impinging on the long range of rocks which terminate in the Table Mountain, is thrown up by them (as marked by the direction of the arrows in fig. 5), makes a clear sweep over the flat table-land which forms the summit of that mountain (about 3850 feet high), and thence plunges down with the violence of a

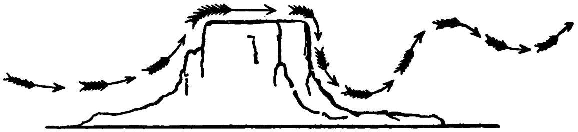

Fig. 5.

cataract, clinging close to the mural precipices that form a kind of background to Cape Town, which it fills with dust and uproar. A perfectly cloudless sky meanwhile prevails over the town, the sea, and the level country, but the mountain is covered with a dense white cloud, reaching to no great height above its summit, and quite level, which, though evidently swept along by the wind, and hurried furiously over the edge of the precipice, dissolves and completely disappears on a definite level, suggesting the idea (whence it derives its name) of a "Table-cloth." Occasionally, when the wind is very violent, a ripple is formed in the aerial current, which, by a sort of rebound in the hollow of the amphitheatre in which Cape Town stands, is again thrown up, just over the edge of the sea, vertically over the Jetty, where we have stood for hours watching a small white patch of cloud in the zenith, a few acres in extent, in violent internal agitation (from the hurricane of wind blowing through it), yet immovable, as if fixed by some spell, the material ever changing, the form and aspect unvarying. The Table-cloth is formed also at the commencement of a "north-wester," but its fringes then descend on the opposite side of the mountain, which is no less precipitous. Fig. 1, Plate III., is a careful representation of such an exhibition of it on May 20, 1835.

(100.) *Nomenclature of Clouds.*—The forms and aspect of clouds are very indicative of the circumstances under which they are in the act of forming or dissipating. Howard (*Askesian Lectures*, 1802) has endeavoured to embody their chief characters in a determinate nomenclature, which has been generally adopted. He divides clouds into three primary modifications; Cumulus, Stratus, and Cirrus, with intermediate forms graduating into one another under the names Cumulo-stratus, Cirro-stratus, Cirro-cumulus, and, lastly, a composite form, resulting from a blending or confusion of the others, under the name Cirro-cumulo-stratus or Nimbus.

(101.) *Cumulus* has been already described. Mr. Howard defines it as *sursum crescens*, increasing upward from a horizontal base. This is in conformity with its origin. When sharply terminated by rounded spherical forms, which under sunshine appear as snow-heaps, the form clearly indicates the act of self-dissipation in invisible vapour into the upper relatively dry air.

(102.) *Stratus* consists of horizontal sheets. Its situation is low in the atmosphere, and may be considered as intermediate between cloud and fog, being chiefly formed at night, and under the influence of radiation either from the surface of a ground fog (as already described), or from impurities floating in the air itself. The latter is remarkably the case in great cities in which coal is chiefly consumed as fuel, and gives rise to those dense, yellow, suffocating fogs which infest London in the winter months. A very peculiar phenomenon exhibited by the London atmosphere has been described to us by the Astronomer-Royal, and appears to be referable to the same cause. In calm evenings after sunset, as seen from the Royal Observatory on Greenwich Hill, the vast irregular mass of smoke hovering over London appears to subside. Its heaped and turbulent outline becomes flat, and sinks rapidly into a low level cloud-bank, with a very definite outline, and fair sky above. It would seem that each particle of soot, acting as an insulated radiant, collects dew on itself, and sinks down rapidly as a heavy body. Stratus is also sometimes formed very suddenly on a higher level, when in a clear, calm night the general temperature of the air sinks by radiation, or by diminution of atmospheric pressure, till at some definite altitude above the surface the dew-point is attained. Thus, on the night of April 19, 1827, the sky, up to 16h. 16m. Sid. T, being perfectly cloudless, and not a breath of wind stirring, stratus at a high level commenced in the eastern horizon, and in eight minutes had extended to the western, obscuring the whole sky, the calm remaining unbroken. In this case the velocity of propagation of the edge of the cloud from east to west (or following the sun) could not have been less than 300 miles per hour (*Mem. Ast. Soc.* iii. 51).

(103.) *Cirrus* consists of fibrous, wispy, or feathery clouds occupying the highest region of the atmosphere. The name of mares' tails, by which cirri are commonly known, describes their aspect well. Of all forms of cloud these present the greatest variety. Their filamentous structure clearly indicates them as either in the act of originating from the union of aerial currents running parallel to each other, or as the residues of dissolving cloud drawn out into fibres by wind. Mr. Howard is disposed to assign to them an electric origin, or at least to attribute their fibrous appearance to electricity, but in this view we cannot coincide. From the great elevation of cirrus it is more than probable that its particles are frozen, and of course crystalline, and that to this constitution it is owing that halos, coronæ, and other optical appearances referable to reflexions and refractions in ice crystals, appear almost invariably in this cloud and in its derivative forms, especially the cirro-cumulus. It is said to be often a precursor of windy weather.

(104.) The *Cirro-cumulus*, most characteristically known as a "mackarel sky," consists often of small roundish masses disposed with more or less regularity and connection. They usually float at great elevations and often appear as a loftier stratum through the intervals of lower clouds, contrasting strongly by their slow (and sometimes contrary) movement, with the scud and drift of the inferior masses. They are frequent in summer, and attendant on dry and warm weather.

(105.) *Cirro-stratus* "appears to result from the subsidence of the fibres of *cirrus* to a horizontal position, at the same time approaching laterally. The form and relative position when seen in the distance frequently give the idea of shoals of fish." It often precedes wind and rain, and often forms the ground on which halos and parhelia are projected.

(106.) *Cumulo-stratus* would seem to be the modification of *cumulus*, when the columns of rising vapour which go to form it arrive in an upper atmosphere not sufficiently dry to round off its summits by rapid evaporation, allowing them to spread horizontally and form flat-topped, mushroom-shaped masses, the upper parts of which are often curled by the wind of an upper current into cirrous wisps, or cleanly cut off by a horizontal plane, forming an "anvil-shaped cloud" with a lateral projection, generally considered as a precursor of wind below [and probably arising from its first impression at a higher level due to the greater mobility of the upper strata of the air, as less retarded by friction]. The tendency of *Cumulo-stratus* is to spread, overcast the sky, and settle down into the *Nimbus*, and finally to fall in rain. When two strata of clouds on different levels tend to unite, it is evident that the intermediate region must be nearly or quite in a state of hygrometric saturation. The cloud then forms confusedly and in irregular masses through the whole region, and finally resolves itself into heavy rain.

(107.) When cloud is present, the sun's rays are of course prevented from reaching the earth directly, and their heat is diffused through the general atmosphere—thus softening and mitigating their ardour. When the sun shines on a cloud, which absorbs its heat, the cloud itself is necessarily partially evaporated, and the vapour by its levity tends to produce an upward current, and thus to counteract the effect of gravity on the globules of which it consists. A globule of water 1-4600ths in. in diameter, in air of five-sixths of the density on the surface, or at the height of about 5000 feet, would have its gravity counteracted by resistance, with a velocity of descent of one foot per second (supposing no friction and no drag); and even if the terminal velocity were reduced to half that quantity by these causes, would still require some such upward action to enable it to maintain its level—a circumstance which sufficiently accounts for the lower level generally observed of cloud during the night. It is more than probable, however, that, when not actually raining, a cloud is always in process of generation from below, and dissolution from above, and that the moment this process ceases, rain, in the form of "mizzle," commences. In a word, a cloud in general would seem to be merely the visible form of an aerial space in which certain processes are at the moment in equilibrio, and all the particles in a state of upward movement.

(108.) IV. *Rain.*—In whatever part of a cloud the original ascensional movement of the vapour ceases, the elementary globules of which it consists being abandoned to the action of gravity begin to fall. By the theory of the resistance of fluids, the velocity of descent in air of a given density is as the square root of the diameter of the globule. The larger globules, therefore, fall fastest, and if (as must happen) they overtake the slower ones, they incorporate, and the diameter being thereby increased, the descent grows more rapid, and the encounters more frequent, till at length the globule emerges from the lower surface of the cloud, at the "vapour plane," as a drop of rain; the size of the drops depending on the thickness of the cloud stratum, and its density. Rain indeed has been observed to fall (at least apparently) from a cloudless sky, but the occurrence is one of extreme rarity, and it seems hardly possible to be certain that it has not been brought by wind at a high level from very great distances. A very minute rain from a clear sky is known in France by the name of *serein*, and seems to be not uncommon.

(109.) The quantity of rain which falls on any given place may be measured by the very simple contrivance called a "rain-guage," which is an open vessel of a definite aperture (suppose a square foot), and of a funnel shape below, to conduct the rain fallen into a graduated vessel where it can be measured to a nicety, a very minute superficial depth of rain being thus read off on a magnified scale, even though hardly more than enough to wet the surface. It is usually recorded in inches of actual depth, and the wetness of a year or of a season is expressed by the number of inches and parts to which the earth's surface would be covered, if it could neither run off, sink into the soil, or evaporate.* Some very extraordinary and unexpected facts respecting the fall of rain have been disclosed by the use of this instrument, which would appear to indicate that its formation is by no means limited to the region of visible cloud. At one and the same place a series of rain-guages, placed at different elevations above the soil, indicate very different quantities of rain, the amount being *greater* at the *lower* level. Thus Dr. Heberden found in twelve months, from July 7, 1766, to July 7, 1767, the amount of rain at the top of Westminster Abbey to be only 12·099 in., while on the top of a house close by, but much inferior in altitude, it was 18·139 in., and on the ground 22·608 in. Thus also Mr. Phillips found the fall of rain at York for twelve months, in the years 1833-34, at the height of 213 feet from the ground, to be 14·963 in.; at 44 feet, 19·852 in.; and on the ground, 25·706 in. Again, at the Observatory of Paris the ratio of the rain collected during the nine

* [It may be as well to notice that an inch of rain on a square yard of surface expresses 46·7408 lbs. *avoirdupois* or 4·6741 gallons of water,—on an acre, 226,225·52 lbs., 22,622·55 gallons, or 100·9935 tons, and on a square mile, 144,784,333 lbs., 14,478,433·3 gallons or 64,635·86 tons. 100 tons *per inch, per acre*, is a rough and ready memorial result. *Feb.* 1861.]

years (1818-1826) on the terrace of the Observatory, and 3 metres from the ground (or 27 metres = 88½ feet lower in level) was that of 1 : 1·116, the difference being much less proportionally than in England, where the ratio from Mr. Phillips's observations is that of 1 : 1·719 at 213 feet, and 1 : 1·296 at 44 feet. The usual account given of this phenomenon (Kämtz, i. 419) is that rain falling from a high level, and therefore colder than the temperature of the air at the surface of the ground, arriving in an atmosphere nearly or quite saturated with moisture, condenses on itself, or causes the condensation, in the chilled air, of an additional quantity of vapour. But it is evident that this cause, though not uninfluential, is totally inadequate to account for so great a difference. Admitting a given weight of rain to arrive at 213 feet from the ground, with the temperature of the region at which it was formed unaltered, and supposing it to acquire in the remaining 213 feet the full temperature of the air (both of them extreme and indeed extravagant suppositions), admitting too (though hardly less extravagant) the mean height of formation of the rain to be 12,000 feet, it would bring down with it a cold of 40° Fahr., which would condense (whether on the drops or in saturated air if diffused through it) only 40-960ths, or 1-24th = 0·042 of its weight, = one-seventeenth of the quantity to be accounted for. Still less can the effect be due to a greater *obliquity* of fall at a higher than at a lower level, since the same quantity of rain must fall on the same horizontal surface after changing its obliquity as before. Dr. Heberden, in the spirit of that meteorology which refers everything not clearly understood to electricity, ascribes an electrical origin to the phenomenon. The real cause is yet to seek, and there is no more interesting problem which can fix the attention of the meteorologist. Visible cloud rests on the soil at low altitudes above the sea-level but rarely: and from such cloud only, would it seem possible that so large an accession of rain could arise.*

(110.) The amount of rain which falls habitually per annum in any locality depends on a great variety of circumstances, the most influential being its proximity to large bodies of heated water, such a prevalent direction of wind as shall not drift the vapour away

* [These remarks were written in 1857. More recently (March 29, 1860), a valuable and important paper was read by Mr. Baxendell to the Lit. and Phil. Soc. of Manchester on this subject. He arrives at the same conclusion as to the insufficiency of the mere condensation of *vapour* on the falling drops to account for the phenomenon in question, and concludes that it is impossible to account for it except by the admission of the existence of water "*not in the state of true vapour*," but already deprived of its latent caloric—in the atmosphere—though not affecting its transparency, so that "a shallow stratum of the lower and comparatively clear atmosphere," may "supply as much rain as a densely clouded and much deeper stratum in the higher regions." Mr. Baxendell hesitates to admit that the water can be thus present in the *actual state of water*, on account of its invisibility. If there be any justice in our remarks in the note † on § 92, this difficulty will disappear. He adds a very remarkable fact recorded by Mr. Binney, who, "in descending the shafts of deep coal-mines, has observed that the drops of water which drip from the upper part of the shaft increase to an extraordinary size in their descent to the bottom."]

from it, and the absence of any lofty mountains in the direction of the moist wind, to act as a barrier by causing its depositions on them. As we recede from the sea into the interior of great continents rain becomes rare, especially if the soil be sandy. Thus in the Great Sahara of Africa rain is unknown, as also in Arabia and part of Persia, in the great desert of Gobi, in the table-land of Thibet, &c. The greater part of the enormous evaporation of the equatorial seas is at once condensed and discharged again in rain from the cumuli which mark its up-rush into the higher and colder regions of the air, the rain being most continuous in those latitudes between the tropics, over which for the time the sun is vertical, or in the region of the calms. In this zone the nights are for the most part clear, but as the day advances the clouds thicken and pour down torrents of rain, clearing again at sunset.

(111.) Rain is of unfrequent occurrence, however, in the zones on either side of the calms, where the trade-winds blow steadily and regularly. These winds themselves, coming from higher latitudes, are *acquiring temperature and taking up moisture* from the sea. The returning counter-currents having discharged their first overload of moisture, pursue their course aloft, free from cloud and relatively dry; and in the neutral interval between them and the opposite lower current, cloud is not generated, or rain produced, by the intermixture of the two—the upper portions of the trades not being saturated, for the reason just adduced. The clouds which do occur in these winds belong not to their higher strata but to a much inferior level, not exceeding five or six thousand feet in altitude, while the medial line between the winds has nearly double that elevation. Such at least are the phenomena on Teneriffe, as exhibited during the late residence of Mr. C. P. Smyth on the summit of that mountain for a fortnight in the month of August, during the whole of which time the sea horizon was never once visible, a stratum of these low clouds lying uninterrupted in every direction, the *upper half* of the peak being free from cloud, and *its summit*, at 12,500 feet, just surpassing the medial line, and coming within the upper or S.W. current.

(112.) Between the tropics there is, properly speaking, no winter or summer. The year is divided into a dry and wet season—the dry, when the sun is in the opposite hemisphere, and the trade wind blows strong; the wet, when in the same, and approaching the zenith. In the neighbourhood of the equator, where the sun passes the zenith twice at several months' interval, there are two dry and two wet seasons, or rather two unequal maxima and minima of rain. Where monsoons prevail, however, the law of rain is different. Thus, on the eastern coast of the peninsula of India, the rains occur during the north-east monsoon, and on the western during the south-east or trade.

(113.) Beyond the tropics, where the *anti-trade* or returning current descends to the level of the earth's surface, and by degrees takes up the temperature of our milder latitudes, its vapour, held so far in abeyance, becomes available for the production of rain, unless intercepted, as above indicated, by some lofty mountain barrier tossing up the stream and prematurely precipitating its vapour. Where this obstacle does not exist, however, the rains are distributed in the extra-tropical regions with considerable indifference as to season; in some, indeed, a certain approach to a wet and dry division of the year prevails, as, for instance, along the coast of Portugal, as well as in Italy and the south of France, where scarcely any rain falls in summer, while at Pekin the contrary rule prevails. Since, however, the deposit of water from the air, as it travels, must of necessity bear some rude proportion to the actual quantity *in transitu*, the amount of rain or snow which falls on any country must, on a general average, diminish as the latitude increases, a conclusion confirmed by observation.

(114.) The west coasts of England and Ireland form a rather remarkable exception to this law. They receive with the west and south-west winds which generally prevail, the vapour of the Gulf Stream. In consequence the annual fall of rain is not only much greater than on the eastern and southern coasts, but in one district, that of the Lakes of Cumberland, is quite enormous. The annual fall at Seathwaite, in Borrowdale (Lake district) amounted, according to the careful observations of Mr. Miller, to no less than 141·54 inches on an average of three years; while that in London is only 23½. To bring this result into comparison with what obtains elsewhere, we subjoin a table (see page 110) of the mean annual amount of rain in some of the more remarkable localities.

(115.) Rain, except in the tropical regions, is perhaps the most irregular of all meteorological phenomena, both in respect of the frequency of its occurrence and in the quantity which falls in a given time. The quantities recorded are, in some instances, truly astonishing. It is considered, in the greater part of England, a heavy rain if an inch fall in the course of twenty-four hours; yet at Seathwaite, above mentioned, 6·62 inches are recorded by Mr. Miller to have fallen on November 27, 1845, in that time. At Joyeuse (Ardeche), in France, 31·173 inches fell in twenty-two hours; at Genoa, 30 inches in twenty-four hours; at Gibraltar, 33 inches in twenty-six hours. "On the mountain tops overhanging Bombay, 24 inches of rain have been recorded in a single night."—(*Perry, Bird's Eye View of India*, p. 17). These are, however, only sudden, unsustained falls. But in tropical regions we have instances of what may almost be called deluges. Humboldt collected, at Rio Negro, in the rainy season in May, *as an ordinary rain*, 1¾ inch in five hours. Admiral Roussin found, for the amount of rain at Cayenne, between the 1st and 24th February 1820, no less than 12 feet 6·96 inches, and on one night, between 8 P.M. and 9 A.M., he collected 10¼ inches. At Cherra Ponjee, in the Khasyah mountains, east of Calcutta, nearly 600 inches per annum are stated to have fallen. [Even in England great and persevering rainfalls occasionally occur in the rainy district of Westmoreland

Thus in January 1851, 38·86 inches are recorded by Mr. Miller (Tr. R. S. Edin. xxi), to have fallen at "The Stye," or "the Shoulder of Sprinkling Fell" in Wastdale, 1600 feet above the sea level.]

MEAN ANNUAL AMOUNT OF RAIN IN VARIOUS PLACES.

| PLACE. | LATITUDE. | RAIN per Annum. |
|---|---|---|
| | | Inches. |
| *Singapore* . . . . . . . | + 1° 16′ | 97.0 |
| Kandy . . . . . . . . | + 7 20 | 52.1 |
| Trevandrum . . . . . . | + 8 28 | 64.5 |
| Sierra Leone . . . . . . | + 8 29 | 86.2 |
| Uttray Mullay . . . . . | + 8 39 | 267.2 |
| Cape Comorin . . . . . | + 8 59 | 28.4 |
| Allepy . . . . . . . . | + 9 27 | 113.3 |
| Cochin . . . . . . . . | + 9 58 | 106.1 |
| *Dodabetta* . . . . . . . | +11 23 | 101.3 |
| Grenada . . . . . . . | +12 7 | 112.0 |
| Seringapatam . . . . . . | +12 26 | 23.7 |
| Madras . . . . . . . . | +13 4 | 44.6 |
| *St. Helena* (very irregular) . | −15 57 | 45.2 |
| Rangoon . . . . . . . | +16 47 | 84.0 |
| Mahabalishwar . . . . . | +18 ... | 254.1 |
| St. Domingo . . . . . . | +18 29 | 107.6 |
| Poonah . . . . . . . | +18 30 | 25.4 |
| *Bombay* . . . . . . . | +18 53 | 75.2 |
| Calcutta . . . . . . . | +22 35 | 76.4 |
| Cherra Ponjee . . . . . . | ... ... | 592.0 |
| Rio Janeiro . . . . . . | −22 54 | 59.2 |
| Havannah . . . . . . . | +23 9 | 91.2 |
| Charleston . . . . . . . | +32 46 | 54.0 |

| Place. | Latitude. | Rain per Annum. |
|---|---|---|
| | | Inches. |
| Madeira . . . . . . . | +33° 30′ | 27.7 |
| Cape of Good Hope . . . | −33 56 | ... |
| Williamsburg . . . . . . | +37 13 | 47.0 |
| Palermo . . . . . . . | +38 8 | 22.3 |
| Lisbon . . . . . . . . | +38 42 | 27.1 |
| *Washington, U. S.* . . . | +38 54 | 41.2 |
| Mafra . . . . . . . . | +38 55 | 44.0 |
| *Pekin* . . . . . . . . | +39 54 | 26.8 |
| *Philadelphia* (Girard Coll.) | +39 56 | 37.2 |
| Cambridge, U. S. . . . | +40 5 | 38.9 |
| Coimbra . . . . . . . | +40 12 | 118.8 |
| *Bacou* . . . . . . . . | +40 22 | 15.2 |
| *Tiflis* . . . . . . . . | +41 40 | 19.9 |
| *Rome* . . . . . . . . | +41 54 | 31.0 |
| *Odd years observed* | | 13.42 |
| *Hobart Town* . . . . . | −42 52 | 18.4 |
| *Even years observed* | | 23.34 |
| Toulon . . . . . . . . | +43 9 | 18.2 |
| Marseilles . . . . . . . | +43 17 | 23.4 |
| Siena . . . . . . . . . | +43 22 | 34.2 |
| Toulouse . . . . . . . | +43 36 | 25.2 |
| *Toronto* . . . . . . . | +43 40 | 39.7 |
| Arles . . . . . . . . . | +43 42 | 23.8 |
| Florence . . . . . . . | +43 46 | 41.3 |
| Orange . . . . . . . . | +44 7 | 30.3 |
| Genoa . . . . . . . . | +44 24 | 47.3 |
| Bologna . . . . . . . | +44 29 | 31.0 |
| Bordeaux . . . . . . . | +44 50 | 25.8 |
| Rovigo . . . . . . . . | +45 4 | 32.9 |
| Turin . . . . . . . . . | +45 5 | 26.6 |
| Padua . . . . . . . . . | +45 25 | 36.9 |

| Place. | Latitude. | Rain per Annum. |
|---|---|---|
| | | Inches. |
| Verona . . . . . . . . | +45° 27′ | 36.9 |
| Vicenza . . . . . . . | +45 32 | 43.8 |
| St. Bernard . . . . . . | +45 50 | 58.5 |
| La Rochelle . . . . . . | +46 9 | 24.5 |
| Geneva . . . . . . . . | +46 13 | 31.7 |
| Milan . . . . . . . . | +46 28 | 37.8 |
| Lausanne . . . . . . . | +46 30 | 40.2 |
| Poictiers . . . . . . . | +46 35 | 23.6 |
| Montpellier . . . . . . | +46 36 | 32.4 |
| Berne . . . . . . . . | +46 55 | 46.1 |
| Zurich . . . . . . . . | +47 21 | 34.3 |
| Troyes . . . . . . . . | +48 18 | 23.9 |
| Augsburg . . . . . . . | +48 21 | 39.1 |
| Ulm . . . . . . . . | +48 25 | 26.8 |
| Tubingen . . . . . . . | +48 31 | 25.5 |
| *Lougan* . . . . . . . . | +48 35 | 13.6 |
| Stuttgard . . . . . . . | +48 36 | 25.3 |
| Paris . . . . . . . . | +48 50 | 22.2 |
| Carlsruhe . . . . . . . | +49 0 | 26.4 |
| Metz . . . . . . . . | +49 5 | 29.0 |
| Manheim . . . . . . . | +49 30 | 22.4 |
| Nismes . . . . . . . . | +50 3 | 25.3 |
| *Prague* . . . . . . . . | +50 5 | 14.1 |
| *Cracow* . . . . . . . . | +50 6 | 13.3 |
| Penzance . . . . . . . | +50 8 | 37.2 |
| Gosport . . . . . . . | +50 48 | 29.7 |
| *Brussels* . . . . . . . | +50 17 | 28.6 |
| *Nertschinsk* . . . . . . | +51 18 | 16.0 |
| Coblentz . . . . . . . | +51 22 | 22.2 |
| Bristol . . . . . . . . | +51 27 | 23.3 |
| Gottingen . . . . . . . | +51 30 | 26.6 |

| Place. | Latitude. | Rain per Annum. |
|---|---|---|
| | | Inches. |
| Middleburg | +51° 30′ | 27.1 |
| *London* (Greenwich) | +51 31 | 24.4 |
| Breda | +51 32 | 26.3 |
| Rotterdam | +51 55 | 22.7 |
| *Oxford* | +51 55 | 26.5 |
| Strasburg | +52 10 | 27.3 |
| Lyndon | +52 42 | 18.3 |
| *Nottingham* | +53 10 | 26.4 |
| Franeker | +53 11 | 30.5 |
| *Barnaoul* | +53 20 | 10.5 |
| *Dublin* | +53 23 | 29.1 |
| Liverpool | +53 24 | 34.5 |
| Manchester | +23 29 | 36.2 |
| Lancaster | +54 3 | 39.7 |
| Isle of Man | +54 15 | 37.1 |
| Kendal | +54 19 | 53.7 |
| Seathwaite | +54 ... | 141.5 |
| *Gorki* | +54 45 | 18.2 |
| Dumfries | +55 4 | 36.9 |
| *Catherineburg* | +55 11 | 15.6 |
| *Zlatoouste* | +55 11 | 17.7 |
| Copenhagen | +55 40 | 18.5 |
| Glasgow | +55 52 | 21.3 |
| Edinburgh | +55 57 | 24.9 |
| Kinfauns | +56 20 | 24.7 |
| *Sitka* | +57 34 | 87.9 |
| Stockholm | +59 20 | 20.4 |
| *Bogoslovsk* | +59 45 | 17.2 |
| Upsala | +59 48 | 17.8 |
| *Petersburg* | +59 56 | 17.3 |
| Bergen | +60 24 | 88.6 |

(116.) V. *Hail.*—In a balloon ascent performed by Messrs. Green, Rush, and Spencer, on September 4, 1838, after mounting to an altitude of 19,185 feet, during which ascent the thermometer, at 12,000 feet, marked 46° Fahrenheit, they found, on descending again to the last-mentioned level, a temperature of 22° Fahrenheit only, or 24° colder than in their ascent. At the same time, they found there a heavy fall of *snow* in progress. It is evident that this arose from the condensation of vapour *at* that level, and that, from the intrusion of some current, a mass of intensely cold air had been introduced, which, finding vapour near saturation, converted it into snow. It is equally evident that, had the latter condition prevailed not at the level in question, but at a somewhat higher, where the condensation might have been into *rain* very near the freezing point, the drops, in descending, would have been frozen solid and fallen as *hail.* It might have been so equally, had the precipitation been so copious as to allow the coalescence of a great number of minute particles in a nascent state into drops frozen together instanter, since there is good reason to believe that the solid form is never assumed without transition through the liquid, however momentary.

(117.) The generation of hail seems always to depend on some such very sudden introduction of an extremely cold current of air into the bosom of a quiescent, nearly saturated mass. Hailstorms are always purely local phenomena, and never last long. They often mark their course by linear tracks of devastation, of great length and very small breadth. In the hailstorm of July 13, 1788, which passed across France from south to north, two such tracks were marked, of 175 and 200 leagues in length respectively, parallel to each other, the one four leagues broad, the other two, and separated by a tract five leagues in breadth, in which only rain fell. A similar character is very common, though not to such an extent. Such linear hailstorms are always attended with violent wind, sudden depression of the barometer, indicating a great commotion in the air, and probable mingling of saturated masses of very different temperature. To attribute to hail, as is often done, an electrical origin, because hail is often accompanied with thunder and lightning ("hailstones and coals of fire"), seems to us to be putting the effect for the cause.

(118.) Hail may be very properly distinguished into single hailstones and aggregated masses. Single stones have generally a crystalline structure, radiating from a centre if large, forming spherical, oval, or rounded masses, often marked out (on making a section) into concentric layers, like the rings in the section of a branch. They fall from the size of small peas to that of an egg, an orange, or a man's head, and weighing from a few grains up to fourteen pounds and upwards. Dr. Thomson, in his *Introduction to Meteorology*, a work in which the reader will find assembled a most extraordinary collection of the recorded marvels of meteorology, gives many instances of the fall of large hail-stones. One, described by Captain Delcrosse, as having fallen at Baconniere, July 4, 1819, fifteen inches in circumference, had a beautiful radiated structure (fig. 6), marking it as a single stone, formed in passing through two distinct regions of condensation. Dr. Buist stated to the Bombay Geographical Society, that in India the hail-stones are from five to twenty times larger than

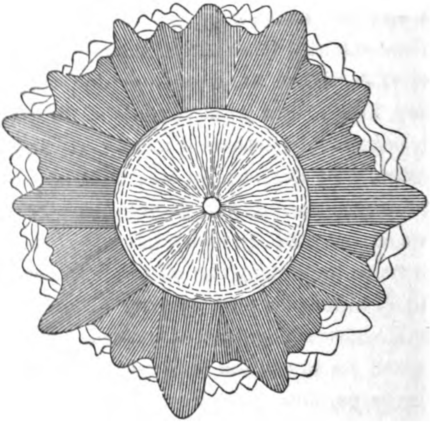

Fig. 6.

those in England, often weighing from six ounces to a pound, seldom less than walnuts, often that of oranges! These storms are almost always accompanied by violent wind and rain, thunder and lightning, and are frequent in the delta of the Ganges, especially in the low country within fifty miles of the Bay of Bengal.

(119.) Great hailstorms are often preceded by a loud clattering and clashing sound, indicating the hurtling together of masses of ice in the air. The recent experiments of Professor Tyndall on the reuniting of broken ice by "regelation," or a sort of welding, fully explains the formation, under such circumstances, of large masses of ice of irregular forms in this aerial conflict. Such are recorded to have fallen of almost fabulous magnitude. In Candeish, in 1826, in a hail-storm which perforated the roofs of houses like small cannon shot, a mass fell which took some days to melt, and must have weighed more than a hundred-weight. —(*Malet.*) On May 8, 1832, a mass fell in Hungary a yard in length and nearly two feet in thickness.—(*Thomson.*) And if it be true, as stated in the *Ross-shire Advertiser* in 1849, that a block "of irregular shape, nearly twenty feet in circumference," fell in August of that year on the estate of Mr. Moffat of Ord, immediately after an extraordinarily loud peal of thunder, Heyne's relation of a hail-stone as large as an elephant, at Seringapatam, in the reign of Tippoo Sultan, may perhaps find believers. The Ross-shire mass is stated to have been composed of lozenge-shaped pieces, one to three inches in size, firmly congealed together.

(120.) VI. *Snow.*—When time is allowed, and the process of precipitation and congelation takes place in a less tumultuous manner, so as to allow the deposited particles to accrete according to regular arrangements, small spiculæ form, crossing one another at angles of 60°, the primitive crystal of ice being a rhomboid of 60° and 120°, producing as one of its secondary forms the regular hexagonal prism, having (as all such crystals) one axis of double refraction parallel to the axis, as is easily seen in a sheet of ice formed in still water on exposure to polarized light. When deposited as hoar-frost in the condensation of dew, the crystallization is confused by contact with and adhesion to the radiant body, but when supported only by air and receiving accretion on all sides, a high degree of regularity is attained, and the most perfect and symmetrical six-rayed star-like forms arise, of which (drawn from actual observation of the falling spangles, in very cold weather) Dr. Scoresby has given several figures, and Mr. Lowe and Mr. Glaisher have more recently published series of engravings. The variety of forms affected by these delicate mechanisms is infinite; the beauty of their patterns incomparable. By Mr. Glaisher's permission we have transferred a few of his figures to our pages (Pl. XIX., figs. 2-15). Mr. Lowe has been fortunate enough to observe them in the act of forming, and to witness the whole process of construction of some of their most elegant and complex varieties.

(121.) It can hardly be doubted that clouds at great elevations consist of frozen particles. The phenomena of parhelia and some species of halos are explicable only by the refraction and reflection of light in prisms, with angles of 120° and 60°, as M. Bravais has shewn (following up the theoretical views of Mariotte and Young) by a neat and elegant mechanism. Now these are the angles of the primitive rhomboid actually measured by Dr. Clark. In *such* clouds, at all events, vesicles cannot exist, and in the gradual melting of the snow spangles, the laws of capillary attraction, by filling up all re-entering corners, would effectually preclude the inclusion of the smallest air-bubble, though a compound snow-flake hurriedly melted might now and then entangle one.

(122.) Fallen snow of even a very moderate depth, is a powerful agent in mitigating the extreme effects of frost on the soil. Owing to its loose texture and its inclusion of eight or ten times its bulk of air, it is a very bad conductor; and although its upper surface may be cooled by radiation or otherwise to a very low point, its interposition cuts off the communication between the chilled surface and the soil beneath it. The farmer looks to a fall of snow as his best security for the preservation of his autumn-sown and sprouting crops through the winter.

(123.) *Level of Perpetual Snow.*—Since by ascending into the atmosphere a temperature inferior to congelation is everywhere met with, it is evident that a mountain of some certain elevation will have the mean temperature of its summit at or below the freezing point; and although it does not follow that where the mean temperature is precisely 32°, snow will necessarily be found all the year round (since this will depend on the greater or less accumulation of it in the cold seasons, and on the greater or less evaporation in the warmer ones), yet, somewhere about this limit, and at all events at no great elevation above it, we must expect to encounter the phenomenon of perpetual snow. If we take 1° Fahr. for the average depression of the thermometer for 100 yards of increased altitude in mountain ascents, as a rough approximation, and assume 84° for the mean equatorial temperature, this would give $(84 - 32) \times 300$ ft. $= 15,600$ ft. for the height above the sea level, at which, under favourable circumstances, the perpetual snow line may occur under the equator; we say under favourable circumstances, for it is evident that if the mean temperature of the year be ever so little above the freezing point, we cannot expect snow to lie all the year round, especially on the summit of a mountain where all the water produced by melting immediately runs off, and therefore ceases from that moment to act as a reservoir of cold. Now the mean of Humboldt's determinations of this element for the mountains of equatorial America from 4°.46 N. lat. to 1°.30 S. (*Asie Centrale*, p. 461, tab.) gives 4774 metres $= 15,670$ feet.

(124.) This, however, must be considered as a *minimum* reckoning. In the celebrated work just cited, Baron Humboldt has given a table of the most authentic determinations of the snow-level for 34 mountains *trigonometrically* measured from 71° N. lat. to 54° S. Of these the mean annual temperatures *at the sea-level* are correspondingly stated for 18 stations—calculating on which it would appear that about 2100 feet on an average ought to be added to the height calculated on the decrement of temperature assumed in the last article, to give that of the snow line.

(125.) In fact, however, no general rule or principle of calculation can be laid down, and though attempts are not wanting to construct formulæ which shall afford a close approximation to the height in any geographical position, it is impossible to place any reliance on them. This will be the more evident when we come to consider the causes which must of necessity influence the result. Of these the principal are—1st, The situation of the slope on which the snow lies on the mountain chain, with respect to the incidence of the sun's rays. Thus, on the southern declivity of the Maladetta in the Pyrenees, the level in question is nearly 1200 feet higher than on the northern; 2d, and more especially its situation with respect to the direction of the wind, which brings the chief supply of moisture to be deposited in snow, and which will naturally be heaped on that side of the mountain which acts as an obstacle to its progress. To these causes must be added, 3dly, the greater or less steepness of the slope; and above all, 4thly, the greater or less degree of habitual *dryness* of the region in which the mountain is situated, by which the snow itself is evaporated and carried off. So great is the influence of these causes, that in the Himalayas, where some of the mountain peaks attain the enormous altitude of 28,000 feet, the snow line on the southern side of the great chain occurs at 13,000 feet, and on the northern at 16,600, or even (according to Mr. Lond) 18,300, the moist winds of the S.W. monsoon depositing their snow almost wholly on the southern side, while the northern is exposed to the evaporation of one of the driest regions of the globe.

On the other hand, on the eastern slope of the Cordillera, in Chili, the snow-level occurs at 15,900, while on the western it rises to 18,500 (Humboldt's *Asie Centrale*, iii. 360), the difference again being attributable to the direction of the wind (the S.E. trade), to which the chain of the Andes forms a barrier, and of which, to a certain extent, it diverts the course, and the excessive aridity of the region between the chain and the Pacific, in which rain is a thing almost unknown. Apart from the illustration it affords of the distribution of temperature in different strata of the atmosphere, the subjects of the level of perpetual snow, the inferior prolongation into glaciers, and the occasional instances where ice occurs in caves far below the snow line, preserved throughout the summer (or even in open pits, as in the quarries of the Niedermennig on the Rhine), belong rather to physical geography than to meteorology proper.

## Atmospheric Electricity, Lightning, Thunder, etc.

(126.) The community of nature between lightning and electricity was suspected from the very earliest discovery of the electric spark, by Wall, in 1708, but it was not till 1752 that Franklin suggested the idea of obtaining evidences of their identity by erecting pointed metallic conductors properly insulated. The experiment was tried in France with success, but Franklin, tired of waiting for the erection of a pointed rod on a spire in Philadelphia, had the happy idea of flying a kite and exploring the string for electricity. The experiment succeeded, meriting by its success that sublime image which forms the inscription on one of his medals,

"Eripuit fulmen cœlo, sceptrumque tyrannis."

Franklin's kite was flown with ordinary pack-thread, held by a few feet of silk line, and the electric effects obtained by him were feeble, though sparks were produced. But Romas, using in place of a string, a fine wire, obtained, during a thunderstorm (1757), flashes of fire nine or ten feet in length, thirty of which succeeded each other in an hour, besides innumerable flashes of seven feet, which, by means of a conductor, insulated by a glass handle, he was enabled to direct at pleasure—not altogether with impunity, being struck down on one occasion; though the terrible catastrophe of July 26, 1753 (when Professor Richmann of Petersburg was killed on the spot while explaining to a companion the construction and movements of an electrometer attached to his conductor) might have warned him of the dangers attending such experiments.

(127.) By means of a wire 370 feet long, attached by a silk cord to the top of a steeple at Maintenon, the Abbé Mazeas, in 1753, ascertained that the presence of a thunder-cloud is not an essential condition for the manifestation of atmospheric electricity, but that in clear, dry, and especially hot weather, electric effects are produced at all hours between sunrise and sunset. He even noticed a certain regularity of diurnal increase and decrease. From that time the exploration of atmospheric electricity has formed a part of meteorological inquiry. It is performed by erecting in a clear exposure, at a considerable height, a pole, carrying at the top an insulated and pointed metallic rod, connected with an insulated wire to convey the electricity into a fitting place for examination. There it communicates with an electrometer, a Leyden jar, a condenser, or an apparatus for measuring the length of the spark (if any), by which the kind of electricity (vitreous or resinous) may be tested, and its intensity measured and registered. When violent, a bell is made to ring by the alternate attraction and repulsion of a metal ball, suspended by a silk thread. The best collector of electricity, which is often used when a rod like a fishing-rod, with an insulating handle, is thrust out from an upper window, is a bit of amadou, held in a metallic forceps, the smouldering smoke of which being an excellent conductor, as it were searches the air into which it ascends, and conveys its electricity down to the wire attached. A sponge moistened with alcohol, and set on fire, is also an excellent collector.

(128.) Read, to whom we owe a very elaborate series of researches, continued almost hourly, without intermission (except for sleep), for two years (1791-2). Coulomb, Cavallo, Saussure, Schubler, Colladon, and others, have shewn that the normal character of aerial electricity is positive or vitreous. Of 987 trials, Read found that 664 gave positive indications; but as his method of observation improved, he found that the ratio of positive cases increased; and, moreover, that a great number of the negative were only apparent, arising from induction, the top and bottom of his rod giving contrary indications. Out of 10,500 observations made at the Kew Observatory in 1845-47, 10,176 shewed positive, and only 364 negative electricity—the latter being almost always accompanied with heavy rain.

(129.) Not only is the normal electricity of the atmosphere positive at all seasons, hours of the day, and places, but the intensity of its manifestation is invariably greater the higher in it a conductor is raised. This would appear to be the case even in the very highest regions. Thus in Gay Lussac's ascent, a wire 150 feet long, hung from the car of the balloon, manifested a *negative* state of induced electric tension at its *upper* extremity (where only it could be tested), thus indicating a higher state of positive electricity in the highest strata; or, in other words, the usual condition of electric observation on the ground being reversed, and the state of the *lower* strata being explored by the wire, it was found to be *relatively* negative. Hence it manifestly follows that, relatively to the air, the earth's surface is habitually negative—the positive electricity being repelled inwards, and the negative drawn to the surface. As moisture is withdrawn from the lower strata of the air, by deposition in dew when evaporation ceases; so electricity, when not in the act of being supplied from below (as presently to be shewn), is perpetually, though slowly, drawn off by conduction.

(130.) Fog is, for the most part, strongly electric, and invariably positive, even during the deposition of dew. Read found the vapour near the ground, in the act of condensing into dew, always highly electric. The importance of this remark will presently appear.

(131). From the observations of Saussure, Arago, Schubler, and others, it appears that the electric tension of the atmosphere is subject to a diurnal periodicity with a double maximum and minimum. The maxima occur about 10 A.M. and 10 P.M., and the minima from noon to 4 P.M., according to the season (summer or winter), and a little before sunrise. The nocturnal minimum is much more strongly marked than the diurnal. The electric tension is also stronger in winter than in summer. On the open sea, except during storms, there is but little indication of atmospheric electricity, but the masts and rigging of ships interfere greatly with the requisite arrangements for observing it.

(132.) The origin of aerial electricity has been traced with every appearance of probability to evaporation. Saussure and Beccaria proved by many experiments that the rapid evaporation of water from heated bodies gives rise to a separation of the vitreous and resinous electricities, the one being carried off by the vapour, the other remaining in the residue or being conducted away by its support, but nothing uniform or consistent either as to the positive or negative character of the electricity thus conveyed into the air, or its amount under given circumstances was obtained, until the subject engaged the attention of M. Pouillet, who, in a remarkable memoir read to the Academy of Sciences in 1825, announced the following results:—

*1st*, Simple change of state from the solid or liquid to the vaporous form of any body, is unaccompanied by any electrical excitement. The evaporation of pure water or of any substance not decomposed, or at least partly decomposed in the act, produces none whatever. *2d*, When evaporation is accompanied with chemical change, electricity is developed. Water evaporated from alkaline solutions carries off resinous and leaves behind vitreous electricity. The reverse happens when it evaporates from an acid, or from neutro-saline solutions, including that of sea salt, or from heated iron which it oxidizes. *3d*, The processes of vegetation in which water is abundantly separated from the other constituents of plants, and perhaps also their disengagement of oxygen under the influence of light, or carbonic acid under contrary circumstances, are also sources of electricity.

(133.) Thus we are led to look to the immense evaporation both from sea and land, and to the vital processes going on in the latter, as furnishing at least the chief supply of electricity to the air. Volcanic eruptions and conflagrations contribute their quota. Thus in the great eruption of Vesuvius in 1794, described by Sir William Hamilton, the dense cloud of mixed vapour, smoke, and ashes, which overhung the mountain, was overcharged with lightning, which darted around in continual flashes (*ferllie*) upon Somma and the slopes of the crater. Wind, too, by its friction, or by that of the dust, &c., which it carries with it, may also contribute somewhat to the general stock.

(134.) In what state free electricity exists in gaseous matter is at present a mystery. The simplest conception we can form, is that of its investing the ultimate molecules of vapour as an electric coating of infinitesimal tension, far too feeble to discharge itself from one to the other, and so to escape by what is called "*conduction through a moist atmosphere.*" If this be granted, we can conceive the co-existence at a distance from each other of masses of air oppositely electrified, and capable of giving out a portion of their contents by *contact discharge,* to a rod, wire, flame, &c., and thus explain the collection of electricity by these means from the air, and its diversity of character as to *plus* and *minus.*

(135.) But whatever may be the state of the ultimate molecules of vapour, it seems impossible but that when a great multitude of them lose their vaporous state by cold, and coalesce into a drop or snow-spangle, however minute, that drop will have collected and retained on its surface (according to the laws of electric equilibrium), the whole electricity of its constituent molecules, which will therefore have some finite, though very feeble tension. Now, suppose any number (1000 for instance) of such globules to coalesce, or that by successive deposition one should gradually grow to 1000 times its original *volume.* The diameter will be only 10, and the surface 100 times increased. But the electric contents being the sum of those of the elementary globules, will be increased one thousandfold, and being spread entirely over the surface, will have a tenfold density (*i.e.* tension). This simple view of the subject, put forward in the most distinct form, at the very origin of the discussion of the nature of lightning by Eeles (*Phil. Tr.* 1752, p. 527), needs only to be carried a very little farther than the then state of electric knowledge enabled its author to do, to render a complete explanation of all the ordinary electric phenomena. And, first: the comparatively high electric state of fog (and cloud is nothing else), is an obvious consequence of it. Every minute globule of water, of which fog consists, carries about with it an electric coating, which it is ready to part with by contact discharge to the surface of any conductor, and the denser the fog, and the larger its globules, the greater the amount of electricity given out. Again, the electricity of the superficial air occasioned by the deposition of dew, is in perfect accordance with this view, and is a corollary from the general proposition too obvious to need insisting on. Again, as regards the diurnal fluctuation, when the air is exhausted of its vapour by night deposition in dew, and by upward diffusion without a new supply, the electricity is at its minimum. It increases as new vapour rises under the influence of the ascending sun, decreases again (though not much) as the increasing warmth of the air renders it more capable of holding the still larger amount of vapour uncondensed, and as the vapour itself rises rapidly to form cloud, increases again as night comes on, dew begins to form at sunset, and vapour to settle into globules by atmospheric radiation, and once more decreases as the quantity of these electrified globules diminishes by deposition and diffusion. There is no doubt a certain amount of slow conduction back into the soil, the intimate nature of which it is very difficult to conceive rightly, but of which the phenomena of electricity of weak tension furnish abundant examples, by which a considerable portion of the electricity near the surface is returned to the earth, and which is more effective, the more "relatively moist" is the air, and by which the march of the diurnal fluctuation, and its epochs of maxima and minima, are materially influenced.

(136.) When condensation of vapour takes place aloft, as when a cloud is formed, the tension on the surface of its globules may increase by the process explained, till a portion of the electricity is enabled to work its way to the surface of the cloud, regarded as a conductor, though a bad one, by the general law of electric equilibrium, which tends to throw out the fluid to the surface, and universally, no doubt, the exterior of a cloud *is* in a higher state of tension than the interior, and its under surface, as opposite to the earth, than its upper. When the almost infinite dimensions of a cloud, in comparison with one of its constituent globules, is considered, it must be evident that, were the whole electricity of each globule thus, at once, determined to the surface, a tension so enormous would arise as would discharge the whole in a single flash at whatever height the cloud might be. But this is assuredly not the case. Probably but a very minute fraction of the interior electricity is at once conveyed to the surface, the further communication being delayed until the exterior tension is relieved, either by slow dissipation or by self-discharge. When this happens, the accumulation commences anew by the same kind of percolation (if we may use the term to express the outward struggle of the electricity of the globules), till another and another discharge at length exhaust the supply.

(137.) It will easily be seen, that when thousands of these electriferous globules again further coalesce into rain drops, a great and sudden increase of tension at their surface must take place. Their electricity, then, is enabled to spring from drop to drop, and rushing in an instant of time from all parts of the cloud to the surface, a flash is produced. Accordingly, in thunder-storms, it is the commonest of all phenomena to find each great flash succeeded by a sudden rush of rain at such an interval of time as may be supposed to have been occupied in its descent.* The sudden precipitation of large quantities of rain, and especially of hail, which is formed in a cold region where the insulating power of the air is great, is almost sure to be

* [Quite recently I have received from a personal friend living at a short distance from my own residence, the following account of his experience of an Electric Stroke. Returning home from a walk a thunder-storm seemed to be brewing. It came on rapidly and he found himself suddenly prostrated "on all fours" by a flash of lightning, a shock which was not, however, strong enough to deprive him for more than a few instants of self-possession, and not at all of consciousness. It did not rain, or but little, when he was struck, but when he got up, he was drenched to the skin.—*Note added. Feb.* 1861.]

accompanied with lightning, which the usual perversity of meteorologists, where electricity is in question, long persisted, and even yet persists, with few exceptions, in regarding as the cause, and not the consequence, of the precipitation. The theories of the electrical formation of hail which have been advanced, indeed appear to us too absurd to need a moment's consideration. The utmost amount of electrical agency which we can conceive influential in determining precipitation, is the sudden relief of tension on the discharge of a flash, which may permit, and perhaps, by the vibration of the air in the thunderclap, cause, the coalescence of *globules* into *drops*, which would otherwise have been kept asunder by their mutual repulsion. *As a cause of winds, or any atmospheric movements not merely molecular, we attribute to it no importance whatever.* As a chemical, and still more as a magnetic agent, however, there is every reason to believe atmospheric electricity to play a very important part in the economy of nature; since we cannot but admit the possibility at least of a connection between the diurnal variations in the electric state of the general atmosphere and the diurnal inequalities of terrestrial magnetism; and the transformation of oxygen into ozone (the most powerful of all known disinfectants) by the electric spark (and therefore on a larger scale by lightning), is not a matter of conjecture but of experiment.

(138.) There is one phenomenon which at first sight seems opposed to the view we have taken of the production of lightning—the negative electricity frequently observed during the descent of rain. But the researches of Faraday (*Phil. Trans.*, 1843) have shewn that the friction of water-drops (when pure) against all substances (and therefore probably against air) developes negative electricity most powerfully in the substance rubbed. And the probability is converted into certainty by the fact that the spray of a descending waterfall fills the air around with negative electricity, sensible even at several hundred feet distance. It is probably to this cause that we must attribute the rapid alternations of positive and negative indications in the atmosphere which always attend thunder-storms.

(139.) It is certain that the flashes of lightning are often some miles in length. The prolonged roar, interrupted by explosions, of the thunder, which, excited at the same instant along the whole course of the flash, reaches the ear in succession by the transmission of sound at a uniform rate from every point, sufficiently proves this. Nothing is more common than to see flashes of lightning subtending at the eye an angle of 30°, the nearest point of which, estimated by the commencement of the thunder, cannot be less than two or three miles distant, and which its prolongation proves to be very oblique to the line of sight. We have been assured by a celebrated Abyssinian traveller, that he has seen flashes in that country extending from horizon to horizon, and which he could not estimate as under 50 or 100 miles in length. It is evident, then, that the electricity in lightning does not merely spring across a nonconducting interval to the nearest object (which in most cases would be the earth), but finds a path of ease, and is led on from interval to interval (as its zigzags denote) along a line of least resistance, and is not improbably reinforced in its course by other electricity not of itself intense enough to break the obstacle opposed to its escape.* By far the greater number of discharges are made into air or into less electrified cloud, and only a very small percentage into the earth.

(140.) Of those which do so, the destructive effects are well known, and volumes might be filled with instances of their amazing power, and capricious and unaccountable forms of its manifestation (Arago, *Bureau des Long.* 1838.) We shall mention only one or two as specimens. In a storm at Ludgvan, in Cornwall, as related by Borlase, *Phil. Trans.*, 1753, a flash of lightning striking a chimney-stack of hewn stone four feet square, carried it bodily away, and threw it into a pond twenty feet distant. In another, described by Arago, a wall containing twenty-six tons of brick-work was carried *en masse*, retaining its vertical position, nine feet from its place. We have seen a large oak tree, near Alton, Hants, which was rent into ribands, and every limb of which had been struck off as if by an axe,

* This is not a mere hypothesis. In an experiment suggested by the author to the late Professor Daniell, and performed as soon as suggested, the striking distance of a voltaic battery was greatly increased by passing a common electric spark from the positive to the negative pole. The vastly increased striking distance of a magneto-electric combination in the neighbourhood of flame, in which its *detours* may be observed, affords a perfect illustration of the process described in the text.

and had fallen around the tree, as by mere privation of support, without lateral projection. In producing these effects, the electricity would seem to act immediately by the expansion of vapour generated by its violent heat. When it strikes into deep sand, it produces those extraordinary hollow tubes *of fused quartz!* known as "fulgurites," of which the British Museum possesses a magnificent specimen, dug out near Dresden by Prof. Fiedler. Other effects of lightning are recorded in the Athenæum, No. 1535, March 28, 1857, too marvellous to be recounted here, but which, should they be verified, would open quite a new field of inquiry in electrical research.

(141.) Thunder-storms occur with very unequal frequency in different geographical situations. In Jamaica, according to Mr. Graham Hutchinson, a thunder-storm bursts over the mountains near Port Royal every day from the beginning of November to the middle of April, at about 1 h. P.M., continuing about an hour and a half. In the neighbourhood of Cape Town, thunder-storms are few and feeble, while on the eastern coast of South Africa they are frequent and violent. The one region is arid, the other well watered.

(142.) The quantity of electricity discharged during some storms must be enormous. In the storm of Aug. 23-4, 1855, the blaze of lightning was almost uninterrupted for many hours, from a series of clouds passing from west to east, in two lines, over the south of England. The commencement of the SW. monsoon in India, in May 1848, was marked by "a thunder-storm extending over 600 miles from N. to S., and measuring 50 miles in breadth." The thunder-storm of September 3, 1841, "visited at the same time London, Paris, Rouen, Magney, Lille, and Evereux."—(*Thomson*). The mere evaporation of water would seem at first sight inadequate for the supply of so vast an expenditure, were it not that we learn from Dr. Faraday that the chemical action of a "grain of water on four grains of zinc can evolve a quantity of electricity equal to that of a powerful flash of lightning!"—(*Phil. Trans.*, 1834, p. 117.)

## Systematic View of Meteorological Periodicities— General Principles of Climatology.

(143.) The climatology of the globe is the summary of our knowledge of the climates of all the places on its surface, so presented to our minds as to convey the notion of law, and give it an ideal unity. To do this it is necessary to study *seriatim* the elements which enter into our estimate of climate, and follow out the course of the variations of each,—first, independently of the others, and then in connection with them, or, in other words, to determine for each of these elements, 1*st*, its mean or average amount, as measured in its appropriate units; 2*dly*, the extent and laws of its deviations from that amount; and, 3*dly*, their mutual interdependence, or the reaction of each element on the rest. Such features as are not susceptible of definite measurement, as have no appropriate units, or as we have no instruments competent to measure, must of course be excluded. Looked upon in this general point of view, the science in question can hardly be considered as advanced beyond its infancy.

(144.) It is a dynamical law absolutely universal, and one which extends even beyond the domain of mere dynamics, that *all periodicity in the action of a cause propagates itself into every, even the remotest, effect of that cause, through whatever chain of intermediate arrangements the action is carried out.* When the effect is indirect, and especially when it is the result of one and the same law of periodicity in the same cause operating circuitously through several systems of intermediate connection, the numerical valuation of the effect (which, in the simplest case of direct action, depends on the calculation of an expression of the form

$$A + B \,.\, \sin.\ (nt + C),$$

where A is the mean or average value of the result, B, C constant quantities, and $nt$ an arc proportional to the time directly, and the length of the period inversely) resolves itself into that of a series of similar terms, containing not merely $nt$, but its multiples $2nt$, $3nt$, &c., each with its own appropriate constants, and which therefore run through their periods respectively in half, one-third, etc., of the period from which they originate. Thus, if the original period be a diurnal one, and $\theta$ be the time converted into arc at 15° per hour, the ultimate expression of the effect will always put on the form,

$$E = A + B \sin.\ (\theta + C) + B' \sin.\ (2\,\theta + C') + \&c.,$$

in which A is the mean or average value of the effect in question, and B, C, B′, C′, &c. constants determined *a priori*, if such determination be possible; if not, by observation from the comparison of as extensive a series as possible of registered values corresponding to determinate instants of time. The term containing $\theta$, which runs through its period in a day, expresses the leading feature of the effect—that which gives it its character of a *diurnal* fluctuation; the others, which run through theirs respectively in 12h., 8h., 6h., &c., express subordinate fluctuations, more or less materially modifying the law of its increase and diminution, and the epochs of its maximum and minimum, and in certain cases giving rise to double maxima and minima in the twenty-four hours. In meteorology, it has hitherto been seldom found necessary to carry such series out beyond their third or fourth terms.

(145.) When the acting cause is subject to two or more distinct periodical fluctuations, these make their appearance in the numerical expression of the effect under the form of periodical combinations, such as may arise from multiplying together terms of a similar form containing $nt$, and another arc $n't$ similarly derived from the other period. In astronomical researches these are usually resolved into sines and cosines of the sums or differences of $nt$, $n't$, and of their multiples. But in meteorology this would be inconvenient, and a different mode of regarding such combinations is found preferable for the following reason:—

(146.) The sun's action being the ultimate efficient cause of all meteorological change, every meteorological fluctuation of a regular character will arrange itself, on the principle above laid down, into diurnal and annual periodicities, including under this expression semi-diurnal and semi-annual ones, &c., and such as may result from their superposition (leaving out of question the period of 11·11 years, depending on the constitution of the sun itself, see art. 7). But the year being a very great multiple of the day, we may regard the solar agency as practically invariable during a single day, or such a small number of successive days as may suffice to bring out the full diurnal effect, which comes to the same thing as adopting in general the diurnal form of expression,

$$E = a + b \,.\, \sin.\ (\theta + c) + b' .\ \sin.\ (2\ \theta + c') + \&c.$$

where $\theta$ is the sun's hour angle reckoned from midnight for the fluctuating effect, and regarding the co-efficients $a$, $b$, $c$, &c., as constant for any single day, but each subject to an annual periodicity, and as being, each of them, expressible under the same general form, substituting for $\theta$ the corresponding annual arc—for which, if we choose, we may use the sun's mean longitude. Thus each of the co-efficients of the diurnal formulæ,

$$a + b \,.\, \sin.\ (\theta + c) + b' .\ \sin.\ (2\ \theta + c') + \&c.$$

comes to be regarded as itself a periodical function of the form

$$A + B \,.\, \sin.\ (\Theta + C) + B' .\ \sin.\ (2\ \Theta + C') + \&c.,$$

$\Theta$ being the sun's mean longitude.

(147.) Every one of these co-efficients, whether diurnal or annual, generally considered, is dependent on the geographical position of the place of observation;

in other words, is the function of the latitude, longitude, and elevation above the sea-level of that place, which, being arbitrary and of unknown form, may be considered as embodying all the local peculiarities of whatever nature; and it is not until all these co-efficients are determined, or at least all which have an appretiable magnitude, for each meteorological element—in temperature, barometric pressure, tension of vapour, rain, &c., wind, and electricity—that the climate of the place can be said to be fully known.

(148.) Any one of these functions, though its analytical form may be quite beyond the reach of our inquiry, yet, by a sufficiently extensive and continuous combination of observation and calculation, carried on upon a system presently to be explained, may become known numerically, and tabulated for every accessible part of the globe; and being so tabulated, the points at which it has equal values may be laid down on a globe or chart. These points being connected by a continuous line, and this done for a succession of values, progressing by convenient and regular intervals in the scale of magnitude of the function, from the maximum which it has in any part of the globe down to the minimum which occurs anywhere; a series of level lines, or isometeoric lines (if we may coin a word to convey the general notion) will arise, which will present to the eye the progression and connection of this particular co-efficient over the world. Exactly as if wishing to convey, for instance, an idea of the exterior form of the solid surface of the globe, we should commence by delineating the coast-lines of the continents and islands, which are the level-lines for 0 ft. from the sea-level, and similarly laying down points wherever the height of 100 ft. above, or depth of 100 ft. below the sea occurred, and connecting them, should get the level lines of + 100 ft. or − 100 ft., *i.e.*, what would be the coast-lines were the sea to rise or sink 100 ft.; and so on, to the tops of the mountains and extreme depths of the ocean.

(149.) This mode of exhibiting to the eye by a picture (a picture which might become a model by executing it in relief) the law of variation of a function known only by observation, over the surface of the globe, or any particular district of it, was first devised by Halley to express the law of the variation of the magnetic compass, but first introduced into meteorology by Humboldt, to exhibit the law of distribution of temperature, by laying down a system of *Isothermic lines*, or those in which the *mean annual temperature* is alike throughout; that is to say, in which the coefficient, A, in the expression for the mean temperature of the whole year, viz., $A + B . \sin. (\Theta + C) + \&c.$, is constant; and which, therefore, serve to connect in idea, as places having at least one very eminent meteorological feature in common, all those points in the globe which receive (from whatever cause) the same annual total of heat. To these lines we shall recur hereafter. Climatology as a science (or rather as a branch of physical geography, to which, rather than to meteorology, it properly belongs), would be complete, or nearly so, if we possessed a complete atlas of such charts, each containing the isometeoric lines for all the really influential co-efficients, both annual and diurnal (which are not very numerous), exhibiting the mean values of each of the annual co-efficients from the observations of many years, and the mean values and annual maxima and minima of each of the diurnal ones. Hitherto only a few of such lines have been traced, and that imperfectly, viz., the lines suggested by Humboldt, or the *Isothermal, Isotheral* and *Isocheimōnal* lines, or those in which the *general* mean temperature, the mean *summer* temperature, and the mean *winter* temperature, are respectively constant; the *Isogeothermal* lines of Kupffer, in which the *mean temperature of the soil* is constant (and which are not always identical with the Isothermals), the Isobarometric lines of Kämtz, in which the limits of fluctuations of barometric pressure are equal (a series of which it is not easy to see the use), and a few others. We shall now proceed to consider by what means such knowledge can most readily and effectually be attained.

(150.) *Determination of Meteorological Averages and Co-efficients.*—The general form into which, as we have seen, every meteorological *quantitative* expression can be thrown, clearly indicates the system of observation which ought to be followed, so as to lead most directly to a knowledge of their mean values. It is a well-known property of the sine or cosine of an arc, that if the circumference be divided into any number, $n$, of equal parts, $\theta$, we shall have,

$$\sin. (\theta + c) + \sin. (2\,\theta + c) + \ldots\ldots \sin. (n\,\theta + c) = 0.$$

Suppose, then, we would ascertain the diurnal mean, $a$, of any element, E, supposed to be expressible as in art. 144. Were we sure that E contained only one periodical term, $b \cdot \sin. (\theta + c)$, it would suffice to make a series of observations at intervals of 12 hours, on summing up which, as the + and − values of this term would destroy each other, the sum divided by the number would afford the value of $a$. If an eight-hourly interval be substituted for a twelve, a like summation will eliminate the terms depending both on $\theta$ and $2\ \theta$; if a six-hourly one, those depending on $\theta$, $2\ \theta$ and $3\ \theta$, and so on. So far as meteorological computation has hitherto been carried, this would appear to be in most cases sufficient, the co-efficients of the successive terms diminishing rapidly. From a simple observation *per diem*, no average can be concluded, except it be made at such an hour as experience shews to be that on which the quantity observed has usually its mean value. This differs for each element and for each locality, and is itself a desirable item of meteorological inquiry.

(151.) Annual means may be obtained by summing diurnal ones. If the series be incomplete, two courses may be followed, viz., *1st*, By subdividing the year into monthly groups, calculating the means for each month from the observations recorded, and taking a mean of the twelve results; or, *2dly*, by striking out days corresponding to those deficient at 3- or 4- monthly intervals from each.

(152.) The *law of fluctuation* requires us to know the values of the several constants which enter into the periodical terms. To do this effectually from a series of recorded observations, requires the application of the "method of least squares." If the observations be numerous, and made at irregular hours, this is attended with a frightful amount of calculation; but if they form a regular series made at definite hours of the day, and either complete, for many days, or *capable of being completed by the insertion of the deficient observations according to any observed law of progression, or in the absence of such law, by a mean of the adjacent day's observations at homologous hours*, nothing can be simpler or more expeditious than the treatment of such a series by least squares, so as to give the most probable values of the constants. The following practical rule, the investigation of which is, we believe, originally due to Bessel, will give them:—

(153.) Suppose we have such a series of observations at epochs $\theta$, $2\,\theta$, $3\,\theta$,..... $n\,\theta =$ dividing any entire period into equal intervals, reckoning from and up to the end of the period, or any other convenient epoch. Let $S_1$, $S_2$, .... $S_n$ be the sums of the observed values, at homonymous epochs, throughout the series. Look out, in a table of sines and cosines, for the sines and cosines of $\theta$, $2\,\theta$, .... $n\,\theta$ converted into degrees at the rate of 15° per hour for the diurnal, or 30° per month for the annual fluctuation (or their logarithms, if we proceed logarithmically), and call the sines in succession $s_1$, $s_2$, .... $s_n$, and the cosines $c_1$, $c_2$, ... $c_n$, observing that $s_n = 0$ and $c_n = 1$. This done, compute the quantities $a_0, a_1, \ldots \ldots a_n, b_1, \ldots \ldots b_n$, by the following formulæ, in which N is the total number of observations at all the epochs :—

$$a_0 = \frac{1}{N}(S_1 + S_2 + \ldots . S_n)$$

$$a_1 = \frac{2}{N}(c_1 S_1 + c_2 S_2 + \ldots . c_n S_n)$$

$$a_2 = \frac{2}{N}(c_2 S_1 + c_4 S_2 + \ldots . c_{2n} S_n)$$

$$a_3 = \frac{2}{N}(c_3 S_1 + c_6 S_2 + \ldots . c_{3n} S_n) \text{ \&c.}$$

$$b_1 = \frac{2}{N}(s_1 S_1 + s_2 S_2 + \ldots . s_n S_n)$$

and so on. These will be the *most probable values*, respectively, of the co-efficients in the general expression of E under the periodical form,

$$E = a_0 + a_1 . \cos. \theta + b_1 . \sin. \theta + a_2 . \cos. 2\theta + b_2 . \sin. 2\theta + \text{\&c.}$$

which may then be transformed into

$$E = A + B_1 . \sin. (\theta + C_1) + B_2 . \sin. (2\theta + C_2) + \text{\&c.}$$

by taking $A = a_0$ ; $B = \sqrt{a_2 + b_2}$ ; tan. $C = \frac{a}{b}$..

(154.) In the practical application of this formula, it is not necessary that the number of the terms of which the final result E is to consist, should be pushed farther than necessity or convenience may require, and it is a peculiarly valuable property of these expressions, that if the approximation be stopped at any one term, as, for instance, at the term $B_1 . \sin. (\theta + C_1)$, and the co-efficients $B_1$ and $C_1$ be determined accordingly, then should it be considered afterwards desirable to carry it a term farther, so as to include the next sub-period expressed by the term $B_2 . \sin. (2\theta + C_2)$, it is not necessary to recompute the former co-efficients, their values remaining unaltered, so that the several sub-periodic terms are separately and independently calculable from any *complete* series of observations, just as if the others had no existence. And moreover, the constitution of the formulæ is such that any number of complete cycles of observation may be treated as a single cycle, by taking the means of the recorded observations at homonymous epochs, and thus forming from them a single cycle.

(155.) For example, supposing we have a series of *mean monthly* results, obtained during a series of years, for any meteorological element, such as temperature, and we wish to deduce from them the law of the annual fluctuation. In the first place, we take the mean of all the results for January as a new January mean, of February for February, and so on, and denoting their means so obtained in their order, by $S_1, S_2, S_3, \ldots . S_{12}$. If we wish merely to obtain the most probable mean annual temperature, we use the expression,

$$A = \frac{1}{12}\left\{ S_1 + S_2 + \ldots . S_{12} \right\}$$

If we would now carry the inquiry one step farther, and determine the amount of fluctuation regarding the curve of temperature as one of a single undulation, neglecting subordinate flexures and sub-periods, we retain the same value of A, and calculate $B_1$ and $C_1$ by the formulæ.

$$6\ a_1 = (S_1 - S_5 - S_7 + S_{11}) \cdot \cos. 30^\circ$$
$$+ (S_2 - S_4 - S_8 + S_{10}) \cdot \cos. 60^\circ$$
$$- S_6 + S_{12}$$
$$6\ b_1 = (S_1 + S_5 - S_7 - S_{12}) \cdot \sin. 30^\circ$$
$$+ (S_2 + S_4 - S_8 - S_{10}) \cdot \sin. 60^\circ$$
$$+ S_3 - S_9$$

$$B_1 = \sqrt{a_1^2 + b_1^2}; \qquad \tan. C_1 = \frac{a_1}{b}$$

And if we would now go on farther to investigate the semi-annual sub-period, or that depending on $2\ \theta$, we retain the means of A, $B_1$, $C_1$, already computed, and still using the same sums $S_1$, $S_2$, &c., go on to find $a_2$, $b_2$, and from them $B_2$ and $C_2$ by the formulæ,

$$6\ a_2 = (S_1 - S_2 - S_4 + S_5 + S_7 - S_8 - S_{10} + S_{11})$$
$$\times \cos. 60^\circ$$
$$- S_3 + S_6 - S_9 + S_{12}$$
$$6\ b_2 = (S_1 + S_2 - S_4 - S_5 + S_7 + S_8 - S_{10} - S_{11})$$
$$\times \sin. 60^\circ$$

$$B_2 = \sqrt{a_2^2 + b_2^2}; \qquad \tan. C_2 = \frac{a^2}{b_2}.$$

In applying which it will be remembered, of course, that as the means $S_1$, $S_2$, &c., belong to the middle of the months, the values of $\Theta$ corresponding to *them* are 30°, 60° &c., so that the commencement of the year from which $\Theta$ reckons, is, in effect, placed in the middle of December. If we reckon the time, then, from the beginning of January, this amounts to putting $\Theta + 15^\circ$ for $\Theta$; or, retaining the same values of the co-efficients A, $B_1$, $B_2$, &c., increasing $C_1$ by 15°, $C_2$ by 30°, &c.

For the third term, the co-efficients are still more simple in their expression, viz.,

$$6\,a_3 = -S_2 + S_4 - S_6 + S_8 - S_{10} + S_{12}$$
$$6\,b_3 = +S_1 - S_3 + S_5 - S_7 + S_9 - S_{11}$$

(156). The application of the formulæ is equally simple and easy in every other case; and, in fact, such is its facility, that it leaves no excuse to meteorologists for not reducing their observations, and should act as a powerful recommendation to induce them, in all cases, to conform to its requisitions in arranging the times of their observations.

(157.) All that depends on regular periodic action may be represented in this manner by periodic functions, the co-efficients of which, as determined by observations for any place, embody the resultant of the mode in which the action is propagated to the place. Each of them is therefore, no doubt, inherently a function of the latitude and longitude of the place, but one complicated with and dependant on the whole geographical system of the globe, as one of its data—the configuration of its land, the height and arrangement of its mountain chains, nay, even the depths of its seas and the form of their beds; since all these elements enter into the list of causes which determine the arrival of heat, wind, and moisture at the place.

(158.) It is the task of the practical meteorologist, each at his own station, to furnish his quota of recorded observation towards carrying out this great work—a task tedious, perhaps, and requiring, like all scientific operations, care in observing and precision of statement, but easy in itself, and full of interest at least to such as are able and willing to execute the reduction of their own observations, and thereby to furnish (so to speak) not merely a lump of material rude from the quarry, but a stone hewn and squared on the spot, and ready to take its fitting place in the general edifice. Having fixed on the range and scope of his observations, the instruments whose indications he proposes to record, and the hours at which his personal convenience, and the dependable means at his command will enable him to record them, all he has to do is to pay scrupulous attention to obviate everthing which may tend to derange the adjustment of his instruments, or affect the fairness of their exposure —to read them off accurately, and register the readings faithfully, and to adhere precisely to system in their reduction. It should be remembered, however, that no series of observations can be considered of any value for the determination of the *diurnal* co-efficients in which the twenty-four hours are not *equally* divided by the epochs of observation, and of comparatively little if they be fewer than four in number; the most advantageous hours for which, generally speaking, will be found to be 3 h. and 9 h. A.M. and P.M., or 4 h. and 10 h. A.M. and P.M., should the habits of the observer render the 3 h. A.M. observation very irksome.

(159.) To those observers, however, whose means will allow them to avail themselves of the resources which modern art affords, the principles of photographic and mechanical self-registry, which have of late been applied to all the most important instruments, affords an alleviation of all the tedium of personal attendance, and supplies what personal observation never can do —an unbroken record of the march of each instrument during the night as well as the day. On the occasion of a reward of £500, offered in 1846 by the Lords Commissioners of the Admiralty, for the discovery of an available application of photography for such purposes, two systems of procedure were devised and carried into effect by Mr. Brooke and Mr. Ronalds, the one at the Royal Observatory at Greenwich, the other at the observatory of the British Association at Kew, both of which have been found perfectly adequate to the object, not only of meteorological, but of magnetic self-registry. Without going into minutiæ (which the reader will find stated for the former system in the Introduction to the Greenwich Observations for 1847, and for the other in three papers published in the Transactions of the Royal Society for 1847), we may state the general principle of Mr. Brooke's method in few words, as follows:—Paper being prepared sufficiently sensitive to receive an impression from the light of an argand or camphine lamp by night, and the reflected light of the sky by day, is stretched between two rollers, so as to be wound on one and unwound from the other uniformly by clock-work, receiving, as it travels, punctures or marks made on it by an appropriate mechanism, at equal intervals of time, suppose hourly, and which, therefore, convert the space travelled over into a scale of time capable of being read off by a scale of equal parts, if necessary. The direction of the motion of the paper is perpendicular to that in which the indicating point of the instrument to be registered moves, whether that be the end of a column of mercury rising and falling (as in the stem of a thermometer, or in the tube of a barometer), on an index arm, capable of carrying a screen pierced with a hole to transmit a small pencil of light. If the former, the light is so arranged that *only the vacant part* of the stem or tube above the mercury shall allow a free passage for it to reach the paper, the shadow of the mercury cutting off all below. If the latter, the whole paper is shaded except that point which happens at each instant to be behind the hole. In the one case, the boundary of light and shadow is marked by a curve terminating the continuous photographic impression formed by the unrolling of the paper; in the other, the impression itself takes the form of a curve line, of which the ordinate indicates the reading of the instrument at the moment of time indicated by the abscissa. To facilitate the subsequent reading off of these curves, the graduation of the scale (in the case of the thermometer), is marked on the paper by the shadows of wires carried across the stem at each degree. In Mr. Ronalds' second or improved method, described in the third of the papers above cited, an image of the index point, terminal line of mercury, or other object which defines the reading of the instrument, is formed by an achromatic lens on the moving paper. One or other of these systems of self-registry, or some equivalent one, is, or ought to be, adopted wherever meteorological observation is caried on as a part of the regular business of a public establishment. Taken in conjunction with the mechanical self-registry of the anemometer, and with that by which the rain-gauge is made to empty itself whenever a definite quantity of rain is collected, and to record the number of such emptyings, and the weight of water it contains at each hour, the system of self-registry may be regarded as complete.

(160.) For the special reductions which each kind of instrument requires, the nature of its adjustments, and the precautions to be observed in its use, we must refer the reader to the descriptions of the several instruments in other parts of this work* under their proper heads; to the Admiralty Manual of Scientific Inquiry already referred to, and the report of the Royal Society on the occasion of Captain Ross' Antarctic Expedition in 1840; and to the former of these separate works for a detail of the particulars which a complete meteorological register ought to embrace, and the most convenient and advantageous form of statement it admits.

## OF THE DISTRIBUTION OF BAROMETRIC PRESSURE, AND ITS PERIODICAL FLUCTUATIONS.

(161.) The mean barometric pressure on any place is of course dependent on its height above the sea level, so that each locality has corresponding to it a certain individual correction or reduction to the

* This refers to the *Encyclopædia Britannica* in which this Essay originally appeared.

sea level, which affects equally all its barometric observations. When the level of the place is trigonometrically ascertained, the mean temperature of the station being known, this reduction may be exactly computed; and were it a fact that the mean barometric pressure at the sea level were everywhere the same, the height of every place might be determined from the mean height of the barometer as given by observation. This, however, is not the case. We have already seen (art. 54) that in the open ocean the pressure diminishes on approaching the equator from either side, as well as the reason for this diminution. But this is not all. The atmosphere is not in a state of statical equilibrium, nor are the forms of its strata of equal density identical (as they would be in that case) with the ellipsoids of equal level, for the very obvious reason, that the surface of a fluid in motion (even when unagitated by waves), is not necessarily and in all cases that of the same fluid at rest. The surface of a river, though smooth, is not a horizontal, but an inclined plane. That of a swift stream with an unequal bottom is not a plane at all, but a surface of ridges and depressions, fixed in place and permanent in form, as is seen in the familiar case of the ripple caused by a smooth round stone at some depth below the surface; hence we might be prepared to expect great differences between the surfaces of equal level and of equal density in the interior of extensive continents, where the atmosphere, swept *en masse* from the sea, up the gradual slope of the land surface, is lifted with all its strata preserving their relative bearings on each other: the extent of elevated country on all sides tending to prevent lateral overflow. Under such circumstances there may, or rather must, exist great discordances between the trigonometric and barometric determinations of altitudes (the only form in which the cause in question can make its appearance), and which, it may be remarked generally, go to render all barometric determinations uncertain in windy weather.

(162.) What may not, however, be so obvious, or rather what, when first proposed, appears quite paradoxical, is that, even in the open ocean, there exist extensive tracts in which a permanent *depression* of the barometer to the enormous extent of an inch and upwards (equivalent to an elevation of 800 feet above the sea level), is found to prevail. Such a tract is the whole extent of the Antarctic Ocean, from 63° to 74° S. lat., and 8° to 7° W. long. as ascertained by Sir James C. Ross (*Voyage of the Erebus and Terror*, ii. 376, 385); and a corresponding depression, though not to so great an extent, appears, by the observations of Ermann, to exist in the region nearly diametrically opposite, about the Sea of Ochotzk, and in the interior of the Asiatic continent of that neighbourhood.

(163.) It is impossible not to perceive, in these singular phenomena, at least a *prima facie* evidence of the existence of what must be regarded as a fixed system of ripples in the general atmosphere, caused by the great system of circulation in both hemispheres of the trades and anti-trades reacting on the general mass of the continents as obstacles in their path, and dependent for their depths and limiting forms on the configuration of the surface of the land. The progressive change of mean atmospheric pressure at sea, in proceeding from the equator southwards, is stated by Sir J. Ross as follows:—

| Lat. South. | Mean Pressure. | Lat. South. | Mean Pressure. |
|---|---|---|---|
| 0° 0′ | 29.974 | 51° 33′ | 29.497 |
| 13 0 | 30.016 | 54 26 | 29.347 |
| 22 17 | 30.085 | 55 52 | 29.360 |
| 34 48 | 30.023 | 60 0 | 29.114 |
| 42 53 | 29.950 | 66 0 | 29.078 |
| 45 0 | 29.664 | 74 0 | 28.928 |
| 49 8 | 29.469 | | |

(164.) For northern latitudes, the results hitherto collected run very irregularly. Meteorologically, however, this is not a cause [in so far as it can be taken as an account of the *whole* of the phenomena in question (*vide* § 171)], which would appear to be productive of any marked train of consequences. And in relation to the matter at present in hand, it goes only to show, that the first term of the periodic function expressing the barometric pressure is not an absolute constant, even for the ocean; but that it has to be tabulated and worked out by local observation into a system of isobarometric lines, carried indifferently over both sea and land, and, as regards the latter, distinct from the level lines. We are far, indeed, from any approach to the construction of such a system.

(165.) The periodic fluctuations of the barometer are annual and diurnal. The consideration of the former will enable us to form a neater conception of the mode in which the latter arise. When it is summer in one hemisphere it is winter in the other. Hence (See art. 78), the air generally incumbent on the heated hemisphere is dilated, and expands both upwards and laterally, not only by its own increased elasticity but also by the increased production of vapour. It therefore not only encroaches on the other hemisphere by lateral extension, but what is far more influential, flows over upon it. In order to perceive clearly the nature of the process, we must separate in idea the aqueous and aerial constituents of the portion of atmosphere so transferred. The generation of the former goes on in the heated hemisphere, and replaces, in part at least, the loss of pressure arising from the transfer of air, while in the other the excess of vapour so introduced is constantly undergoing precipitation, and is thus continually being withdrawn from the total mass, leaving behind it, however, to accumulate, the dry air which accompanied it. Thus, if we regard the total barometric pressure as subdivided into that of the dry air and of the aqueous vapour, and denote the former by P, the latter by V, we see that the dry pressure P is diminished in the hot, and increased in the cold hemisphere, without any countervailing action, while V is in process of increase from below by evaporation, and of diminution from above by overflow, in the former: and *vice versâ* in the latter. If, then, the observed barometric pressure at every point in either hemisphere be analysed by calculation into its two constituents, by taking account of the hygrometric state of the atmosphere, and subtracting from the total pressure P + V the portion V due to the amount of vapour present, the remainders ought to exhibit, as a general result, an excess of dry pressure P in the winter hemisphere over that in the summer.

(166.) So far as observation has hitherto gone, this result is perfectly corroborated, though unfortunately there are not yet accumulated sufficiently numerous and extensive series of observations in which the effects of the aqueous pressure can be duly separated from the dry. As examples, we shall select the series for the Indian stations, Calcutta, Benares, Seringapatam, and Poonah, calculated by Dove from the observations of Prinsep, Sparmann and Colonel Sykes, as compared with that at Apenrade from those of Neuber, and with the results obtained at the Meteorological Observatories of Prague, Toronto, and Hobart Town, V.D.L.

| Stations. | P, PRESSURE OF DRY AIR. | | | V, PRESSURE OF VAPOUR. | | |
|---|---|---|---|---|---|---|
| | Max. in | Min. in | Differ. | Max. in | Min. in | Differ. |
| | | | inches. | | | inches. |
| Calcutta ...... | Jan. | July | 1.019 | Aug. | Jan. | 0.551 |
| Benares ...... | Dec. | July | 1.244 | July | Dec. | 0.645 |
| Seringapatam | Jan. | June | 0.455 | May | Jan. | 0.217 |
| Poonah ......... | Dec. | June | 0.760 | July | Dec. | 0.435 |
| Apenrade ...... | Feb. | July | 0.450 | July | Jan. | 0.346 |
| Prague ......... | Dec. | July | 0.383 | July | Jan. | 0.285 |
| Toronto......... | Dec. | July | 0.271 | Aug. | Feb. | 0.380 |
| Hobart Town | July | Nov. | 0.218 | Feb. | July | 0.125 |

These differences are large quantities; but we see that as the maxima of P correspond in point of time with the minima of V, it is only their differences which constitute the total or observed annual fluctuation of barometric pressure.

(167.) Since, as observed (art. 165), the annual fluctuation of V is the result of an excess of supply over expense in one hemisphere, and of expense over supply in the other, it may very well happen that the annual fluctuation of V in certain localities may exceed that of P, and being in a contrary direction, may either neutralize the fluctuation of the gross pressure P + V, or convert it into one of an opposite character. This, however, is but rarely the case, and where instances of it do occur, as at Sta. Fé de Bogota, and Bangalore (*Kämtz*, ii. 299), they are for the most part readily enough accounted for by the influence of local peculiarities.

(168.) If we consider that in general the values of P and V, regarded independently, fluctuate in opposite directions, and hence the maximum of the one corresponds, or nearly so, in epoch with the minimum of the other, we shall easily see that, representing P by

$$P = A + B \cdot \sin. (\Theta + C) + B' \cdot \sin. (2\,\Theta + C') + \&c.$$

we shall have, at least approximately, for V an expression such as,

$$V = \alpha + \beta \cdot \sin. (\Theta + C + 180^\circ) + \beta' \cdot \sin. (2\,\Theta + \gamma') + \&c.$$

the value of C in the term $\Theta$ differing by 180°, while those in other terms (C′, $\gamma'$, C″, $\gamma''$, &c.) may or may not stand to each other in a similar relation—the only condition being, that they shall be such as to render the co-efficients B, B′, &c., $\beta$, $\beta'$, &c., all positive. The gross pressure P + V, then, will come to be expressed by the form,

$$P + V = (A + \alpha) + (B - \beta) \,.\, \sin.\, (\Theta + C) + M \,.\, \sin. \; (2\,\Theta + N) + M'' \,.\, \sin.\, (3\,\Theta + N') + \&c.,$$

Since $B' \,.\, \sin.\, (2\,\Theta + C') + \beta' \,.\, \sin.\, (2\,\Theta + \gamma')$ may always be reduced to the form,

$$M \,.\, \sin.\, (2\,\Theta + N), \;\&c.$$

(169.) Thus we see that the tendency of the cotemporary action of the two elements composing the gross pressure is, 1*st*, to produce a mean annual pressure $(A + \alpha)$ equal to the sum of the separate pressures; 2*dly*, to subdue the influence of the term depending on $\Theta$, by reason of the opposition of signs affecting B and $\beta$ in the joint co-efficient $B - \beta$; and thus, 3*dly*, to give a greater *comparative* influence to the terms depending on 2 $\Theta$, 3 $\Theta$, &c. Now it will be observed that a series thus constituted, of sines of $\Theta$, 2 $\Theta$, &c., when made to run through its whole period by varying $\Theta$ from 0 to 360°, will have only a single maximum and minimum when the co-efficient of sin. $(\Theta + C)$ is large in compa rison with those of the other sines, but when the contrary is the case, a double, or even triple or multiple maximum and minimum may result from such mutual relations among the co-efficients as may very easily occur. The principal terms nearly neutralizing each other by their mutual opposition, leave the general character of the law of periodicity of the compound effect to be decided by the relations *inter se* of the subordinate ones, and thus is explained, without prejudice to the general reasoning in art. 77, 78 (which remains true as regards the *form* of the atmosphere as disturbed by the sun's action), the fact, which appears on first sight in opposition to that conclusion, that the annual oscillation of the gross barometric pressure presents in a great many localities the phenomenon of a double maximum, or even a still more complex character. Thus, in Paris, to take a single instance, from a mean of eleven years' observations (1816-1826), the total pressure exhibits two maxima in January and in July, the former being highest, and two minima in April and October, the latter being the lowest (*Kämtz*, ii. 295).

(170.) The great length of time in which the efficient causes are acting in one direction, to produce the annual oscillation in question, admits of a very considerable fraction of the atmosphere to be transferred from hemisphere to hemisphere, and to allow a range in the values of P, for instance, to the large extent (as we have seen in the case of Benares) of nearly an inch and a quarter of mercury, partially neutralized by a fluctuation of more than half an inch of aqueous vapour. Thus the effects are brought out into prominence, in both elements, by the long-continued action of the causes; and thus, by the study in the first instance of the annual oscillation, we are led to an easy understanding of the perfectly analogous phenomena in the diurnal oscillations (or, as they have sometimes though in fact improperly been called, "atmospheric tides") which have a good deal perplexed meteorologists, but whose analysis, into what we have for convenience called wet and dry pressure, has happily been suggested by M. Dove as affording a rational explanation.

(171.) To simplify our conception of the diurnal oscillation, we will suppose the sun to have no declination, but to remain constantly vertical over the equator. The surface of the globe will then be divided into a day and a night hemisphere, separated by a great circle passing through the poles, coincident with the momentary horizon, and revolving with the sun from east to west in twenty-four hours. The contrast of the two hemispheres, both in respect of heat and evaporation, in this case will evidently be much greater than in that of art. 165, and therefore the dynamical cause, the motive force, transferring both air and vapour from the one to the other, will be much greater. But on the other hand, much less time is afforded for this power to work out its full effect, and long before this can be accomplished for any locality, the circumstances are reversed, and a contrary action commences. The causes, then, and the mode of their agency, are perfectly analogous, in the production, whether of the annual or diurnal oscillation; but in the former, the feebler acting cause is aided by the very much greater length of the period; in the latter, its superior intensity is in great measure neutralized by the frequency of its reversal. There is another consideration, moreover, which cannot be without a great effect in establishing a distinction between the two cases. By far the larger portion of the land is distributed over the northern hemisphere, and of the water over the southern. The former is more uniformly terrene, the latter more uniformly aquatic; and as, under the circumstances now considered, the transfer of air does not take place in the direction of meridians, but at right angles (mainly) to their direction, we should be led to expect that the amount of counteraction in the diurnal fluctuations of the dry pressure $p$ by those of the wet $v$, would be, generally speaking, very different in the two hemispheres, and that therefore the extent of fluctuation in the gross pressure $p + v$ would, generally speaking, present a corresponding difference. A sufficient amount of observation has not yet been accumulated to bring this conclusion to the test of experience; but we cannot help remarking that the very same cause (the excess of water in the southern hemisphere), acting according to the difference of conditions, ought, in the case of the annual oscillation, to result in an average uncompensated action on the dry air, urging it towards the northern hemisphere, and to its replacement, bulk for bulk, by vapour, which, being lighter than air, [is assuredly one, and it may be the most efficient] of the causes of the generally lower atmospheric pressure over the Southern Ocean—a certain percentage of the due proportion of dry air being *permanently* driven out and prevented from returning by the constant outflow of vapour. See § 164.

(172.) It ought to be observed, that the oscillations in question are only in appearance analogous to those of the oceanic tides. In the latter, the tide wave is merely a circulating form without any [bodily transfer to any great distance]. The sun's heating action on the atmosphere is not one which, destroying a portion of its gravity, tends to alter its form of equilibrium, but one which, leaving its gravity unaltered, tends to throw its strata by their dilatation, and by the introduction of vapour from below, into forms incompatible with equilibrium, and therefore necessarily productive of lateral movements. When anemometry is further perfected, we may expect to trace the influence of this chain of causation into a morning and evening tendency of the wind (on a long average of observation), to draw towards the points of sunrise and sunset, to compensate the overflow from off the heated hemisphere, which takes place aloft in the contrary direction.

(173.) *The diurnal oscillation of the barometer* is a phenomenon which invariably makes its appearance in every part of the world *where the alternation of day and night exists*, on reducing any considerable series of hourly observations, though in extra-tropical latitudes it is for the most part so overlaid by casual variations as not to be remarked in a single day. On the other hand, between the tropics, and especially in the equatorial regions, its regularity of progress is most striking. Thus Colonel Sykes remarks (*Phil. Trans.*, 1850) that, among many thousand observations taken personally by himself on the plateau of the Deccan (1825-30), there *was not a solitary instance* in which the barometer was not higher at 9-10 A.M. than at sunrise, and lower at 4-5 P.M. than at 9-10 A.M., whatever the state of the weather, &c., might be. Humboldt also observes (tom. i. p. 308):—"this regularity is such that, in the daytime especially, we may infer the hour from the height of the column of mercury without being in error on an average more than 15 or 17 min. In the torrid zone of the New Continent I have found the regularity of this ebb and flow of the aerial ocean undisturbed either by storm, tempest, rain, or earthquake, both on the coasts and at elevations of nearly 13,000 English feet above the level of the sea. The amount of horary oscillation decreases from the equator to 70° N. lat., where we have very accurate observations made by Bravais at Bosekop, from 0.117 in. to 0·016 in." Within the Arctic Circle however, the diurnal, for very obvious reasons, dies out, or rather merges in the annual oscillation.

(174.) Generally speaking, the diurnal oscillation presents the phenomenon of a double maximum. The epochs of the maxima are about 9 h. or 9¼ h. A.M., and 10½ h. or 10¾ h. P.M., and the minima at 4 h. or 4¼h. P.M. and 4 h. A.M. The fact that the barometer frequently, "both in summer and in winter, stands higher in the cold mornings and evenings than in the warmer midday," seems to have been first made matter of remark by Dr. Beale in 1666. In 1682, Messrs. Des

Hayes and De Glos observed that at Goree the barometer was usually lowest when the thermometer was highest, that it stood higher by night than by day, and that the daily depression (between the morning and evening maxima) exceeded the nightly. At Surinam the same phenomenon was noticed by an anonymous observer, and distinctly described in 1722. Towards the middle of the last century (1735-61), its existence at Quito, in the Antilles, in India, and at Sta. Fé de Bogota, was severally established by Godin. The observations of Humboldt as to the extreme regularity of its progression in equatorial America are corroborated by those of Colonel Wright in Ceylon. That the double maximum and minimum of its march really originates in almost all cases in the manner above explained, by the approximate destruction of the second term in the series

$$(A + a) + (B - b) \,.\, \sin.\ (\theta + C) + \beta \,.\, \sin.\ (2\,\theta + \gamma) + \&c.$$

owing to the opposite march of the dry and wet elements of the total pressure, has been put out of doubt by the calculations of Dove. Yet there are localities, as for instance at Bombay, in which even in the expression of $p$, the co-efficient of the second term is so small in comparison with the others as to give rise to the appearance of a double maximum in the dry pressure itself, and the mode in which this is accomplished is evidently referable to the more complicated local relations which arise from the juxta-position of land and sea under exaggerated circumstances of temperature and radiation, giving rise to alternating sea and land breezes—one minimum of the dry pressure being found to coincide with the greatest strength of the sea breeze, the other with that of the land breeze, and the maxima with the minima of force of the wind.

(175.) If we regard only the gross pressure $p+v$, the following table will exhibit the amount of its daily fluctuations above and below the mean value, as deduced from the calculations of Kämtz (ii. 254, &c.)—

| Place. | Latitude. | Morning Min. | Forenoon Max. | Afternoon Min. | Evening Max. |
|---|---|---|---|---|---|
| | | in. | in. | in. | in. |
| Atlantic Ocean | 0° 0′ | −0.056 | +0.069 | −0.045 | +0.045 |
| Pacific Ocean | 0 0 | −0.032 | 0.040 | 0.045 | 0.028 |
| Payta......... | 5 6 S. | +0.004 | 0.051 | 0.082 | 0.050 |
| Sierra Leone | 8 30 N. | −0.022 | 0.032 | 0.038 | 0.031 |
| Cumana...... | 10 28 N. | 0.022 | 0.043 | 0.050 | 0.037 |
| La Guayra | 10 36 N. | 0.023 | 0.054 | 0.048 | 0.029 |
| Callao ...... | 12 3 S. | 0.038 | 0.045 | 0.044 | 0.035 |
| Lima ......... | 12 3 S. | 0.071 | 0.065 | 0.067 | 0.050 |
| Pacific Ocean | 16 0 S. | 0.021 | 0.040 | 0.040 | 0.028 |
| Otaheite...... | 17 29 S. | 0.035 | 0.052 | 0.030 | 0.018 |
| Pacific Ocean | 18 0 N. | 0.020 | 0.034 | 0.044 | 0.027 |
| Calcutta...... | 22 35 N. | 0.017 | 0.052 | 0.038 | 0.018 |
| Rio Janeiro | 22 54 S. | 0.036 | 0.040 | 0.040 | 0.030 |
| Cairo ......... | 30 2 N. | 0.008 | 0.035 | 0.055 | 0.030 |
| Padua ...... | 45 24 N. | 0.004 | 0.012 | 0.014 | 0.007 |
| Munich ...... | 48 8 N. | 0.011 | 0.011 | 0.008 | 0.009 |
| Halle ......... | 51 29 N. | 0.006 | 0.013 | 0.012 | 0.005 |
| Abo ......... | 60 57 N. | 0.009 | 0.002 | 0.005 | 0.008 |

(176.) As examples of the application of the general form of expression in cosines of the sun's hour angle from noon, we shall subjoin only the values obtained by Kämtz by the method of least squares from the whole series of observations recorded for three of the above localities, viz., Payta, Callao, and Padua.

For Payta.

$$p + v = 29^{\text{in.}} \cdot 840 + 0^{\text{in.}} \cdot 050 \sin. (\theta + 203^\circ\ 2') + 0^{\text{in.}} \cdot 037 \sin. (2\,\theta + 153^\circ\ 43').$$

For Callao.

$$p + v = 29^{\text{in.}} \cdot 824 + 0^{\text{in.}} \cdot 099 \sin. (\theta + 180^\circ\ 59') + 0^{\text{in.}} \cdot 036 \sin. (2\,\theta + 171^\circ\ 6').$$

For Padua.

$$p + v = 29^{\text{in.}} \cdot 797 + 0^{\text{in.}} \cdot 005 \sin. (\theta + 183^\circ\ 46')\quad 0^{\text{in.}} \cdot 010 \sin. (2\,\theta + 135^\circ\ 59').$$

(177.) The stations in the foregoing table are (except in the cases of Munich, Halle, and Abo), at the sea level. On mountain stations, or at least on such as rise abruptly from that level, or from an extensive plain, there exists a cause of diurnal oscillation in the barometric pressure of quite a different nature from that above considered. The whole vertical column of air, from the sea level to the top of the atmosphere, being dilated by the increase of diurnal temperature, it is evident that in the hotter portion of the twenty-four hours, a certain portion of the air below the cistern of the barometer must be lifted above it, and *vice versâ* for the colder. The actual weight of air incumbent on the mercury at a fixed altitude above the sea level must thus be alternately varied in excess and defect of its mean amount, and the mercurial column balancing it must rise and fall accordingly. The effect of this cause (whose action is explained in art. 77, *a*), is easily calculable for any given elevation and diurnal change of temperature. Supposing that of the whole aerial column between the sea and the station uniform, and equal to the mean of the upper and lower, it is easily shewn that the effect in question will attain its maximum value at an altitude where the barometric pressure is one 2·7182818th of that at the sea level, *i. e.*, $11^{\text{in.}}$·03, corresponding to about 26,100 feet, and at this height the total diurnal fluctuation due to a change of temperature of 30° Fahr. would amount to the very considerable quantity $0^{\text{in.}}$·672. The effect at inferior elevations for 10° of diurnal oscillation of temperature is calculated in the following table :—

| Alt. in Feet. | Diurnal Oscillation for 10° F. | Alt. in Feet. | Diurnal Oscillation for 10° F. | Alt. in Feet. | Diurnal Oscillation for 10° F. |
|---|---|---|---|---|---|
| | inches. | | inches. | | inches. |
| 1000 | 0.022 | 6000 | 0.111 | 11.000 | 0.168 |
| 2000 | 0.043 | 7000 | 0.125 | 12.000 | 0.176 |
| 3000 | 0.062 | 8000 | 0.137 | 13.000 | 0.184 |
| 4000 | 0.080 | 9000 | 0.148 | 14.000 | 0.191 |
| 5000 | 0.096 | 10000 | 0.159 | 15.000 | 0.197 |

These quantities, when increased in the ratio of the actual diurnal changes of temperature, are quite large enough at any considerable elevation to overlay and mask the real diurnal oscillation, and ought therefore to be applied as a reduction to the sea level, whenever local circumstances are such as to render such reduction safe and possible, which is seldom the case. [We cannot therefore help recommending the special investigation of the laws of diurnal fluctuation at considerable altitudes, by direct observation, and as compared with those at the nearest sea level, to the attention of meteorologists, as a matter hitherto somewhat unduly neglected.]

## Diurnal and Annual Fluctuations of Temperature, and Climatological Distribution of Heat.

(178.) We have seen (arts. 11, 107) that moisture in the form of visible clouds, or even in that *excessively divided, yet unevaporated state* which is sufficient to injure the transparency of the atmosphere, and which must be confessed to belong to the yet unresolved problems of meteorology, produces absorption of the sun's rays, and the conversion of sensible into latent heat. The diurnal march of temperature, then, in the general atmosphere is intimately connected with its hygrometric state, and especially with its degree of *relative* dryness, *i. e.*, its more or less near approximation to a state of saturation. And for the same reason that the heat of the day is mitigated by the evaporation of the diffused moisture, so is also the cold of night by its deposition, and hence arises a phenomenon of very general prevalence, viz., that the difference between the daily and nightly extremes of temperature, or the extent of its diurnal fluctuations, is greater in summer than in the winter, or rather to speak more generally, and in language applicable alike to inter and extra tropical localities, in those seasons where the air is *relatively drier* or *moister*. In fact, it is evident that when the air is relatively dry, evaporation during the day is more active, and a larger portion of the incident heat becomes latent. On the other hand, as it is necessarily the dew-point which limits (at least approximately) the temperature of the lowest stratum of air at night (see art. 45), since in the act of condensation the vapour gives out its latent heat, and therefore so long as the supply is continued prevents its further depression; the farther removed from saturation the air is, the greater depression can be effected by radiation before that limit is reached. The near coincidence of the dew point with the lowest nightly temperature, at every season of the year, has been shewn by Anderson from observations made at Kinfauns Castle during the year 1815, and the calculations of Kämtz shew that the difference between the daily extremes of temperature is universally greatest in those months of the year when the relative dryness of the air is the greatest.

(179.) In India, again, where, properly speaking, there cannot be said to exist a winter, the moist and cloudy season is that in which the least diurnal fluctuation of temperature occurs—a circumstance sufficient of itself to shew that it is not merely to the difference in the lengths of day and night, or to the low altitude of the sun in winter that the phenomenon in higher latitudes must be attributed, since between the tropics these causes can have but little influence. The east and west coasts of Ceylon exhibit in this respect a pointed contrast. At Colombo, on the western side of the island, the least diurnal change of temperature takes place in July, and the greatest in January, the rainy season being that of the S.W. monsoon, when the sun is north of the equator; while at Trincomalee, on the eastern side, the reversed conditions as to moisture obtain, accompanied with a corresponding reversal in the extremes of temperature.

(180.) The uniformity of temperature which prevails at sea, and the greater general uniformity of an insular as contrasted with a continental climate, has already been noticed (art. 40), and is at least partly referable to the same cause, viz., the alternate conversion of sensible into latent heat, and *vice versa*, by the evaporation and condensation of moisture disseminated through the atmosphere during day and night, in addition to the causes there enumerated. In consequence, in the neighbourhood of the sea, on an average of the whole year, the twenty-four hours are unequally divided into the hotter and the colder portions; that is to say, those in which the temperature is above, and in which below the mean—the comparative shortness of the hotter portion being compensated by a greater absolute elevation of temperature, and the length of the colder by a less absolute depression.

(181.) The foregoing considerations sufficiently shew how vain would be any attempt to conclude even an average of the progression of daily temperature, *a priori;* setting out with a knowledge of the declination of the sun and the latitude of the place, and thence calculating the amount of heat received even in a calm atmosphere. Observation only can lead to any just conclusion, and the general process indicated in art. 150 must be resorted to, leaving to subsequent theoretical enquiry the difficult (indeed at present impracticable) task of assigning to direct solar and terrestrial radiation, moisture, and wind, their share in producing the final result. As instances, however, of the kind of results which are attainable in this direction, we shall here set down the formulæ for the mean diurnal temperature, calculated by Kämtz from the hourly observations of Chiminello at Padua, and those instituted by Sir David Brewster, at Fort Leith, near Edinburgh, viz., for Padua—

$$t = 56^\circ.75 + 4^\circ.79 \text{ sin. } (\theta + 51^\circ.47') + 1^\circ.00 \text{ sin. } (2\theta + 66^\circ.33') + 0^\circ.22 \text{ sin. } (3\theta + 233^\circ)$$

and for Fort Leith—

$$t = 48^\circ.24 + 3^\circ.03 \text{ sin. } (\theta + 44^\circ.43') + 0^\circ.43 \text{ sin. } (2\theta + 44^\circ.43') + 0^\circ.14 \text{ . sin. } (3\theta + 175^\circ.11').$$

(182.) It is a matter of much importance, in cases where a complete and continued series of meteorological observations cannot be obtained, and in sea voyages, where no lengthened stay is made at any one place, to ascertain the mean temperature approximately from the least possible number of observations. This may be accomplished in different ways, viz.—1*st*, By taking care to observe at those hours, or one of them, in which the temperature is habitually, exactly or very near its mean through the twenty-four hours, or at such hours as shall have the mean of their temperatures very nearly coincident with that of the day. Such hours are 4 A.M. and 4 P.M., or more conveniently 10 A.M. and 10 P.M. If four observations *per diem* can be made, these four epochs should be chosen in preference. *2dly*, By taking the mean of the maximum and minimum for the mean temperature. This, however, is a coarse and rude approximation, as is obvious on considering what has been above stated, art. 180, as to the greater length of time during which, at stations near the sea, and still more at sea, the temperature ranges below the mean than above it. Kämtz recommends (from a discussion of the observations at Padua and Fort Leith above mentioned) to employ the formula

$$m + \frac{M - m}{36}(5{\cdot}076 + x)$$

where $x$ is a variable co-efficient, fluctuating from 0·366 in December to 0·560 in August; and which may, for the purpose in question, be taken quite near enough at $0.44 . \sin. (\odot + 120°)$, $\odot$ being sun's mean longitude. The mean temperature of the day may also be very approximately obtained from three temperatures $t$, $t'$, $t''$, observed at 7 A.M., 2 P.M., and 9 P.M., by the formula

$$\frac{t + t' + 2\,t''}{4}$$

or if observed at 8 A.M., 3 P.M., and 10 P.M., from the expression

$$\frac{7\,t + 7\,t' + 10\,t''}{24}$$

(183.) The annual fluctuation of temperature is derived from the consideration of the consecutive values of the mean temperatures of each day, or of the constant co-efficient A in the expression of the diurnal temperatures, considered as a periodical function of $\Theta$, the sun's mean longitude; or, if we please, of the arc proportional to the time commencing from any given date. For simplicity we shall suppose, however, that the value $\Theta = 0$ commences on the 1st of January, so that $\Theta = 15^\circ$ corresponds to the middle of January, $45^\circ$ to that of February, &c., or rather to the exact days nearest the middle of each month, which divide the year into 12 equal parts. The monthly mean of temperature being obtained by taking the arithmetical means of the daily ones for each month, the annual formula

$$T = A + B_1 . \sin. (\Theta + C_1) + B_2 . \sin. (2 \Theta + C_2) + \&c.,$$

will be obtained, as in art. 155. The following values for a series of stations in order of latitude calculated by Kämtz, will serve as examples for extra-tropical latitudes:—

| Place of Observation. | Latitude. | Value of A deg. Fahr. | Value of B. | Value of C. | Value of B′. | Value of C′. | Hottest day. | Coldest day. |
|---|---|---|---|---|---|---|---|---|
| Enontekies ...... | 68°40′ N. | 26°.85 F. | 23.93 | 266°59′ | 1.92 | 404°21′ | July 26. | Jan. 20. |
| Upsal ............ | 59 48 N. | 41 .70 | 19.77 | 266 23 | 1.07 | 420 15 | July 21. | Jan. 16. |
| Christiania ...... | 59 54 N. | 41 .60 | 19.15 | 264 26 | 2.13 | 434 29 | July 20. | Jan. 17. |
| Manchester ...... | 53 29 N. | 47 .66 | 12.09 | 264 46 | 0.98 | 372 32 | July 27. | Jan. 12. |
| Paris ............ | 48 50 N. | 51 .44 | 14.48 | 266 13 | 1.39 | 344 31 | July 28. | Jan. 15. |
| Padua ............ | 45 25 N. | 54 .21 | 21.03 | 260 52 | 1.15 | 381 17 | July 26. | Jan. 15. |
| Turin ............ | 45 5 N. | 53 .00 | 20.08 | 267 41 | 1.81 | 343 41 | July 27. | Jan. 5. |
| Fort Sullivan ... | 44 0 N. | 41 .81 | 20.59 | 258 31 | 0.49 | 361 3 | July 29. | Jan. 24. |
| Rome ............ | 41 54 N. | 59 .87 | 14.64 | 260 21 | 1.23 | 386 14 | Aug. 1. | Jan. 16. |
| Fort Johnston... | 34 0 N. | 66 .60 | 15.19 | 265 31 | 0.49 | 408 20 | July 21. | Jan. 18. |
| Cape Town ...... | 33 52 S. | 66 .49 | 8.72 | {264 38 −180} | 1.28 | 357 43 | Jan. 6. | Aug. 4. |
| Abusheher ...... | 28 15 N. | 77 .06 | 16.89 | 262 47 | 1.57 | 352 20 | July 18. | Jan. 12. |

To which, as a further example, we shall add the expression of the annual variation of temperature at St. Petersburg, from the *Correspondance Meteorologique* of M. Kupffer, 1848, where the terms beyond the 3d order, though given in the original, are suppressed as insignificant, viz.—

$$\begin{aligned} T = 38^\circ{\cdot}73 &+ 23^\circ{\cdot}32 \,.\, \sin.\ (\Theta + 263^\circ\ 42') \\ &+ \ \ 0^\circ{\cdot}89 \,.\, \sin.\ (2\,\Theta + 115^\circ\ 27') \\ &+ \ \ 0^\circ{\cdot}39 \,.\, \sin.\ (3\,\Theta + 234^\circ\ 31') \end{aligned}$$

(184.) The general *coup-d'œil* of the annual progression of temperature afforded by these results is not a little remarkable. The values of C, upon which the epochs of the maximum and minimum and mean temperature mainly depend, are very nearly alike, and have but little reference to the latitude of the place, and as we see the epochs set down (those for Cape Town, whose latitude is south being reversed), all agree in placing the extreme of heat and cold nearly about the 26th July and the 14th January. The epochs of the mean computed from the formulæ offer a similar agreement; all fall within a very few days of the 24th April and 21st October. A general mean of the whole, which may be taken as a very near approximation to the law of annual temperature over at least the whole of the extra-tropical northern hemisphere, and probably also of the southern, may be expressed thus :—

$$\begin{aligned} T = A &+ \tfrac{1}{2}\,(M - m) \,.\, \sin.\ (\Theta + 263^\circ\ 54') \\ &+ \tfrac{1}{30}\,(M - m) \,.\, \sin.\ (2\,\Theta + 23^\circ\ 46') \end{aligned}$$

Where M and $m$ are the maximum and minimum respectively of the mean diurnal temperatures (*Kämtz*, i. 126). As the co-efficient of the second term is 1-15th that of the first, which is the precise fraction by which the intensity of solar radiation fluctuates by reason of the change of the sun's distance—this might almost lead to a surmise, that the semi-annual term has its origin in this cause (since it is obvious that it cannot have a purely local origin). In effect, if we consider the simple expression, $T = A + B . \sin. (\Theta + C)$ as varied by regarding A and B (which are evidently proportional, *cæteris paribus*, to the force of direct solar radiation) each to be variable by reason of the varying proximity of the sun, and to be represented respectively in general by $A + a . \sin. (\Theta + \alpha)$ and $B + b . \sin. (\Theta + \beta)$; A and $\beta$ being still the *mean* values of these co-efficients in a whole revolution, the expression for T will become

$A + a . \sin. (\Theta + \alpha) + B . \sin. (\Theta + C) + b . \sin. (\Theta + \beta) . \sin. (\Theta + C)$, which is reducible to the form

$$M + N . \sin. (\Theta + n) + \frac{b}{2} . \sin. (2 \Theta + p),$$

M, N, P, $n$, $p$, being constants. This cause, then, would in fact introduce a term depending on $2 \Theta$, or having a semi-annual period, into the ultimate effect of the sun, and proportional to the eccentricity of the earth's orbit. We are quite ready to admit that this reasoning is not very strict, but the coincidence is a remarkable one, and it is rather thrown out as a surmise than as a demonstration.

(185.) Between the tropics, however, other and powerful causes, having obvious reference to geographical situation, tend to increase the semi-annual term, depending on 2 ⊖, and by rendering it more nearly comparable to that depending on ⊖, disturb the regular increase and decrease in a very marked manner. Not only does the sun between the tropics pass twice a year through the zenith of each station, but the interception of his beams by cloud during the afternoon at least of almost every day in the wet season, the descent of a large quantity of cold rain from the upper regions of the air, and its evaporation from a heated soil, all go to disturb the simple law of increase and diminution of heat with the sun's meridian altitude and the length of the days, which moreover vary but little in these regions. Owing to these causes, then, the heat in those regions near the tropics where a rainy monsoon prevails, instead of continuing to increase as the sun becomes more nearly vertical, so as to produce a burning summer, remains nearly stationary, and even in some localities undergoes a slight depression, thus producing a double minimum with the progress of the rains, while in others, where this cause does not act, no such duplication takes place.

(186.) To determine with precision the mean annual temperature of a place requires the accumulation of many years' observation. This is abundantly shewn by comparing the results obtained in successive years for a long period, wherever records exist of a dependable character, which can hardly be said to be the case, however, earlier than the year 1770, owing not only to absence of due care in ascertaining the zero points, and verifying the scales of thermometers, but also to the want of sufficient attention to circumstances of exposure, &c. Where, however, such records do exist, it is found that differences to the extent of two or three degrees of Fahrenheit in the means for individual years from a general mean of the whole occur. Thus in a series of annual temperatures deduced by Mr. Glaisher from the records kept at the Royal Observatory at Greenwich, during the 85 years elapsed from 1771 to 1855 (both included), we find the extremes of cold and hot years to be respectively 51°.3 and 45°.1, differing by 6°.2 *inter se*, and 3°.1 each from the general average. So also in the series of mean temperatures for Manchester for 25 years from 1794 to 1818, derived by Dalton, we find a variation of 5° F. in hot and cold years; and in a similar series for Paris, as deduced by Bouvard from the records of the Observatory of that city for 21 years, nearly as much. Such differences might be expected when we consider the exceedingly variable influence of winds and cloudy and rainy seasons; and the differences, moreover, from year to year, succeed each other with great irregularity, so that it becomes exceedingly difficult to form any judgment as to the existence of a law of periodicity in this respect. The observations of Mr. Luke Howard, indeed, in the neighbourhood of London, have led him to suspect a decennial period of fluctuation; and the records of the Greenwich Observatory above mentioned, shew a marked tendency to a regular increase and diminution, with a period of 14 years from minimum to minimum; but these two results partly contradict each other, and, so far as other similar records have been examined, no distinct conclusion on the subject would appear to have been arrived at. We shall not long, however, remain in ignorance on this point. Multiplication of stations, in which normally accurate observations are made, will furnish data in 15 or 20 years fully competent to decide the question; since any cause of a general or astronomical nature (such as that alluded to in art. 7) must of necessity make its appearance on the comparison of a great many stations, in the lapse of a single period, quite as evidently, indeed more so, than at one and the same station in the lapse of many.

(187.) As the mean annual temperature at any place is a very important element in its climatological relations, it is desirable to point out means by which it may be obtained with the least possible amount of observation and registry by residents whose avocations will not allow them to perform a complete series of meteorological observation. From what has been said (art. 184), it will easily be collected that from observations of the daily temperature from a week before to a week after the 24th April and the 21st October, in any part of the world beyond the tropics, will afford a certain approximation to the temperature in question; so will also a mean between the extreme temperatures (similarly observed at about epochs of maximum and minimum, January 14 and July 26). Another method consists in deadening and weakening the effect of casual diurnal fluctuation by recording twice in the 24 hours, at 12 hours' interval, the readings of a thermometer with a long stem, having the bulb and lower part of the stem packed in a tin box of dry sand or saw-dust, but otherwise fairly exposed. A few days' attention to such a thermometer will shew at what interval beyond the hottest and coldest times of the day its indications attain their maxima and minima, the means of which will give very nearly indeed the mean diurnal temperatures. The enclosure of a maximum and a minimum self-registering thermometer in a large cask of dry sand, which might be opened and read off twice a year, would also probably afford a very accurate mean result.

(188.) From what is said in art. 39, it is evident that the temperature of the soil at some considerable depth below the surface will never vary greatly from the mean annual temperature of the air, and that therefore the temperature of the last-drawn portions of large quantities of water, freshly drawn from deep closed wells, or that of copious perennial springs, which there is reason to believe do not rise from any very great depths (and so bring up the higher temperature of the interior of the earth), or descend from much higher land in the neighbourhood, will also afford a considerable approximation. At four feet deep the mean temperature of the soil in extra-tropical regions may be considered as attained about the 10th of June and the 6th of December, at which times, therefore, its observation will give nearly the yearly mean temperature. Boussingault states that under the equator it is sufficient to observe the temperature of the soil at that or even a less depth, at any time, to obtain a very near approximation to this element.

(189.) As this element of all other meteorological data is that which it is desirable to obtain with the greatest precision, it is necessary to be on our guard against receiving, as final, results so obtained. The temperature of the soil is necessarily influenced by that of copious rain, which brings with it the temperature of the upper strata of the atmosphere, and carries it rapidly down below the surface, in a very different manner from that of sunshine, nocturnal radiation, or aerial conduction. Where the rains are distributed with tolerable equality over the year, the aberration of the mean temperature of the soil from that of the air from this cause is not likely to be material. But it is otherwise where the reverse of this condition prevails. Thus Smith found, in Congo, the temperature of a well 100 feet deep 73° F., being 5° below the mean temperature of the place of observation. Again, when the earth is long covered with snow, which during its melting preserves a uniform temperature of 32°, and while unmelted, greatly impedes the free communication of heat between the air and the earth, it cannot be that the same law of the downward propagation of temperature should be followed as if the same amount of water had fallen in a liquid form. M. Kupffer has constructed a series of lines analogous to Humboldt's isothermal lines, which he terms isogeothermal lines, and which connect the points at which the mean temperature of the soil is constant, thus forming a series of curves for 0°, 5°, 10°,... as far as 25° Cent. These are by no means coincident with the isothermal lines of the same temperatures. Thus, for instance, the two curves for 10° C., which coincide over the southern part of England, begin to diverge where they enter on the continent of Europe, —the isogeothermal curve deviating northwards in its eastern progress, until at a point in Asia, about half way between the Baikal Lake and the Caspian Sea (or in lat. 50°, long. 80° E.) it meets the isotherm of 5° C., thus indicating a difference of 5° C. = 9° F. between the air and soil; and again, at a point north-east of Petersburg, in lat. about 63°, long. 40° E., a similar encounter between the isotherm of 0° (32° F.) and the isogeotherm of 5° (41° F.) takes place.* It is probable, however, that in most places where the soil is porous or gravelly, and where well-water is not found but at some considerable depth, the temperature of the soil at three or four feet deep under an area extensively roofed over and well drained around, and where no artificial temperature is kept up (and in cities many such may be found), a very exact annual temperature might be obtained.

(190.) But it is rather to careful observations of the temperature of the equatorial seas (according to a suggestion of Arago) at a few feet below the surface that

* We are bound to state what we find recorded, but we must confess that such results appear to us hardly credible.

we should look for normal results, capable of being compared from year to year with a view to bring into view any secular or periodic change of mean annual temperature. There are vast regions of the Pacific where, "over thousands of square miles, a wonderful uniformity of temperature prevails," and where both the diurnal and annual fluctuations are reduced within exceedingly narrow limits. In these, therefore, the accumulation of observations during voyages made with instruments *really* dependable, and executed with *really* scientific precautions, would very soon put us in possession of some decisive conclusion on this most interesting point.

(191.) The influence of the alternate annual approach and recess of the sun, consequent on the eccentricity of the earth's orbit, to produce an annual fluctuation of the *mean temperature of the whole earth*, has been shewn in art. 12 to be *nil*. But Prof. Dove has shewn, by taking at all seasons the mean of the temperatures of points on its surface diametrically opposite to each other, that the *average temperature of the whole earth's surface* in June considerably exceeds that in December. This is owing to the great excess of land in the northern and of water in the southern hemisphere, which gives to the general climate of the former more the character of a continental, to the latter more that of an insular or oceanic one (art. 40). Suppose A and *a* to be the summer and winter average temperatures in the former, and B and *b* in the latter. Then the summer falling in June in the northern, and in December in the southern, the June temperatures in both will be A, $b$, and their mean, or the average June temperature of the whole earth, $\frac{A+b}{2}$. Similarly the average December temperature will be $\frac{a+B}{2}$, and the difference, or (June —December) will be $\frac{A+b}{2}-\frac{a+B}{2}=\frac{A-a}{2}-\frac{B-b}{2}$, which is a positive quantity, because the fluctuation $A-a$ is (for the reason assigned) greater than $B-b$.

(192.) The best general idea of the distribution of heat over the globe is to be gathered from a chart of the isothermal lines; and as the limits of this article forbid our entering into any detailed account of a subject which properly belongs rather to the department of physical geography, we shall content ourselves with referring to that given in Plate II. The curves about the north pole bear no inapt resemblance (as remarked by Sir David Brewster) to the isochromatic lines, or coloured sphærolemniscates exhibited by polarized light in a biaxal crystal, whose optic axes are inclined to each other about 30°, having the pole itself almost centrally situated between them, and their line of junction nearly coincident with that diameter of the polar basin which bisects it and passes through its two great outlets into the Pacific and Atlantic oceans—a most remarkable feature, strongly indicative of the absence of land, and of the prevalence of a materially milder temperature (possibly not averaging below 15° F.) at the actual pole. Of the point or points of maximum cold in the southern hemisphere we know nothing.

(193.) The general equation of the optical curves in question is,

$$\sin.\ \theta\ .\ \sin.\ \theta' = T.$$

T being a number expressing what is called in optical language the *order* of the tint exhibited (and which varies in arithmetical progression, on passing from one curve to another in succession of the same colour) and $\theta$, $\theta_{\prime}$ the distances of any point in one and the same curve from the two poles respectively. Thus in fig. 7,

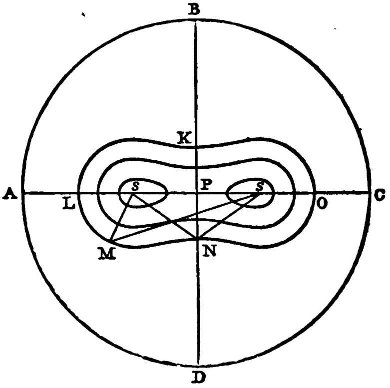


Fig. 7.

S and S′ being the poles, P the middle point between them, A B C D the *optic equator* of the polarizing crystal, A P C, D P B meridians, the one passing through S S′, the other at right angles to it, and M N any one of the isochromatic curves of the order T, we shall have S M = $\theta$, S′ M = $\theta'$. There can be no doubt then, from the general resemblance of the two sets of curves that supposing a mean temperature thermometrically indicated by T to prevail at any point, M, in north latitude, a curve K L M N O traced by calculation from the equation $a$ . sin. $\theta$ . sin. $\theta' = T - \tau$ ($a$ being some certain numerical constant independent of $t$), would approximate at least in some rude and general way to the isothermal line corresponding to T. Suppose this done for temperatures varying by *equal thermometric intervals* and a series of curves so drawn. It is obvious, then, that these curves, in respect of their magnitudes, distances from their foci and the pole P, as well as in their general gradations of flexure, will coincide, or nearly so, with a series of isochromatic curves *equidistant in their orders of tint.* Now, this latter series will divide the meridians B P D and A P C, in a succession of points distributed over them, not at equal differences of distance from the pole P, nor alike in the two meridians, but following a certain law of progression in each. Let us inquire what this law is; and to begin with the meridian P D, passing through the poles:—Take $\lambda$ = A L, the latitude of L, then, for the values of $\theta$ $\theta'$ corresponding to the point L, we have $\theta = 90° - (c + \lambda)$ and $\theta' = 90° - (c - \lambda)$ and therefore

$$T - \tau = \text{sin. } \theta \text{ . sin. } \theta' = \text{cos. } (c + \lambda) \text{. cos. } (c - \lambda)$$
$$= \frac{a}{2}\left\{ \text{cos. } 2\, c + \text{cos. } 2\, \lambda \right\}$$

or, which comes to the same thing, putting $\gamma = 90 - c$ ($= 75°$, since $c = 15°$ or thereabouts).

$$T - \tau = a\ (\cos.\ \lambda^2 - \cos.\ \gamma^2)\ .\ .\ .\ (1)$$

Now it is remarkable that this is precisely the form in which Mayer endeavoured to express empirically the decrement of temperature in proceeding from the equator towards the pole, from such observations as could be obtained about the middle of the last century, and which has been adopted by Kirwan and most other meteorologists since his time with various more or less successful attempts to assign values to the constants $a$ and $a\ .\ \cos.\ \gamma$ (regarded as a single co-efficient). M. Kämtz, who has taken vast pains to combine by the method of least squares, the mean temperatures on different meridians, so as to afford the most probable value of the co-efficient of Mayer's formula $a.\ \cos.\ \lambda^2 + \beta$, assigns for the meridian now under discussion, running from Melville Island through the interior of the American continent, as the centigrade reading of the mean temperature $T = 56°\ 77' + \cos.\ \lambda^2 - 21°.56$, which it is obvious agrees with our equation (1) by a proper assumption of $a$ and $\tau$. On the prolongation of this meridian on the other side of the pole, the stations are too few in number and probably too loosely determined to afford any satisfactory comparison.

(194.) Let us next consider the meridian BD at right angles to the former. Here we have for the point N, $\theta = \theta'$, and $a.\ \sin.\ \theta^2 = T - t$; but we have also $\cos.\ \theta = \sin.\ \lambda.\ \cos.\ c$, $\lambda$ being now the latitude BN reckoned on this meridian; so that our equation becomes in this case,

$$T - \tau = a.\ \cos.\ c^2 \left\{ \cos.\ \lambda^2 + \tan.\ c^2. \right\}\ .\ .\ (2)$$

which again agrees in its form with Mayer's formula. Comparing this with the formula (1), it appears that the co-efficients of cos. $\lambda^2$ in the two meridians are to each other in the proportion of 1 : cos. $c^2$, or about 100 : 93. The mean of the results obtained by Kämtz *in the northern portions* of the Atlantic and Pacific Oceans, compared with that similarly derived for the opposite meridian, gives 100 : 69 for the same ratio, which at least is so far satisfactory in the way of agreement, that the difference lies in the right direction. It will, of course, be understood that we have not the smallest intention of tracing any *physical* analogy between the two sets of curves, our only object being to point out the coincidence between them (which we do not remember to have seen before noticed), in respect of the arithmetical progression of temperature in the one series corresponding to that of chromatic sequence in the other, as something different from and additional to a mere general resemblance of form.

(195.) Another consequence of the general causes pointed out in arts. 37, 38 of the different habitudes of land and water as regards their reception and retention of heat, is the general law which appears to prevail in respect of the comparative severity of the winters and heat of the summers in the interior of the great continents of the northern hemisphere and on their coasts, and of the general mildness of climate on west coasts as compared with east, in the extratropical latitudes. The former is a very obvious result, and is strongly exemplified in the interior of Russian Asia. Thus

Tobolsk, Barnaoul, and Irkutsk, with summers in which the thermometer for weeks together attains 86° or 88° F., have winters in which the *mean* temperatures are from − 0° to + 4° F. Thus too, at Astrachan, the mean summer temperature averages 70° F., allowing the production of the most magnificent grapes in the open air, with a mean annual temperature of only 48°, that of London. At Kislar, at the mouth of the Terek, in 44° N. latitude, that of the south of France, the thermometer sometimes falls in winter to −22° F. It is to Leopold Von Buch that we owe the first notice of this remarkable contrast of climates, the subject of which has been extensively pursued by Humboldt, Schouw, and others. The other consequence is not so obvious. Where the prevalent winds (the anti-trades) blow from the south-west, they carry with them an oceanic temperature and an abundant supply of vapour (which, as we have seen, tends to equalize the extremes of temperature) to coasts having a westerly exposure, while, on the other hand, the same winds arriving on eastern coasts after passing over extensive continents, propagate forwards in that direction the extreme climates of their interior. Again, those winds which are incident on eastern coasts from the seaward side, having mainly a north-eastern character, bring with them the cold of a higher latitude. This latter effect is strongly felt on the east coast of our island, while the extreme mildness of the west coast of Ireland and the north-west coast of Scotland equally testifies to the powerful influence of the there prevalent south-westerly winds.

(196.) Before quitting the subject of temperature and its variations, we must notice a conclusion which has been supposed to be obtained by dividing the year into penthemers or portions of five days each (with one of six in leap years), and calculating from extensive series of observations the mean temperature of each penthemer. This task has been executed by Ofverbom for a series of fifty years' observations taken at the Observatory of the Academy of Sciences at Stockholm, and by Brandes for a great many other European stations from Petersburg to Rome. The results go to indicate two rather remarkable *hesitations,* or even slight retrogressions in the generally regular increment of temperature from winter to summer, viz., one about the 12th of February, the other between the 4th and 14th of March, the date being later as the station lies more to the south. Both would seem to be attributable rather to northerly or north-easterly winds setting in about those dates than to any general cause, though some speculations would go to assign them a very remote origin, and even to trace them up to a periodical partial obscuration of the sun by flights of meteors (!)

## Of the Periodical Fluctuations in the Hygrometric State of the Atmosphere, and of the Distribution of Aqueous Vapour on a large scale.

(197.) With exception of a few very limited regions in which fogs are habitually prevalent, and certain points here and there occurring in which rain is almost constantly falling, the general state of the atmosphere is one of more or less hygrometric dryness, so that, as a rule, evaporation may be considered as going on continually over the whole surface of the globe, being only interrupted where that surface is during certain hours of the night cooled by radiation below the dew-point. During these, the earth is actually abstracting moisture from the air, at all other times supplying it; but far more copiously during the day than the night. Meanwhile, the very highest regions of the atmosphere being from time to time drained of their moisture by precipitation, there is always a demand for vapour upwards, which (in the view we have taken of cloud, art. 107) is no way intercepted in its ascent by the existence of a region where it assumes for a while a visible form, and which can only be looked upon as a temporary halting place, the upper surface of the cloud evaporating while the cloud itself is renewed by condensation of the ascending vapour at the lower; unless, indeed, the radiation from the cloud itself should for a time so far lower its temperature as to suspend for a while or even reverse the process. (See art. 95.)

(198.) At the epoch of maximum cold, when the surface of the earth is at or near the dew-point, the hygrometric state of the air, to a considerable altitude, is near saturation, and frequently either a stratus cloud rests on the ground or exists at a much lower altitude than in the day, and when this is not the case, still the whole column of air, by reason of the general depression of temperature, is much nearer to its point of saturation than in the day time.

(199.) It is the practice of meteorologists to designate by the expression "humidity of the air," the degree of its approach to complete saturation with vapour, and to give precision to this language by attributing to that degree a numerical value, viz., the ratio of the quantity of vapour actually present per cubic foot, as calculated from the dew-point, or otherwise determined (art. 89), to that which would exist per cubic foot were the air saturated, or were the dew-point identical with the actual temperature. Thus a scale of degrees of humidity is formed, 1·00 being that of complete saturation, and 0 that of absolute dryness. In this sense of the word it will, of course, be readily understood that a low degree of "humidity" is compatible with the presence of a large quantity of aqueous vapour. It is not the vapour as such (which, while it exists as a gas, is, like other gases, "dry"), but its readiness to be deposited in a "wet" state on a surface but little lower in temperature, that is intended to be expressed. To obviate the discordance between this language and that of common parlance, the terms "relative humidity" and "relative dryness" are sometimes used.

(200.) As a general meteorological fact, however, there is not merely a want of accordance, but an actual opposition between both the diurnal and annual progress of the "degree of humidity" or "relative humidity" of the air and the "tension of vapour" as indicated by hygrometric observation—a seeming paradox, but one very easily explained. To take the case in hand—the diurnal variation—we have seen that at those epochs of the night when the temperature has reached its lowest point, and dew is either actually deposited or nearly so, the humidity is at its maximum. But it is precisely at that moment that the supply of vapour from the earth having been for several hours cut off, or even a reverse process in progress, while yet vapour has been diffusing itself into the non-saturated regions aloft, and is still continuing to do so, the actual amount of moisture per cubic foot is small, and is still in process of diminution. This epoch is usually a little before sunrise. As the day advances, the temperature increases, and becomes more and more in excess of the dew-point. The air, therefore, becomes relatively drier, evaporation goes on more rapidly, the lower strata become fuller of vapour, as measured by its tension, which at length becomes such as to keep pace with the upward diffusion, which now in its turn is stimulated. The cloud level, or vapour-plane, rises; and if the night has been clear, the air calm, the sun powerful, and the soil wet, the appearance of cumuli soon begins to render visible testimony to the nature of the process in progress. When the heat of the day has reached its maximum, this process is in its greatest activity. The "humidity" has now reached its minimum, and the evaporation, which is in the direct ratio of the temperature and relative dryness, its maximum. From this epoch, however, the supply of vapour from below being most copious, while the temperature no longer increases, it is evident that the humidity must begin to increase, while the tension also, for a longer or shorter time, will do the same, until by the decline of the sun the increase of humidity so far puts a stop to the evaporating process as to render it barely competent to supply the expense of upward diffusion, at which moment the tension becomes a maximum, and from which it also decreases, and continues to do so, the humidity increasing, during the remainder of the twenty-four hours until next sunrise, when the same cycle of causes and effects will recur.

(201.) Such at least will be their succession in calm and clear weather, and in a normal state of circumstances; and as regards the generally contrary march of the relative humidity as compared with that of the temperature and the vapour-tension, such is really the course of the phenomena. The epochs, however, and their order of priority, are obviously very liable to be disturbed by a variety of circumstances, among which the most influential are rain, winds (especially such as recur in daily periodicity, as sea and land breezes), and cloud which cuts off the sunbeams from the soil, and puts a stop to the increase of evaporation *before* the temperature has attained its maximum, thereby tending to bring the epoch of maximum tension towards coincidence with that of maximum heat. We find, for example, on comparison of the three elements in question, as derived from six years two-hourly observations at the Royal Observatory at Greenwich (1842-1847), the following results :—

| | Maximum. | Minimum. |
|---|---|---|
| Temperature, | 55°· 22 F. at 1h. 20m. P.M. | 44°· 85 F. at 4h. 10m. A.M. |
| Vapour-tension, | 0·345 in. at 1h. 20m. P.M. | 0·303 in. at 3h. 40m. A.M. |
| Humidity, | 0·938 in. at 4h. 30m. A.M. | 0·758 in. at 1h. 20m. P.M. |

Where it should be observed that the amount of cloud at Greenwich is a maximum at 0 h. 20 m. P.M., at which hour 73 per cent of the sky, on a general average, is covered, and a minimum at 9 h. 44 m. P.M., when 60 per cent of cloud prevails, the general average of the year being two-thirds cloudy. For other exemplifications of the same law, the reader is referred to the table of normal results in fixed observatories at the end of this article.

(202.) The annual march of humidity and vapour-tension as compared with that of temperature depends on the same principles, and is governed by the same laws; the humidity, however (as is also the case with the diurnal cycle), being much more regular in its progress than the vapour-tension, and the limits between which the latter element oscillates being much wider, as might be expected, from the greater duration of the cycle, and the consequently longer time given for the causes in action to work out their full effect before removal. Thus in Greenwich the annual maxima and minima, and their approximate epochs, as appears from the series of observations already referred to, are for the

| | Annual Maximum. | Annual Minimum. |
|---|---|---|
| Temperature, | 63°· 37 F. in July. | 34°· 20 Jan.-Feb. |
| Vapour-tension, | 0·466 in. in July. | 0 195 in. Jan. |
| Humidity, | 0·930 in. in Jan. | 0·783 in. June. |

(203.) *Of the general distribution of moisture through the atmosphere.*—Locally and temporarily, nothing can be more capricious than either the humidity or the vapour-tension, as we ascend into the higher regions of the air. Meteorologists, from Saussure and Deluc downwards, have sought in vain for anything like a regular law of decrement like that which at least approximately prevails respecting temperature. Mr. Rush relates that in his sixteenth ascent to the height of 19,440 feet in the Nassau balloon, June 29, 1850, with Mr. Green, they traversed a stratum of air 8600 feet in thickness, in which *absolute hygrometric dryness*, the zero of vapour-tension, existed. This must of course be received with some reserve; but it suffices at least to shew that in regions of the globe where cloud is the rule and pure sky the exception, masses of air are occasionally intermingled with the generally moist atmosphere, which would seem to have been all but absolutely drained of their moisture, either by long sojourn in the polar regions, or in the highest and coldest strata of the atmosphere. Meanwhile, at the ordinary levels, we know little at present of the average or *climatic* distribution of vapour. Of some things, however, we may be certain, viz., 1*st*, That on the open ocean, far from land, the dew-point, in the day time, can never be many degrees below the actual temperature of the air, and at night must always be very nearly identical with it. 2*dly*, That the mean vapour-tension in hot climates must necessarily be greater than in cold.

*3dly*, That, *cœteris paribus*, the relative humidity of the air must be a maximum over the sea, and a minimum in the interior of continents, especially where there is much sand, which allows the rain-water to sink, and which speedily dries at the surface: or much bare rock, which, never being more than superficially moistened, affords no supply of vapour to the air. For it is obvious that in such regions there must be less evaporation for an equal incidence of sunbeams; that therefore less of their heat will become latent, and their efficacy in heating the air will be in consequence greater, so that the temperature will rise in the day-time faster than the dew-point, and that in an increasing ratio; and, moreover, that from the very combination of these causes, there will be less tendency to the formation of cloud over such regions, and therefore a greater amount of direct sunshine thrown on the soil. Thus we have a system of mutually reacting causes and consequences (no uncommon arrangement in meteorology), all tending to exaggerate both the heat of the climate and its relative dryness: the only counteracting power being that of radiation, both diurnal and nocturnal, but especially the latter. Where, in addition to all these causes, those winds which blow from warmer regions or from tropical seas, before arriving over the place in question, have to pass over lofty mountain ranges, and have been chilled in so doing, and drained of their moisture, by the precipitation of snow or rain, it may well be imagined that a state of extreme relative aridity will prevail.

*4thly* and *lastly,* We may be very sure that the upper regions of the atmosphere (not only as being colder, and therefore incapable of retaining without deposition a quantity of vapour equal to that of the lower, but for the reasons assigned in art. 88) must be *habitually, and on a general average,* both absolutely and relatively drier than the lower: though the existence of cirrus cloud at very high levels (certainly sometimes exceeding 30,000 feet) sufficiently proves that even at such altitudes saturation with moisture occasionally takes place. During the sojourn of Mr. P. Smyth on the Peak of Teneriffe, the aridity of the air was found to be always excessive. On one occasion at Guajara (alt. 8843 feet) the depression of the dew-point below the temperature of the air was observed to be no less than 54° F., and on another, at Alta Vista (10,707 feet), 40°, the depression at the sea level being habitually about 10° in the middle of the day.

(204.) In actual cloud (although in the earlier history of hygrometry the fact was questioned, owing to the imperfection of the hygrometers used), both common sense and observation go to prove that the extreme point of humidity is attained, since where water is bodily present in every cubic inch of air, and refuses to disappear by evaporation, a state of absolute saturation must exist, just as in brine in which finely-powdered salt is suspended without solution we conclude a state of saline saturation. Hence we are led to some singular enough conclusions with respect to the law of decrement of *humidity,* as distinct from vapour-tension.

(205.) In the day time, so long as the sky is cloudless over any spot, it is evident that there is no point in the aerial column above it at which the dew point is surpassed, so that the supply of moisture from below is carried off by diffusion upwards, and it will depend entirely on the copiousness of this supply, and the rapidity with which it ascends into the higher regions, whether, as the day advances, the vapour-tension and humidity shall follow a contrary or similar progression. If the supply be abundant and borne up rapidly to a colder level, a cloud will be formed, and it is obvious that for some time before its actual visible appearance, the air in that region where it is about to be formed must be gradually approaching saturation, and attain it at the moment of deposition of the first molecule of water in a liquid state (and here we cannot help remarking, *obiter*, that it is utterly inconceivable how, under such circumstances, a *vesicle* should be formed). From the ground, then, up to the vapour-plane, wherever such plane exists, whatever be the law of vapour-tension, the humidity (perhaps with some interruptions in respect of regularity) continually increases up to 1·000, its natural limit, which it maintains through the whole thickness of the cloud stratum. This level passed the upper surface of the cloud *performs, to all intents and purposes, as regards the higher atmosphere, the office of a lake or sea,* being a thoroughly *wet* surface on which that atmosphere reposes. Henceforward, therefore, the law of decrement of moisture will be the same as it would be over the sea itself under the same circumstances of temperature and pressure. Nor does anything prevent (the sun striking on and evaporating it) why a second layer of cloud should not be formed again at a higher level, and so on—a phenomenon, in fact, of no rare occurrence. In such a case, if we take the height for an abscissa, as A B, the curve of humidity will be an undulating one, such as E F G H I attaining its maximum, 1·000 (= B F or C H) at F or H, and having a minimum between them as at G, while the

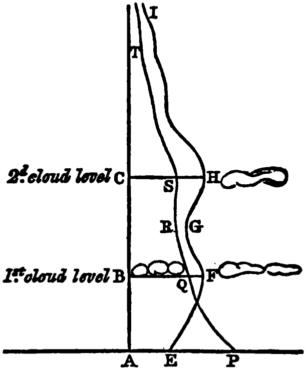


Fig. 8.

curve of tension P Q R S T follows a progression totally different—the relation between any pair of their respective ordinates, C H, C S, being that which subsists between the temperature, tension, and humidity generally, a relation expressible by the equation,

$$V = H \cdot \varphi\,(t)$$

where V is the vapour-tension, H the humidity, and $\varphi$

$(t)$ the function of the temperature $t$, which expresses the force of saturated vapour at that temperature (art. 92).

## Dependency of Atmospheric Pressure, Temperature, and Moisture on the Direction of the Wind. Dove's General Views of this Dependence.

(206.) There can be no doubt that by persevering and long-continued observation, the same laws of diurnal and annual periodicity will be found to be observed in the direction and force of the wind as in the other meteorological elements; but they are so much more masked by what we must at present term casual and accidental causes, that, except in certain great features (such as have already been described, art. 58, *et seq.*) and in certain geographical situations, they cannot emerge from the mass of overlying irregularities except in very long periods. The extreme mobility of the air, the powerful agencies at work to set it in motion, and the extensive propagation and prolonged duration of movements once communicated to an elastic fluid so constituted, all go to mix up, at each particular spot and moment, into one common resultant, motions which have originated at many very remote points, and at very different epochs. Along the coasts of heated continents, or even islands in tropical regions, indeed, the diurnal alternation of sea and land breezes is a result obvious enough of itself and confirmed by observation; and in the temperate zones, the approach of the sun to their respective poles is masked by a bias in the general direction of the wind towards an easterly, and its recess by one towards a westerly direction, the more marked the nearer the point of observation is to the exterior limit of the trade winds. But as regards the wind in general, it is found more advantageous to abandon this point of view, and to regard it, not in its remote connection with the general cause of periodicity, but in its immediate relation to the other meteorological elements with which it stands in more obvious connection.

(207.) The winds, which are originally caused by the equatorial heat and generation of aqueous vapour, or by extensive local agencies of the same kind elsewhere produced, act as their transporters from place to place, and as their distributors over the globe. It is, therefore, very obvious that a wind blowing with any degree of continuance and force from a lower to a higher latitude must bring with it to the latter both the superior temperature and moisture of the region it has left, and *vice versâ*. Thus in our latitude, a southwest wind is warm and moist, a north-east cold and dry. The excess of vapour in the former has a powerful tendency to form cloud in coming into a colder climate, and to be deposited in rain; the latter arriving with a low vapour-tension in a warmer region, absorbs both heat and moisture, clearing the sky of cloud, and, while depressing the temperature, gives that peculiar "bracing" quality which is the effect of a cold, dry air, in contrast with the "relaxing" influence of moist warmth. These effects are familiar to every one, and have been remarked from the earliest times. The general indication thus afforded has been, however, pursued into minute detail by M. Dove in his excellent work entitled *Meteorologische Untersuchungen* (Berlin, 1832), in which he has succeeded in exhibiting in a very distinct manner, by an extensive induction from observations in almost every region of the globe, the close and immediate dependence of all the three great meteorological elements, temperature, moisture, and atmospheric pressure, on the direction of the wind, or the point of the compass from which it blows. In other words, assuming $\theta$ to represent the angle which that direction makes with the meridian of the place (reckoned from the north or south according to the denomination of the elevated pole), any one of these elements, E, is found to be expressible, on an average or mean value during a whole year or series of years, by the equation of the form,

$$E = A + B_1 . \sin.(\theta + C_1) + B_2 . \sin.(2\theta + C_2) + \&c. \ldots (a)$$

(208.) The mode in which a law of this kind may originate is not difficult to understand. Suppose, 1*st*, the earth without diurnal rotation, and the sun to move round it from east to west, and at any given spot (suppose in the northern hemisphere) let a wind blow direct from the south with a certain force and during a certain time, this will bring over the place of observation the warmth and moisture of a latitude more southerly (suppose) by 10°. But now suppose a wind of the same force to blow for the same time, not from the south, but from the eastward or westward of south, at an angle $\theta^\circ$ with the meridian; the atmosphere of a place 10° remote, measured on a great circle, will be still transferred to the place, but owing to the inclination of its path, only $10^\circ \times \cos. \theta$ more south. If, therefore, the former wind brought with it an accession of temperature or moisture, represented by $e$, this will bring the accession $e \,.\, \cos. \theta$ proportional to the difference of latitude travelled over. It may happen, however, from the circumstances of the locality, that the warmest or moistest region in the neighbourhood may lie, not due south of the place, but in a direction making an angle $90^\circ - C$ with the meridian. In this case, then, the extraneous temperature, or moisture so induced, will obviously be represented, not simply by $e \,.\, \cos. \theta$, but by $e \,.\, \cos. (\theta + C - 90^\circ)$ or $e \,.\, \sin. (\theta + C)$.

(209.) The effect of the earth's diurnal rotation is to cause a wind setting in from the southward to veer more and more westerly the longer it has continued to blow, and from the northward more easterly, so that, to use M. Dove's expression, the direction of the wind belies the region from which it has travelled. The wind, therefore, which really reaches the spot in question from the most southern region (and which brings the greatest amount of extraneous heat and moisture) will not be a south wind on its arrival, but one having more or less of a westerly character, according to the latitude of the place and other circumstances of local resistance, and *vice versâ* for the opposite influences.

In so far, then, as the great equatorial and polar system of wind-currents is concerned, the general effect will be represented nearly by the formula,

$$e\,.\,\text{sin.}\ (\theta + C')$$

on a mean of every season and of every direction of the wind; and if to this be added the subordinate influences which may be propagated to the locality in question from regions nearer at hand than the equator, and which may each and all of them give rise to similar effects, represented by $e'$. sin. $(\theta + c')$, $e''$. sin. $(\theta + c'')$, the total effect, being the sum of all these, will, as is easily seen, be reducible to a single term of the general form, E. sin. $(\theta + C)$.

(210.) The effect of any wind in heating a place will evidently be proportional not merely to its excess of temperature, but to the quantity of air having that excess which passes over the place, and which has changed its latitude, that is to say, in the absence of any information as to its velocity, to the degree of frequency and duration of that particular wind. The co-effieient $e$, then, in the expression $e$. sin $(\theta + C)$ is dependent on this degree, which itself, in any given locality, is dependent on $\theta$, the north-east and south-west winds being most frequent, and the other winds rarer, in some definite relation to their duration. In other words, $e$ is a function of $\theta$, having two maxima, viz., for $\theta = 45°$ and 225°, and two intermediate minima, not necessarily at right angles to these. $e$, then may be conceived as generally capable of expression in some such form as $(e) + f \cdot \sin.(\theta + g) + h \cdot \sin.(2\,\theta + i)$, the combination of which with $\sin.(\theta + 45°)$, or $\sin.(\theta + C)$, will give rise to a set of terms containing the sines and cosines of $\theta$ and its multiples, with co-efficients depending on $(e)$, $f$, $g$, etc., and which are reducible, in their ultimate expression, to the general form in art. 146.

(211.) The dependence of the barometric pressure on $\theta$ in a similar form of expression is not so evident on these principles. But it must be remembered that a warm and moist atmosphere is lighter, bulk for bulk, than a dry and cold one, and that as the effect of a surface wind (at least of one of any continuance) is to transfer bodily the lower strata of the atmosphere of one place to another, so the barometer, apart from all other causes of periodical fluctuation, will vary in inverse correspondence with the temperature and moisture.

(212.) M. Dove, and after him Kämtz and others, following out in greater detail this train of inquiry, have come to very positive and distinct practical conclusions on all these several heads. In fact, it appears, as a general law, that in the "wind-rose," or compass-card, there are two points not far from diametrically opposite each other; the one in the neighbourhood of the N. E. point, the other in that of the S. W., from which when the wind blows, *on the long average*, both the temperature and the vapour-tension have their maxima and minima, the former at the N. E., and the latter at the S. W. The same, or nearly the same, points or poles of the compass-card indicate, reversely the minimum and maximum, of barometric pressure.

Particular localities shew deviations from each other and from the general and normal form of expression, both in respect of the precise situation of these "weather-poles" on the compass-card, and in their exact diametral opposition, as also in the situation of the intermediate mean position. On the whole, however, for each locality, and for each of the three elements in question, it is found practicable to represent its variation in terms of the azimuth $\theta$ of the direction of the wind, by the expression,

$$E = A + B_1 . \sin. (\theta + C_1) + B_2 . \sin. (2\,\theta + C_2)$$

in which $C_1$ is very nearly the same angle for all of them, and in which $B_2$ the co-efficient of the term of the second order, is found to be small in comparison of $B_1$, that of the first. And it is evident that the total barometric pressure $P + V$, and the vapour-pressure $V$, having both this form of expression, their difference $P$, or the pressure of dry air, will admit of a similar one by a proper determination of its co-efficients, which are easily deduced from those of its component elements by putting

$$\begin{aligned} &P_0 + P_1 . \sin. (\theta + C_1) + P_2 . \sin. (2\,\theta + C_2) \\ &+ V_0 + V_1 . \sin. (\theta + c_1) + V_2 . \sin. (2\,\theta + c_2) \\ &= P'_0 + P'_1 . \sin. (\theta + C'_1) + P'_2 . \sin. (2\,\theta + C'_2) \end{aligned}$$

where $P'$ represents the mixed pressure, and the several numbered and accented letters the respective co-efficients of the general formula, and which, reduced by the usual trigonometrical transformations, afford equations by which any one set of these values may easily be derived from the other two. It is evident, moreover, without any calculation of this kind (as M. Dove observes), that since the elastic power of the vapour has its maximum at the SW. point, where the *total* barometric pressure has its minimum, the dry pressure P must have its minimum there also; in other words, that $c_1$ being approximately $= C_1 + 180°$, $C'_1$ will be nearly identical with C.

(213.) Pursuing the inquiry still further, M. Dove finds, as indeed might be expected, that these co-efficients are severally and separately, like all meteorological local elements, periodical functions of the season of the year, or of the sun's mean longitude; and he has been enabled to assign for several localities their spring, summer, autumn, and winter values, his conclusions having been completely established, in their general expression, by all subsequent observation.

(214). It is sufficiently obvious, from the principle with which we set out (art. 208), that a similar series of relations ought also to subsist in the southern hemisphere, *mutatis mutandis;* that is to say, that the directions of the maxima and minima, instead of NE. and SW., will be SE. and NW., in conformity with the general law of the winds in the two hemispheres.

(215.) As an example of the results obtained in this branch of meteorological inquiry, we shall here set down the values of the co-efficients in the expression $E = A + B_1 . \sin. (\theta + C_1) + \text{etc.} \dots$ as calculated by Prof. Johnson from the series of meteorological observations made under his superintendence at the Radcliffe

Observatory at Oxford. These are (*Radcl. Obs.* 1854, p. xxvi.) for the

| | A | $B_1$ | $C_1$ | $B_2$ |
|---|---|---|---|---|
| Temperature T | 48°·60 F. | 2°·34 | 254°35 | 0 |
| Dry Pressure P | 29·404 inch. | 0·108 inch. | 75 33 | 0 |
| Vapour-Press. V | 0·307 inch. | 0·026 inch. | 259 39 | 0 |

where it will be noticed, that $180° + 75° 33' = 255° 33'$, and therefore, conformably to the theoretical views above delivered, the dry pressure has its minimum very nearly corresponding to the maximum of temperature and of vapour-pressure. Whenever, as in this case, which is the most common, the terms of the second and higher orders, are insensible or nearly so, the coefficient $B_1$ determines the maxima and minima, so that the respective values of 2 $B_1$ will express the total amount of fluctuation in temperature, pressure, etc., at the stations which have their origin in changes of wind.

(216.) It is very easy to perceive that with this dependence of the great elements of weather upon the direction of the wind, the other features which stand to them in the relation either of immediate consequences or proximate causes, must go hand in hand—such as cloud, rain, etc. For instance, at Karlsbad, from the calculations of Eisenlohr, it appears that, during the prevalence of SW. wind, 1 day out of 17.29 on an average only is free from cloud, and during that of NE.

1 out of 3·04, the intermediate winds being accompanied with intermediate degrees of frequency. So also for rain: 1 day out of 2·75 during SW., and one out of 11·92 NE.; the minimum of rain, however, here occurring with an E. or ENE. wind; stormy weather 1 out of 17·36 of SW., and 401·50 NE., clearly indicating the influence of the headlong down-rush of the upper equatorial current of the *anti-trades* in the manner indicated (art. 62).

(217.) Not less distinctly marked is the degree of frequency of each particular direction of wind in connection with the direction itself. Out of 40 places enumerated by Dove in every part of Europe in which sufficiently prolonged series of observations of the direction of the wind had been collected by him, 21 have a very large and decided predominance of days of west wind, 16 of SW., 2 only of NW., and only one (Kasan) SE. We have already seen (art. 83) that the prevalent wind in Europe generally is WSW. or thereabouts. After these, the other or inferior maximum occurs at E. in 18 places, NE. in 11, N. in 5, and SE. in 6, the average direction of this maximum being about ENE., so that the position advanced in art. 216 is fully borne out by observation.

(218.) At the end of this work the reader will find a table containing the mean, the maximum, and the minimum values (with their epochs diurnal and annual) of the principal meteorological elements obtained from the data afforded by the best and most systematically conducted series of observations, being for the most part those which have been carried on since 1840, in the magnetic and meteorological observations established by the British, Russian, American, Belgian, and other governments, and national and local institutions, on a concerted system of hourly or bi-hourly observation. They afford numerous and striking exemplifications of the laws explained above, and clearly shew their general applicability, especially as regards the contrary march, both annual and diurnal, of the humidity and vapour-tension; the greater range of the annual as compared with the diurnal fluctuations, and the dependence of the average amount of vapour present in the air, and the extent of both kinds of fluctuation on the latitude. It would have been easy to have covered our pages, indeed to fill volumes with climatological records and statements, such as the reader will find in Humboldt (*Asie Centrale*, vol. iii.), amassed by the diligence of Mahlman; in the more extensive collections of the latter and Prof. Dove, in the 4th vol. of the *Repertorium der Physik;* and in the Reports of the Senate of the University of New York to Congress; the *Correspondance Meteorologique* of the Russian observatories, &c. Not only, however, do the limits allowed us forbid the adoption of such a course, but we consider it more instructive to concentrate attention upon a few carefully determined and selected cases than to diffuse it over a larger field of bewildering particulars.

## Optical Phenomena of Meteorology.

(219.) I. *The Rainbow.*—The explanation of the rainbow, suggested by Roger Bacon, but only first clearly made out by Newton, is so familiar an illustration of the laws of coloured refraction in every treatise on optics, that we should not have thought of introducing it into this essay but for the vagueness of idea and misconception which are generally prevalent respecting the origin of the "supernumerary bows," *i.e.*, those coloured fringes which are often seen in the interior of the primary rainbow, and more rarely (on account of the comparative faintness of the whole phenomenon) at the exterior of the secondary rainbow. They have been explained by Dr. Young on his fertile principle of interferences, but his explanation (*Phil. Trans.* 1804) is so obscurely expressed, or rather indicated, as to be hardly intelligible, which is perhaps the reason why Kämtz, the most exact and industrious of reporters in matters of meteorological theory, while assembling all the other explanations which from time to time had been put forth by Pemberton, Venturi, Brandes, and others (some of them very absurd, and with none of which he appears to feel satisfied), passes this, the only correct one, in silence. Neither is it noticed by M. Pouillet in his recent elaborate *Elémens de Physique*, who in place of it, offers a surmise as to their origin which cannot be the true one, and which is refuted by an experiment of M. Babinet, which he cites in illustration. Mr. Coddington, in his treatise on reflexion and refraction, explains only the Newtonian Bows, his subject not extending to the phenomena of interferences, while Dr. Lloyd, in his treatise on light and vision, contents himself with mentioning the fact of their having been explained by Dr. Young, without giving the steps of the explanation. We shall not, therefore, scruple to devote some small portion of our allotted space to rescuing this very beautiful illustration of the law of interference from unmerited neglect.

(220.) Let $\theta$ be the angle of incidence of a solar ray on the surface of a spherical drop of water ($\theta$ being $0^\circ$ when the ray enters at the vertex next the sun, and passes diametrically through the drop, and $90^\circ$ where it just grazes its circumference), $\varphi$ the corresponding angle of refraction, and $\mu$ the refractive index for a ray of any given colour. $\mu$ being greatest for violet and least for red rays. Then shall we have sin. $\theta = \mu$ . sin. $\varphi$, and the deviation of the ray by refraction will be $\theta - \varphi$. If the ray be reflected internally after entering the drop, it is easy to see, by tracing its course within the sphere, that at each reflexion an additional deviation in the same direction of $180^\circ - 2\varphi$ will take place, and at its final emergence a further deviation (still in the same direction) equal to that at entering or $= \theta - \varphi$, so that the total deviation after $n$ reflections will amount to $n$. $180^\circ + 2\theta - 2\ (n + 1)\ \varphi$, which is a function of $\theta$ in virtue of the relation sin. $\theta = \mu$ . sin. $\varphi$; $(a)$. Now this function, which is $n$. $180^\circ$ when $\theta = 0$, diminishes as $\theta$ increases (since $\mu$ being nearly $\frac{3}{2}$, $2\ (n + 1)\ \mu$ is necessarily greater than 2), and continues to diminish until it attains a minimum, when its differential vanishes, or when $d\ \theta = (n+1)\ d\ \varphi$, which by eliminating $d\ \varphi$ by combining this with the differential of equation ($a$) gives

$$\sin.\ \theta = \sqrt{\frac{(n+1)^2 - \mu^2}{(n+1)^2 - 1}}$$

and for the case of the primary bow, where $n = 1$, $\sin.\ \theta = \sqrt{\frac{4-\mu^2}{3}}$ in which substituting for $\mu$ the exact refractive indices of the extreme red and violet rays for water, we find for the red rays $\theta = 59°\ 32'$, $\varphi = 40°\ 22'$, and $\Delta$ (the deviation) $= 137°\ 36'$, and for the violet the corresponding values 58° 46′, 39° 30′, 139° 32′. When the deviation is a minimum, the rays incident more and more remotely from the vertex of the drop, and which, up to that point, were dispersed at their emergence by their change of deviation, cease to be so, and emerge parallel. An eye, then, properly situated with respect to the drop will receive a parallel red pencil of rays in a direction 137° 36′ remote from that of the sun, and one of violet in a direction 139° 32′ remote from it; or in other words, at the angular distances 42° 24′ and 40° 28′ respectively, from the point of the heavens opposite to the sun, which are therefore the angular radii of the elementary red and violet rainbows.

(221.) So far the Newtonian explanation of the bow. As regards the fringes, if we put $D = 180° - \Delta$, it is evident that D will represent the deviation of the emergent ray, not from the direction in which the sun's rays *proceed*, but from that in which the sun is *seen*, and will therefore express the *dispersion outwards* of the emergent ray from the latter direction, and will be a maximum when $\Delta$ is a minimum. The parallel *pencil of rays*, therefore, by which the rainbow is seen, has the maximum angle of dispersion outwards from the sun, and all other rays at their emergence will have a less, whether their points of emergence be nearer to or farther from the vertex of the drop. For every such point, then, *more* remote from the vertex, it will be possible to find a corresponding point less remote, such that individual rays (*not pencils*) emerging from both shall have the same angle of dispersion; and which, of course, shall pursue parallel directions, and when incident on the eye shall be collected on the same precise point of the retina, and shall therefore be in a condition to interfere with, and destroy or reinforce each other, according to the difference of their total paths traversed both within and without the drop, before reaching the eye.

(222.) Let A B D be a section of the drop through the sun (in the direction C S from the centre C). Draw D E perpendicular to C S; and taking the principal focus for rays refracted at the convex surface E A D, let D G F be the caustic of the quadrant D A. Let S Q G *q*, be the course of the pencil of rays which emerges parallel along *q* M (as the drop's contribution to the rainbow), and taking any point P between A and Q, draw P *c* H, touching the caustic in H, and cutting the surface in *c*. Then will P *c* be the course of the refracted ray before, and *c p* after reflection, and *p* L its ultimate diversion on emergence. From *c* draw *c* K R touching the caustic in R. This will be the direction of another ray S R after refraction, and supposing *c r* to be its reflected course, the incidences of the rays *c p*, *c r*, on the one side of the sphere will be symmetrical to those of *c* P, *c* R, on the other, and therefore P S and R S (regarded as rays from *c* refracted outwards) being parallel to each other, *r* N and *p* L,

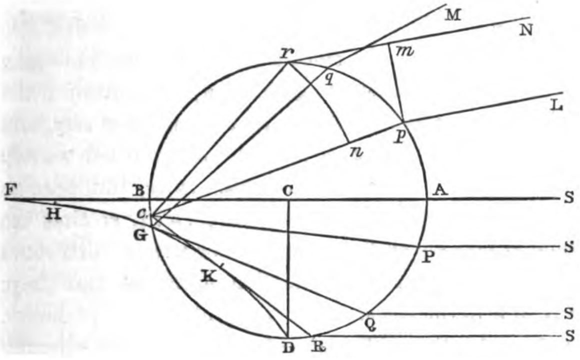


Fig. 9.

the courses of *c r* and *c p* after emergence, will also be so; and P, R will lie on opposite sides of Q, and *p*, *r* of *q*, because as *c* approaches to G the point where the caustic meets the sphere, H and K both do so also. P and R approach and ultimately coincide at Q, and *p r* at *q*, the latter being the point at which *contiguous* rays emerge parallel. Thus, for every point of emergence *p* nearer the vertex than *q*, another *r* more remote has been found, under the condition appropriate to the interference of the emergent rays.

(223.) Thus we see that every ray emerging between A and $q$ will have a fellow ray emerging parallel to it between $q$ and E, and interfering with it by a difference of undulations, determined by drawing $p\ m$ perpendicular to $r$ N, and $r\ n$ a circle, having $c$ for its centre; for the difference in question ($\delta$) will be expressed by $\frac{r\,m}{v} - \frac{n\,p}{v'}$ where $v$, $v'$ are the velocities of light in air and in water, that is, since $v' : v :: 1 : \mu$, by $r\,m - \mu . n\,p$. It is not necessary to go into any calculation of the value of this; it is sufficient that it increases regularly from 0 (when $r$ and $p$ coincide with $q$) *not merely because both r m and n p vanish there,* but because at $q$ and its neighbourhood $r\,m : n\,p : \mu : 1$, so that the parallel rays which form the rainbow have no difference of phase, while as the inclination of the emergent rays $r$ N, $p\ l$, to the visual ray of the rainbow $q$ M increases, so does also their difference of phases.

(224.) The larger the drop the greater are the linear magnitudes of all the elements composing its form, and therefore of $r\ m$ and $n\ p$, and consequently $\delta$. Hence, to the same difference of angular directions between the rainbow and any pair of interfering rays will correspond a larger value of $\delta$ the larger the drop, and therefore a greater difference of phase and number of fringes; or, in other words, the angular breadths of the successive fringes are inversely as the diameters of the drops. If, then, the drops differ much in diameter, and there be no greatly prevalent average diameter, the fringes formed by one drop will confuse those by another. It is only, then, when owing to some existing condition in the formation of the rain, there is a large preponderence of drops having very nearly the same diameter that these fringes will be visible. They are especially well seen, and the whole phenomenon of the primary bow is exhibited with peculiar distinctness, when on a sunny morning the eye is held close to a gossamer covered with dew (in perfectly distinct microscopic globules of nearly equal magnitude), the back being turned to the sun and the head so placed as to allow his light to fall laterally on the net-work on which the globules are strung like beads. Four or five internal fringes may be distinctly traced within the bow formed by an even undisturbed gossamer.

(225.) The angle of dispersion D being a maximum for rays forming the rainbow, it is obvious that no drop outside of the bow can send to the eye any ray once internally reflected from the sun. Hence the greater apparent illumination of the ground of the sky inside of the bow. The rainbow ray is, in fact, the asymptote of the exterior caustic for rays twice refracted and once reflected.

(226.) In reference to the formation of a rainbow on cloud or fog in the entire absence of rain (art. 93), Colonel Sykes, in his paper on the Meteorology of the Deccan (*Phil. Trans.* 1835), relates a remarkable instance of one seen by him from the top of a precipice from 2000 to 3000 feet in perpendicular height, forming the north-west scarp of the hill fort of Hurrachandarnaghur, among the Ghauts, overlooking the plains of the Concan (Konkhun), densely covered with fog-cloud, rising somewhat above the level of the precipice, but not covering it. Under these circumstances, having the sun at a low elevation at his back, he says, "A circular rainbow appeared, quite perfect, of the most vivid colours, one half above the level on which I stood, the other below it. Shadows in distinct outline of myself, my horse, and people, appeared in the centre of the circle, as in a picture to which the bow formed a resplendent frame." "From our proximity to the fog, I believe the diameter of the circle at no time exceeded 50 or 60 feet. The brilliant circle was accompanied with the usual outer bow in fainter colours." In the same paper, he also records his observation of a white rainbow in a fog-bank near Poonah, within which he was riding. "Suddenly I found myself emerge from the fog, which terminated abruptly in a wall some hundred feet high. Shortly after sunrise, I turned my horse's head homewards, and was surprised to discover in the mural termination of the fog-bank a perfect rainbow, defined in its outline, but destitute of prismatic colours." "Niehbuhr in his Voyage to Africa, describes a white rainbow, and Mr. St. John, in his Lives of Celebrated Travellers (iii. 121), mentions having seen one, on the 21st May 1830, in Normandy, on 'the morning mist.'" On the other hand, it should be mentioned that Mr. Smyth, in his recent sojourn on the Peak of Teneriffe, with a cloudless sky and perpetual sunshine above, and with a boundless sea of cloud continually extended in all directions below him, makes no mention of a rainbow being at any time formed upon it.*

(227.) II. *Halos.*—These are of two kinds: the first, large circles of definite and constant diameters, one of 45°, the other of 92°, and which are seldom both seen together. The colours are very feeble, especially of the larger, which is usually almost or quite white. The formation of the lesser of these, as explained by Mariotte, is due to the existence of minute prisms of ice floating in the air, having refracting angles of 60°, and their axes turned in all possible directions. If we take a triangular prism of glass, and turn it about in a sunbeam,

* [The external portion of a very remarkable appearance observed by Mr. Cockin in Lancaster (*Phil. Trans.* 1780 157) in a mist would seem also to have been the lower portion of a colourless rainbow. I may observe here in reference to the note on p. 90 (§ 92), that in this account Mr. Cockin *does* distinctly notice, as a matter of surprise, "the *little humid particles* which occasioned the mist, and which were floating around the bushes at about half an inch distance from one another," "where the sun shone" on them. But he does not call them *bubbles*, and it is evident that what he saw was not the watery globules themselves, but the infinitesimal spark of light from each of the globules constituting its contribution to the rainbow, which, if the focus of the eye were not adjusted to its distance, might easily have been dilated into an annular appearance, or a disc mistakeable for a bubble. In reference to the usual want of colour in lunar and fog rainbows, it may be observed that the prismatic colours are not well distinguished in either very brilliant or very feeble spectra. And as regards the non-formation of rainbows on clouds at *very* great altitudes, anyhow they evidently could not be so formed, the particles of the cloud being not globules, but crystallized bodies.]

it will refract out from one of its angles a coloured beam, whose deviation from the direction of the incident light varies as the prism is turned, being at first very great, but diminishing until at one point of the rotation the deviated beam becomes for a while stationary, and then (the rotation continuing in the same direction) begins again to increase. There exists, then, for every refracting angle of the prism a minimum angle of deviation, dependent on the refractive density and the angle of the prism. In ice, with a refracting angle of 60° this deviation is about 23° for red light, and therefore, among an infinite multitude of such prisms scattered through the air, a far greater number will throw out a refracted beam 23° inclined to the direct ray of the luminary than in any other direction, since about the position of the maximum a considerable amount of rotation of the prism causes but a very trifling change in the direction of the refracted ray. At the angular distance of 23°, then, from the apparent place of the luminary, there will be a much larger percentage of prisms in the visual line capable of sending a refracted beam to the eye than at any other, and a dim circle faintly coloured with red internally, and better defined within than without, will be seen.

(228.) The halo of 92° diameter is accounted for in a similar manner by refraction through the angle of 90°, at which the sides of hexagonal or triangular prisms intersect their basis, and which in ice gives a minimum deviation for red rays of about 46°. Besides the agreement of these angles assigned by theory with the measured semidiameters of the halos, we have a direct proof, in the fact observed by Arago, that their light is partially polarized in a plane tangent to the circumference of their circles, that they consist of refracted light. The light of the rainbow, similarly examined, indicates reflexion as its principal origin, being polarized in a plane at right angles to the arc, or passing through the sun.

(229.) Besides these principal halos there are smaller ones which are frequently seen encircling the moon, often two, very rarely three, and which are sometimes called *coronas*, a very proper distinction, their origin being quite different from that of the large ones as well as their colours, which are much more lively and inverse as to their order, the red being outward and the violet inward. When two or more are seen at once, the diameter of the second is double that of the first —of the third triple. But the diameter of the interior corona (the unit of the scale) is not always the same, varying from 2° to 4°. The succession of colours is approximately that of the reflected series of thin plates, and they are obviously interference fringes, and as such have been very satisfactorily explained by Dr. Young, who considers them to arise from the interference of rays passing on either side of minute globules, all (or a preponderant average) of which have at the time very nearly the same size, assimilating them to the colours of fine even-stapled wool or to lycoperdon dusted over glass, and held between a candle and the eye. Dewed glass so held often exhibits similar rings, and occasionally the cornea of the eye itself becomes filmy by the diffusion over it of minute particles which (such at least is our personal experience) exhibit round a candle two or three beautiful coronas, the second of 17° 57′ in diameter, of vivid colours and most perfect definition. The reason why coronas are seldom seen round the sun is the dazzling brightness of that luminary. If its light be enfeebled by reflection in water, or by a coloured glass, they are often visible. Newton observed three such on one occasion by this means.

(230.) Interference colours are frequently seen irregularly distributed over cloud masses. We had the satisfaction of witnessing a fine display of them from the Col du Mont Cervin on the occasion of an ascent of the Breithorn (Kleine Monte Rosa) in 1821, and since, in cirrostratus covering the sun, on Sept. 17, 1852, when the pink, blue, and green colours of a mackerel's skin were visible in irregular patches. But the beautiful phenomenon which it was our good fortune to observe on the 14th July 1841, at 4h. 50m. P.M., being, so far as our reading extends, unique in meteorology, appears to merit a particular description. While riding on that occasion near Hawkhurst, in Kent, with a companion, the attention of both was attracted by the pale well-defined silvery disc of the sun as seen through a very high cloud, of a character between cirro-stratus and cirro-cumulus—like a high "mackerel sky" blotted by a remarkably uniform fog. After a few moments we perceived the edges of the cloud to be beautifully tinged with bands of colour, not disposed in a circular form round the sun as a centre, but following all the sinuosities of the outline of the cloud. The colours, commencing from the white area forming its interior, and proceeding outward to the edge, were—1*st*, white; 2*d*, very pale pink; 3*d*, blue-green, a stronger colour; 4*th* (at the edge), purplish pink, considerably intense; beyond which pure blue sky. At one place a 5*th* band of colour, blue-green (very different from the blue of the sky) formed the edge; the line of demarcation between this and No. 4 distinctly running out at the edge so as to *cut* the outline of the cloud. What, however, was especially remarkable, was that *the same fringes were observed bordering detached portions of neighbouring clouds of similar character*, the colours having obviously no reference to more or less proximity to the sun, but *depending on the thickness of the cloud* or the length of the path within it traversed by the visible ray. After watching this phenomenon for a quarter of an hour, the coloured bands grew broader and the tints very strong, and a tendency to form a corona about the sun was perceived. Probably with a darkening glass, one or more might have been well made out. It seems impossible to regard these colours otherwise than as the resultants of the super-position of a series of interference fringes following a regular progression of breadth (due to a progressively increasing size of the drops) from the exterior to the interior of the cloud.

(231.) III. *Parhelia and Arcs of light passing through the sun.*—A horizontal band of light is occasionally seen to pass through the sun when at a low altitude, and to be prolonged into a circle parallel to the horizon. This is evidently what would result from reflection on, or refraction through, the faces of innumerable ice prisms floating in *perfectly calm* air with their axes vertical, but having their lateral faces disposed equally in all azimuths. Minute crystals, when formed by precipitation in a liquid at rest, always arrange themselves with their axes parallel as they sink, which may often be rendered sensible by a silky appearance in the liquid produced by agitation (of which iodide of lead precipitated from a dilute solution containing ether affords a beautiful example). Under this condition, then, the dispersed light, which in the halos is scattered in all planes equally, is here confined to a horizontal one, resulting in a bright horizontal circle, the parhelia being the intensified effects of a greater condensation of the dispersed rays at the angles of minimum dispersion, corresponding to the halo itself as the circle does to the diffused illumination of the cloud on which the halo is depicted.

(232.) Any one who considers the complicated forms of snow crystals (art. 120), and the various ways in which refractions and reflections, both external and internal, may take place among them, bearing in mind also that ice is *doubly refractive*, and that at the planes of junction of macled crystals, phenomena of coloration of an intricate nature are presented, will not be surprised to find a great variety and complication of luminous arcs, more or less coloured, and intersecting one another in such a way as to form singular interlaced patterns occasionally developed under the influence of a bright sun, intense frost, and generally clear sky, on the principles above explained; such, for instance, as the superb exhibition witnessed by Scheiner at Rome in 1629, and repeated in higher perfection, and with fuller detail for several days in succession, at Moscow, when occupied by the French army in 1812. This most striking phenomenon, which is very seldom more than partially visible, consists of two brilliant halos about the sun, cut diametrically across by a horizontal circle continued all round the heavens, with well-developed parhelia at their intersections, and a third at a very large angular distance, more feeble, the intersections also marked with parhelia. At the summits of the two inner halos, and touching them externally, other circles, as it were their reflected images, pass upwards and include the zenith, that which touches the inner halo having a parhelion at the point of contact. Circles of this description are clearly not phenomena of interference, and can only admit of explanation by the intervention of ice crystals.

(232, *a.*) Fringes or glories of light, more or less coloured, are also often seen in fogs surrounding the outline of the shadow of the head or of the whole person of the spectator. The inner portion of Mr. Cockin's phenomenon referred to in the note on § 226 would seem to have been of this nature—at least he refers it to his own shadow. It consisted of two very regular concentric *elliptic* bands of light surrounding the "shadow" and separated from each other by a broad dark band:—the inner, yellowish flame colour—the outer, rainbow-tinted; on a base (the shorter axis of the Ellipse) about 10° or 12° in extent.

(233.) IV. *Polarization of Sky Light.*—This is a very mysterious and a very beautiful phenomenon, when observed by the aid of a polariscope, consisting of a tourmaline plate, with a slice of Iceland crystal or nitre, cut at right angles to its optic axis, and applied on the side of the tourmaline farthest from the eye. In a cloudless day, if the sky be explored in all parts by looking through this compound plate, the polarized rings will be seen developed with more or less intensity in every region but that nearest the sun and that most distant from it—the maximum of polarization taking place on a zone of the sky 90° from the sun, or in a great circle having the sun for one of its poles. The plane of polarization, whatever the direction of the visual ray, passes through the sun, so that the cause of polarization is evidently a reflection of the sun's light *on something.* The question is, on what? Were the angle of maximum polarization 76°, we should look to water or ice for the reflecting body, however inconceivable the existence in a cloudless atmosphere and a hot summer day of unevaporated molecules of water. But though we were once of this opinion (art. Light, *Encycl. Metropol.* § 1143), careful observation has satisfied us that 90°, or thereabouts, is the correct angle, and that therefore, whatever be the body on which the light has been reflected, *if polarized by a* *single reflexion*, the "polarizing angle" must be 45°, and the index of refraction, which is the tangent of that angle, unity; in other words, the reflection would require to be made *in* air *upon* air! The only imaginable way in which this could happen would be at the plane of contact of two portions of air differently heated, such as *might* be supposed to occur at almost every point of the atmosphere in a bright sunny day; but against this there seems to be an insuperable objection. The polarization is most regular and complete, as we have lately been able to satisfy ourselves under the most favourable possible atmospheric conditions, after sunset, in the bright twilight of a summer night, with the sun some degrees below the horizon, and long after all the tremors and turmoil of the air, due to irregular heating, must have completely subsided. Even at midnight, the moonlit sky* exhibits the same phenomenon, bearing the same reference to the moon's position as to that of the sun by day, the black cross of a polariscope being distinctly perceptible. The difficulty, therefore, of conceiving the polarization as operated by a single reflexion is very great. On the other hand, if effected by several successive reflexions, what is to secure a large majority of them being in one plane (in which

* It did so on the night of the evening referred to. This was after a very hot day, and a series of very dry weather. Repeating the observation the next lunation after copious rains, no trace of the cross or polarized rings could be anywhere discerned, and the skylight, examined by a doubly refracting prism, shewed only a feeble partial polarization in the most favourable position. Perhaps there was unperceived cirrus.

case only their polarizing effect would accumulate); and of those which become ultimately effective, what is there to determine an ultimate deviation of 90° as that of the maximum? The more the subject is considered, the more it will be found beset with difficulties; and its explanation, when arrived at, will probably be found to carry with it that of the blue colour of the sky itself and of the great quantity of light which, (whether reflected, refracted, or fluorescent) it actually does send down to us, and of which we confess our inability to render any account less unsatisfactory than that of Newton, who refers it to reflexion on thin transparent particles. These cannot be air, because there can be no reflexion upon air in contact with air of the same density. And they cannot be water, it being impossible to realize even in imagination the existence of globules or bubbles of the requisite dimensions maintaining themselves unevaporated for an instant, when disseminated through the atmosphere of a clear, dry, and sultry day, when through its whole extent there is no doubt of the dew-point being far below the actual temperature, that is to say, under conditions where a sheet of wet paper would become dry in a few minutes—over a sandy desert, for instance, where rain never falls, and cloud is a rarity. We may observe, too, that it is only where the purity of the blue sky is most absolute that the polarization is developed in its highest degree, and that where there is the slightest perceptible tendency to cirrus it is materially impaired. Neither is it in the upper regions only that it is effected. The polarized rings are formed, though much more feebly, and under the same conditions of reference to the sun's position below the limit of the visible horizon as above it, provided only the visual ray have a mile or two of air to traverse in full sunshine.

(233, *a.*) M. Arago has shewn that there exists a neutral point or point of no polarization situated in the vertical passing through the sun, and at 150° or 155° distant from the sun. Sir D. Brewster finds this angle to be variable with the sun's altitude. When on the horizon he assigns 161° for its value, and when 11 or 12° high 168° or 169°. M. Babinet also indicates another neutral point less distinctly marked, at about 18½° from above the sun when rising or setting. Several other less distinctly marked "neutral points" are also stated by Sir D. Brewster to exist, and a regular law indicated, according to which the polarization varies for different altitudes of the sun, for which, as we see no physical cause adequate to give rise to it, we must refer the reader to his treatise on optics. *Encyclopædia Britannica*, xvi., 692.

(234.) V. *Colours of Clouds.*—Whether or no pure air be an absorptive coloured medium, transmitting the blue rays and absorbing the yellow, we may be very sure that the terrestrial matter which, in the form of smoke, dust, and general undefinable impurity, defiles its lower regions, does exercise an absorptive action of a contrary nature, absorbing the violet end of the spectrum and letting pass the red. This is quite sufficient to account for the red and golden hues of sunset, and of those clouds which are high enough to catch the last rays of the declining sun after its disappearance from the horizon of the spectator on the earth. The red, and sometimes greenish, light thrown on the moon by the earth's atmosphere acting as a lens, and concentrating on it light which has undergone its absorptive effect, sufficiently indicates the nature of that absorption on a general average of the whole atmosphere, which, however, is sometimes singularly suspended, and even changed into one of an opposite character, as in the instance of the blue sun seen at Bermuda from 6 A.M. to 5½ P.M. August 13, two days after the great hurricane of August 10, 1831, a phenomenon which Arago has regarded as merely an effect of contrast, but which, described as we happen to have it very circumstantially in a letter from an eye-witness, we must consider to have been an objective reality.

(235.) Professor Forbes, in a very curious paper published in the *Edinburgh Phil. Trans.*, vol. xiv., has shewn that high pressure steam, in the act of expansion and while still transparent, is highly absorptive of the violet, blue, and a portion of the green rays of the spectrum; and in a second memoir in the same volume, suggests that without supposing absorptive coloration in the air itself, it may exist in a mixture of air and vapour, the latter being in that peculiar intermediate absorptive state which his experiments have clearly shewn under certain circumstances (certainly very remote from atmospheric ones) to exist. Whether the ruddy hues above alluded to in the lower atmosphere be really owing to the presence of absorptive steam, is doubtless a question which may be entertained and more fully discussed; but if the sky be blue by reason of absorption, that absorption must be of a directly opposite character (*i. e.*, most energetic on the red rays of the spectrum). [More recently it has been observed by M. Carré that ammoniacal gas, escaping from a pressure of two or more atmospheres into the air, assumes a decided blue colour, "similar to that of the smoke of certain woods when burning."]

(236.) VI. *Refraction, Mirage, Lateral Refraction.*—[The air being a refractive medium of variable density, diverts from its rectilinear course the lights of the stars and other heavenly bodies, thus giving rise to the phenomenon of "Astronomical refraction." Calculation on the refractive power of air, agrees with experiment in assigning 33′ 0″ for the mean amount of the "horizontal refraction," and 57″·524 for that of a luminary at 45° altitude. When the ray does not traverse the whole thickness of the atmosphere, the amount of refraction, of course, is less, but is very appretiable in increasing the apparent angular elevation of any lofty object seen from a lower level, and has to be allowed for in all trigonometrical surveys and other operations where precision is required.] When the surface of the soil is greatly heated, the air in contact with it is dilated, and while yet supporting the incumbent atmospheric pressure, its elasticity being increased, does so with diminished density. In such a case, rays of light coming from a distant object at great obliquities, before they can reach the ground, are bent upwards by refraction, and pursue their further course as if reflected from the surface of water. Thus, to a spectator receiving both these reflected rays and those which, diverging from the same object, reach his eye directly, having never passed into the heated stratum, both the object and its reflected image will be seen, the one direct, the other inverted, and joined by their bases, as if rising out of a lake of still water, which in arid deserts such a stratum of hot air exactly resembles. Under certain circumstances, on sea coasts, such a layer of hot air (drifted probably from a shore of heated sand) occupies a higher level, and in it, as if in a mirror suspended in the air, the inverted images of ships, mast-head to mast-head with the direct, are seen; and even in some rarer cases, again, another repetition of the image upright above both. Singular instances of this kind are described by Professor Vince as seen at Ramsgate (*Phil. Trans.* vol. lxxxix). M. Biot has given an elaborate explanation of the theory of such phenomena, in a paper in the *Memoirs of the French Academy.* The accounts of arctic voyages are full of extraordinary exemplifications of the same general principle, where the powerful radiation of an arctic summer sun acts on a surface loaded with ice, and produces great contrasts of local temperature.

(237.) When a current of heated air passes through a body of air generally colder, a lateral mirage is sometimes, though rarely, produced. Thus, on the Lake of

Geneva, the image of a boat sailing on it has been seen reflected on such a vertical plane of demarcation. A similar effect is sometimes produced by the sun striking on a wall. We remember when walking on a hot sunny day under the south wall of Kensington Gardens, the sun shining full upon it, to have observed the distinct reflection of persons walking on the same footway. A single soldier, for instance, appeared as two; the shape and colours of the uniform being visible in the reflected image on the wall, which appeared invested with a glassy, mirror-like coating. [Von Humboldt has recorded an instance of lateral refraction of a singular nature witnessed on the Peak of Teneriffe. The image of a bright star was observed to rise, move laterally, descend, and resume its former position, the excursions being very visible to the naked eye. A very similar phenomenon is described by Froebel as having been witnessed by him in one of his journeys near El Paso.—(*Seven Years' Travel in Central America*, p. 189.)]

## AURORA BOREALIS.

(238.) As a meteorological agent, electro-magnetism, to which department of physics this phenomenon refers itself, has no claim to be regarded. So far as has hitherto been proved, there is no meteorological effect either as regards temperature, moisture, barometric pressure, or wind, which is in the smallest perceptible degree influenced by its most vivid displays. They appear to be developed for the most part in a region of the atmosphere too high, and of too great rarity to affect either our instruments or (except on these occasions) our senses, and the only interest they offer to the meteorologist otherwise than as brilliant spectacles, consists in the evidence which they afford of the existence of *some* matter of inconceivable tenuity no doubt, in those elevated regions capable of being thrown into a luminous state by the passage through it of the electric discharge. Whether electricity passing through an absolute vacuum be luminous, we have no means of determining by experiment, since such a vacuum is beyond our power to produce, though the experiments of Davy would appear to indicate that beyond a certain degree of tenuity (already very extreme) in the gaseous or vaporous medium filling glass vessels admitting of inspection of what passes, the electrical discharge between the poles of a battery not only begins to be less luminous, but the conduction itself is impaired. But in certain phases of an auroral display, indications of a very unequivocal character are afforded of a distribution of material substance in forms which, could they be seen under ordinary circumstances, would be called clouds. We allude to those luminous bands extending across the horizon, and patches of auroral light which are either stationary or nearly so in the sky, but which, when attentively watched, are usually perceived to be slowly drifting southwards, and are generally the precursors of a more active phase of the aurora when it bursts into streamers. These perhaps belong to comparatively less elevated regions, and possibly in some cases to be identifiable with the very highest perceptible cirrus cloud. But besides these, there are others probably at a much greater elevation, and which become perceptible only when traversed by those undulating pulsations of light, converging to the magnetic zenith, which constitute a marked feature of certain auroras. As a flash of what is called sheet-lightning (*i. e.* the reflection of an unseen flash on a distant back-ground of cloud) will often disclose the outlines of intermediate cloud otherwise unsuspected, so these pulsations when carefully watched, will be seen to consist of waves of light traversing regions of space, bounded by more or less definite outlines, within which light is momentarily developed by the passage of each pulse, and whose existence, as occupying place and having form, whatever else their nature, is only revealed to us in those moments, not as in the case just alluded to by their projection as intercepting masses on a luminous ground, but as giving off light out of their own substance.

(239.) The height of the auroral arch in that form in which it stretches across the sky as a luminous band at right angles to the magnetic meridian has been estimated on several occasions from its apparent zenith distance as seen from different stations, variously at from 50 to 300 miles above the earth. The most unexceptionable determination seems to have been that of an arch observed simultaneously at Gosport, Keswick, and Newtown-Stewart in Scotland, on Oct. 17, 1819, which, by the calculations of Dalton, *Phil. Trans.* 1828, from the zenith distances observed, was 100 or 102, miles above the earth.* It has been suggested that such measurements are inconclusive, on the ground that (as in the case of the rainbow) each observer sees his own arch, and that no one spectator sees the same arch as another. But it is obvious that this applies only to an optical image reflected or refracted from some original source of light elsewhere situated, whereas no one can doubt that the light of the aurora originates nowhere but in the place where it is seen. A planet or comet might with equal justice be considered as the image (formed on some unknown reflector) of some other planet or comet not seen. But the want of absolute fixity in the apparent place of the arc itself is a great obstacle to exactness of determination, as such observations are rarely made at precisely noted and astronomically corrected moments of time. There is very positive evidence, however, that auroral light has been seen below the clouds (as in the Polar Seas by Parry, Sherer, and Ross, on Jan. 27th, 1825; near the chain of the Rocky Mountains in North America on December 2, 1850, by Hardisty; and at Alford in Scotland on Feb. 24, 1842, by Farquharson), nay, even habitually

* [Quite recently (March 9, 1861) a magnificent aurora observed by Mr. Lowe at Nottingham, and by myself at Hawkhurst in Kent, afforded an excellent opportunity for determining the height of the arch. It passed (as seen from Nottingham) over Jupiter, on or near the meridian, and therefore south of the zenith, at an altitude of about 52°. At or very nearly at the same time, it attained at Hawkhurst (130 miles south of Nottingham) an altitude of about 52° also, but to the *north* of the zenith. Its height therefore above the ground was 83 miles.]

seen as if hovering over the Coreen Hills in the last mentioned neighbourhood, at a height from 4000 to 6000 feet (Farquharson, *Phil. Trans.* 1839).

## METEORS, SHOOTING STARS, &c.

(240.) The fall of a stone or a shower of stones from the sky would seem at first sight to be quite as fairly entitled to be regarded as a meteorological phenomenon as that of a shower of hail; nay, hailstones are *said* to have fallen, each containing a nucleus of iron pyrites. At all events, falls of stony masses accompanied with aerial detonations and luminous appearances are too numerous and well authenticated to admit of doubt. But there is not the smallest reason to believe that such can be formed in, or anyhow collected from, disseminated particles scattered through the air, and on the contrary, so great a mass of facts go to connect "shooting stars" with astronomical phenomena, that we cannot hesitate in assigning them to that department of physics. This, however, does not apply to a class of meteors of which the great one of August 18, 1783, was an eminent example—great fiery globes, of many hundreds, nay thousands of feet in diameter, evidently not of solid materials, being of fluctuating and continually varying form, and giving out most intense light, many of them being compared not merely to the moon in illuminating power, but to the full light of day. The name Bolis or Bolide has been applied to this class of phenomena. That above mentioned traversed the whole of Europe from the North Sea to Rome, at an altitude tolerably well ascertained of about 50 miles, and with a velocity of from 20 to 40 miles *per second.* Its diameter could not have been less than 4000 feet, having been seen under an angle equal to one-third of the moon's apparent diameter when vertically over the eastern counties of England, from Edgeworthstown in Ireland, at a distance of at least 300 miles. That it must have been a body of extremely small density is evident from the fact of its having made a sudden flexure in its course at a certain point of its progress. There is so much that is enigmatical about these bodies—the trains they leave behind them, and which often remain long visible, and change their aspect and form like luminous clouds; the immense velocity of some, approaching to planetary (yet far short of that of the electric spark), and the complete apparent fixity of others; and their tendency (alleged) to affect the direction of the magnetic meridian (which that of 1783 certainly did)—as to take them out of the domain of exact science. In fact, no theory of their origin, making the smallest approach to plausibility,* has hitherto been advanced, though the records of the observations of such meteors would fill volumes, and may be found by consulting the indices of almost every

* [The *most* plausible is that which assimilates them (as well as the slow-moving "globes of fire" mariners are in the habit of talking about, as seen to approach and sometimes strike their ships in violent thunderstorms), to the glow-discharge of a very enormous electric reservoir of low tension, venting itself through an imperfect conductor.]

collection of scientific memoirs or notices, and every philosophical magazine and journal. See especially the reports of luminous meteors, from A.D. 338-1293, by Chasles (*Comptes Rendus*, March 15, 1841); the great collection of Chladni; four reports by Prof. Powell to the British Association, 1841-51; two by M. Quetelet to the Royal Academy of Brussels, 1839 and 1842; and Schmidt's *Resultate aus* 10-*jährigen Beobachtungen über Sternschüppen.*

## WHIRLWINDS, WATERSPOUTS, DUST-STORMS.

(241.) Whenever two currents of air running in opposite directions approach and graze one another, eddies will arise, the air of which, forced into rotation, compressed by its own impulse, and finding no escape downwards or laterally, is driven upwards, and ascends with a vorticose motion, which, as a necessary consequence of the dynamical principle of the "conservation of areas," becomes swifter the nearer the indraughted air approaches the axis of the eddy. Whirlwinds so generated differ widely from cyclones, inasmuch as the ascensional movement is not the cause but the consequence of the indraught of air; they are whirlwinds of compression, whereas cyclones are whirlwinds of rarefaction. The greater part of those violent and sudden whirlwinds which are confined to limited and linear tracts of land, which carry up into the air haystacks, unroof houses and scatter the materials around, tear off branches of trees, upset boats, and commit other local havoc, are probably of this kind. In such whirlwinds, the law of the direction of rotation which the true cyclone obeys (art. 72) is not necessarily observed, and their rotation may be indifferently direct or retrograde, according to the relative situation and direction of the currents from which they originate. They are often terminated by heavy falls of rain, a very obvious consequence of the sudden transfer of a great mass of air nearly saturated with vapour at the surface of the earth to a much higher level (art. 110); for the same reason, that is, that a fall of rain has been not unfrequently observed to follow great natural conflagrations, as in the burning of forests or prairies in North America, or in volcanic eruptions, nay, is even said to have been brought on by fires kindled for that express purpose.

(242.) Whirlwinds of this kind taking place at sea give rise to waterspouts (*trombes de mer*), which are very singular and sometimes dangerous phenomena. Tall columns, apparently of cloud, and reaching from the sea to the clouds, are seen moving majestically along, often several at once, sometimes straight and vertical, at others inclined and tortuous, but always when approached perceived to be in rapid rotation. At their bases the sea is violently agitated, and heaped up with a leaping or boiling motion. Indeed water would seem, at least in some cases, to be actually carried up in considerable quantity, and scattered round from a great height, as solid bodies are on land. Hence they have been supposed by some to draw water from the sea by *suction*, a thing obviously impossible. A notion is prevalent among seamen that they may be cut asunder and dispersed by firing a cannon-shot through them, an effect for which no good reason can be rendered, and which certainly savours of the marvellous. Appendages evidently in the nature of imperfectly formed waterspouts are often seen descending from the under surface of rainy clouds on land (we have such a one before our eyes—August 5, 1857), like long loose tapering tails floating in the air, but not meeting the earth. Viewed through a telescope, they are evidently seen to be hollow vaporous cylinders or conoids—a light medial line or axis being clearly traceable through their whole length, and the rotation perceptible on attending to the slight irregularities in their outline (which is very definite).

(243.) During the hot season, in parched and sandy tracts of flat country, whirlwinds of an opposite character arise from the ascent of the violently heated air in sheets or streams, determined by accidents of local exposure or by any slight elevation of the soil, up which gliding on all sides, the superficial air becomes concentered for the moment, as we see flames arise and divide themselves. When this takes place on a large scale, a true cyclone may be thus generated; but if the ascensional movement be broken up into numerous partial ascending columns, the wind-flaws which sweep along the surface to feed them, wherever they encounter one another, will from that circumstance alone take on an eddying motion and generate whirlwinds, carrying up with them clouds of dust. These in the African deserts, often appear as tall columns of sand, revolving and advancing, suffocating and actually overwhelming men and horses, and even armies (as in the memorable expedition of Cambyses into the Lybian desert). That the heat of a wind thus loaded with sand may be insupportable, or even deadly, will be easily conceived when it is remembered that a sandy soil, down to several inches in depth, when undisturbed, may under a tropical sun attain a temperature perhaps exceeding 200° F. (see art. 38), and when suddenly swept up and mingled with air, itself already greatly heated, will communicate its accumulated heat to the general atmosphere, and impart to it, at the same time, a drying power proportioned to its elevation of temperature and absence of vapour. The destructive effects attributed to the Simoom are readily explicable on this view of the causes of its heat, without attributing to it any poisonous quality; and the Simoom itself is not improbably in the nature of a cyclone so originating.

(244.) The "dust whirlwinds" of India, which are very frequent in the district about Lahore and in the Punjab, are sometimes stationary for a long time, sometimes advance with great rapidity. "The sky is clear, and not a breath moving; presently a low bank of clouds is seen in the horizon, which you are surprised you did not observe before; a few seconds have passed and the cloud has half filled the hemisphere, and now there is no time to lose—it is a dust storm, and helterskelter every one rushes to get into the house in order to escape being caught in it." "A broad wall of dust is observed advancing rapidly, apparently composed of a number of large vertical columns, each preserving its respective position in the moving mass, and each column having a whirling motion of its own." "Precisely the same phenomena in kind are observable in all cases of dust storms, from one of a few feet in diameter to those that extend for fifty miles and upwards." "Their rotatory action seems to be continuous above as far as the eye can reach, and the cloud of dust carried up by them, even at the height of some thousand feet, to possess a gyratory motion." "Towards the close of a storm of this kind a fall of rain suddenly takes place."—*Baddeley on the Dust Storms and Whirlwinds of India.* As might be expected from the powerful friction of the dust on the earth when dragged along and in the act of leaving it, the air in these columns is highly electrical. Mr. Baddeley states that during the passage of dust storms, he obtained vivid sparks, and in some cases streams of electricity, from a wire suspended from an insulated bamboo, which would instantly cease on the fall of the terminating shower.

(245.) A vast quantity of solid matter is thus carried up into the higher regions of the air, and no doubt conveyed to great distances, where it sometimes falls, intermingled with rain. Along the west coast of Africa the air is frequently loaded with drifted dust, which covers the decks of ships far out of sight of land. Nay, even on the peak of Teneriffe, up to the height of 10,700 feet, Mr. P. Smyth relates that the air during his sojourn on the mountain was very frequently rendered hazy by floating dust, of which there were often several strata, separated by perfectly clear intervals which could be distinctly traced as projected on the distant mountain heights of Palma, far above the uniform cloud-level (described in art. 111) and of such density as totally to obscure the sun previous to his descent below the cloud level. Showers of fish, frogs, flannel (matted confervæ), bread (edible fungus), infusoria, and other unaccountable substances, are among the more palpable evidences on record of the elevating and transporting power of whirlwinds.

(246.) In conclusion, we subjoin a table of the mean values and annual and diurnal average maxima and minima, at a few select stations, of the chief meteorological elements of temperature, pressure, vapour-tension, humidity, and cloud, not as embodying any general climatological results, but in illustration of the main features of meteorological action laid down in the foregoing pages. In the table, to save room, the letters B, P, V, T, H, C, R, are used to denote respectively the total barometric pressure, that of dry air, and that of aqueous vapour or the vapour-tension, the temperature of the air, the degree of relative humidity, the amount of cloud estimated in tenths of the hemisphere covered, and the rain or other aqueous precipitation. Capital letters are used to indicate the annual and monthly means, corresponding to the months of annual maxima and minima, whether simple or multiple, the means for the whole year being entered in the column marked $\alpha$, and those for the maxima and minima in their order of succession and their epochs, in the subsequent columns $\beta$, $\gamma$, $\delta$, &c. Similarly for the diurnal march of the same quantities, these are represented by small letters: their means (being identical with the annual means) are not repeated in col. $\alpha$, but their daily maxima and minima, with their epochs, and hours of their occurrence, *reckoned from noon*, occupy the subsequent columns. In the monthly epochs, (3), (2), (3), &c., represent January, February, &c. Where ½ occurs, whether in the indication of the month or the hour, the average moment of the maximum or minimum falls on or about the limit between two consecutive months or hours. These epochs are, however, only approximate. The barometric and vaporous pressures are in English inches, the temperatures in degrees of Fahrenheit's scale, and degrees of humidity and cloud in hundredths of their respective units, viz., complete saturation, and a totally clouded sky.

# TABLE OF METEOROLOGICAL ELEMENTS.

| | | α | β | γ | δ | ε | ζ | η | θ | ι |
|---|---|---|---|---|---|---|---|---|---|---|
| *Royal Observatory*, GREENWICH. *Lat.* + 51° 31′; *Long.* 0°; *Alt.* 155 *feet.* | B | 27·763 | 29·923 | (1½)? | 29·627 | (3½)? | 29·909 | (7½)? | 29·602 | (10) |
| | P | 29·439 | | | | | | | | |
| | V | 0·324 | 0·466 | (7) | 0·195 | (1) | | | | |
| | T | 49·27 | 63·37 | (7) | 34·20 | (1½) | | | | |
| | H | 0·85 | 0·93 | (1) | 0·78 | (6) | | | | |
| | C | 0·68 | | | | | | | | |
| | R | 24·40 | | | | | | | | |
| | *b* | ... | 29·773 | 22 | 29·755 | 4½ | 29·772 | 10¼ | 29·752 | 16 |
| | *p* | ... | | | | | | | | |
| | *v* | ... | 0·345 | 1½ | 0·303 | 15½ | | | | |
| | *t* | ... | 55·22 | 1½ | 44·85 | 16 | | | | |
| | *h* | ... | 0·94 | 16½ | 0·75 | 1½ | | | | |
| | *c* | ... | 0·73 | 0½ | 0·60 | 9½ | | | | |
| *Mag. and Met. Observatory*, TORONTO. *Lat.* + 43° 40′; *Long.* 79 21′ *W.*; *Alt.* 108 *feet above Lake Ontario.* | B | 29·616 | 29·654 | (4) | 29·565 | (5) | 29·675 | (9)? | 29·587 | (2) |
| | P | 29·357 | 29·508 | (12) | 29·137 | (7) | | | | |
| | V | 0·260 | 0·489 | (8) | 0·109 | (2) | | | | |
| | T | 44·33 | 65·77 | (7) | 23·93 | (2) | | | | |
| | H | 0·79 | 0·85 | (11) | 0·71 | (4) | | | | |
| | C | | | | | | | | | |
| | R | 89·69 | | | | | | | | |
| | *b* | ... | 29·644 | 22 | 29·599 | 4 | 29·616 | 10 | 29·612 | 16 |
| | *p* | ... | 29·389 | 18 | 29·316 | 3 | | | | |
| | *v* | ... | 0·287 | 2 | 0·231 | 17 | | | | |
| | *t* | ... | 50·31 | 2 | 38·93 | 17 | | | | |
| | *h* | ... | 0·86 | 17 | 0·69 | 8 | | | | |
| | *c* | | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Mag. and Met. Observatory,* Hobart Town. *Lat.* −42° 52′; *Long.* 147° 25′ *E.*; *Alt.* 105 *feet.* | B | 29·781 | 29·830 | (3) | 29·669 | (11) | | | | |
| | P | 29·478 | 29·567 | (7) | 29·349 | (11) | | | | |
| | V | 0·302 | 0·372 | (2) | 0·247 | (7) | | | | |
| | H | 0·76 | 0·88 | (7) | 0·65 | (12) | | | | |
| | T | 53·48 | 62·11 | (1) | 43·73 | (7) | | | | |
| | R | 18·40 | | | | | | | | |
| | *b* | ... | 29·801 | 21 | 29·747 | 8 | 29·800 | 9½ | 29·772 | 16 |
| | *p* | ... | 29·500 | 19½ | 29·429 | 3 | 29·502 | 10 | 29·488 | 15 |
| | *v* | ... | 0·320 | 1 | 0·287 | 16 | | | | |
| | *t* | ... | 60·65 | 2 | 48·27 | 17 | | | | |
| | *h* | ... | 0·84 | 16½ | 0·66 | 2 | | | | |
| | *c* | | | | | | | | | |
| *Mag. and Met. Observatory,* Longwood, St. Helena. *Lat.* −15° 57′; *Long.* 5° 41′ *W.*; *Alt.* 1765 *feet.* | B | 28·278 | 28·360 | (7) | 28·225 | (3) | | | | |
| | P | 27·808 | 27·948 | (7) | 27 666 | (3) | | | | |
| | V | 0·470 | 0·559 | (3) | 0·411 | (8) | | | | |
| | T | 61·40 | 66·24 | (3) | 57·07 | (9) | | | | |
| | H | 0·87 | 0·89 | (3) | 0·86 | (6½) | 0·89 | (9) | 0·86 | (1) |
| | C | | | | | | | | | |
| | R | 45·2 | | | | | | | | |
| | *b* | ... | 28·315 | 22 | 28·248 | 4 | 28·302 | 10 | 28·252 | 16 |
| | *p* | ... | 27·838 | 21 | 27·770 | 8 | 27·835 | 10 | 27·795 | 16 |
| | *v* | ... | 0·486 | 1 | 0·456 | 17½ | | | | |
| | *t* | ... | 64·86 | 2 | 59·31 | 18 | | | | |
| | *h* | ... | 0·91 | 16? | 0·80 | 2 | | | | |
| | *c* | | | | | | | | | |

| | | α | β | γ | δ | ε | ζ | η | θ | ι |
|---|---|---|---|---|---|---|---|---|---|---|
| *Mag. and Met. Observatory,* PETERSBURG *Lat.* +59° 57′; *Long.* 30° 28′ *E.* | B | 29·962<br>... | 30·124<br>... | (1)<br>... | 29·813<br>... | (2½)<br>... | 30·077<br>30·119 | (4½)<br>(9) | 29·846<br>29·800 | (7)<br>(11) |
| | P | 29·734 | 29·946 | (1)? | 29·491 | (8)? | | | | |
| | V | 0·228 | 0·441 | (8) | 0·091 | (2) | | | | |
| | T | 39·17 | 63·07 | (7½) | 13·75 | (2) | | | | |
| | H | 0·82 | 0·93 | (0½) | 0·70 | (5) | | | | |
| | R | 17·30 | | | | | | | | |
| | *b* | ... | 29·968 | 23½ | 29·960 | 6 | 29·969 | 11 | 29·948 | 19 |
| | *p* | ... | 29·746 | 14 | 29·722 | 4 | | | | |
| | *v* | ... | 0·241 | 3 | 0·215 | 16 | | | | |
| | *t* | ... | 42·89 | 3 | 35·17 | 16 | | | | |
| | *h* | ... | 0·88 | 16 | 0·76 | 3 | | | | |
| *Mag. and Met. Observatory,* CATHERINEBURG. *Lat.* +56° 50′; *Long.* 60° 44′ *E.* | B | 29·036 | 29·226 | (11) | 28·827 | (6) | | | | |
| | P | 28·851 | | | | | | | | |
| | V | 0·185 | 0·425 | (7) | 0·057 | (0½) | | | | |
| | T | 33·37 | 63·73 | (7) | 2·00 | (1) | | | | |
| | H | 0·80 | 0·96 | (1) | 0·62 | (5) | | | | |
| | R | 15·60 | | | | | | | | |
| | *b* | ... | 29·041 | 21 | 29·028 | 8 | 29·041? | 10? | 29·037? | 17? |
| | *p* | ... | | | | | | | | |
| | *v* | ... | 0·191 | 2 | 0·163 | 16 | | | | |
| | *t* | ... | 89·46 | 2 | 27·70 | 15 | | | | |
| | *h* | ... | 0·89 | 16 | 0·69 | 2½ | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Mag. and Met. Observatory,* BARNAOUL. *Lat.* + 53° 20′; *Long.* 84° 7′ *E.* | B | 29·593 | 29·928 | (1) | 29·232 | (7) | | | | |
| | P | 29·404 | 29·882 | (1) | 28·792 | (7) | | | | |
| | V | 0·189 | 0·440 | (7) | 0·046 | (1) | | | | |
| | T | 32·45 | 66·65 | (7) | 2·79 | (1) | | | | |
| | H | 0·77 | 0·90 | (2)? | 0·61 | (5) | | | | |
| | R | 10·5 | | | | | | | | |
| | *b* | ... | 29·603 | 22 | 29·587 | 4½ | 29·593? | 7½ | 29·588 | 16? |
| | *p* | ... | 29·440 | 17 | 29·403 | 3 | | | | |
| | *v* | ... | 0·209 | 1 | 0·167 | 16 | | | | |
| | *t* | ... | 40·53 | 2 | 25·40 | 16 | | | | |
| | *h* | ... | 0·84 | 16½ | 0·68 | 3 | | | | |
| *Mag. and Met. Observatory,* NERTSCHINSK. *Lat.* + 51° 18′; *Long.* 119° 46′ *E.* | B | 27·783 | 28·001 | (1) | 27·580 | (7) | | | | |
| | P | 27·622 | 27·986 | (1) | 27·129 | (7) | | | | |
| | V | 0·161 | 0·451 | (7) | 0·015 | (1) | | | | |
| | T | 24·46 | 64·35 | (7) | 21·26 | (1) | | | | |
| | H | 0·71 | 0·83 | (12) | 0·54 | (5) | | | | |
| | R | 16·00 | 4·4+ | (6½) | 0·3+ | (1) | | | | |
| | *b* | ... | 27·798 | 21 | 27·762 | 3½ | 27·788 | 10½? | 27·785 | 15? |
| | *p* | ... | 27·661 | 16 | 27·582 | 3 | | | | |
| | *v* | ... | 0·181 | 1 | 0·139 | 16 | | | | |
| | *t* | ... | 32·90 | 2 | 17·23 | 17 | | | | |
| | *h* | ... | 0·77 | 16 | 0·63 | 3½ | | | | |

| | | α | β | γ | δ | ε | ζ | η | θ | ι |
|---|---|---|---|---|---|---|---|---|---|---|
| *Mag. and Met. Observatory,* PEKIN. *Lat.* + 39° 54′; *Long.* 116° 28′ *E.* | B | 29·946 | 30·319 | (12) | 29·533 | (7) | | | | |
| | P | 29·629 | 30·216 | (12) | 28·754 | (7) | | | | |
| | V | 0·317 | 0·779 | (7) | 0·087 | (1½) | | | | |
| | T | 52·36 | 82·17 | (7) | 23·67 | (1) | | | | |
| | H | 0·64 | 0·69 ? | (12) ? | 0·49 | (5) | 0.80 | (8) | 0·61 | (10½) |
| | R | 26·80 | 9·8 | (7½) | 0·03 | (1) | | | | |
| | *b* | ... | 30·000 | 21 | 29·900 | 4½ | 29·961 | 12 | 29·936 | 16 |
| | *p* | ... | 29·675 | 20 | 29·581 | 5 | | | | |
| | *v* | ... | 0·326 | 1 | 0·316 | 5 | 0·327 | 8½ | 0·293 | 17 |
| | *t* | ... | 60·39 | 2½ | 45·20 | 17 | | | | |
| | *h* | ... | 0·75 | 17 | 0·51 | 2½ | | | | |
| *Mag. and Met. Observatory,* SITKA. *Lat.* + 57° 40′; *Long.* 135° 18′ *W.* | B | 29·884 | 30·101 | (5) | 29·585 | (1) | | | | |
| | P | 29·642 | | | | | | | | |
| | V | 0·238 | 0·361 ? | (8) ? | 0·146 ? | (1) | | | | |
| | T | 41·24 | 55·20 | (7) | 26·51 | (1) | | | | |
| | H | 0·83 | 0·87 | (2) | 0·74 | (5½) ? | | | | |
| | R | 87·90 | 15·0+ | (10) | 1·2+ | irreg. | | | | |
| | *b* | ... | 29·969 | 0 | 29·959 | 6 | 29·965 | 11½ | 29·957 | 16 |
| | *v* | ... | 0·252 | 0 | 0·224 | 15 | | | | |
| | *t* | ... | 45·68 | 1½ | 89·91 | 15 | | | | |
| | *h* | ... | 0·85 | 14 | 0·75 | 1 | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Mag. and Met. Observatory,* TIFLIS. *Lat.* + 41° 40′; *Long.* 42° 50′ *E.* | B | 28·542 | 28·727 | (12) | 28·385 | (7) | | | | |
| | P | 28·237 | 28·581 | (0½) | 27·893 | (7½) | | | | |
| | V | 0·305 | 0·493 | (8) | 0·145 | (1) | | | | |
| | T | 54·78 | 75·44 | (7½) | 31·66 | (1) | | | | |
| | H | 0·69 | 0·82 | (1½) | 0·57 | (8) | | | | |
| | R | 19·90 | 4·1+ | (7) | 0·4+ | (2) | | | | |
| | *b* | ... | 28·564 | 21 | 28·503 | 4 | 28·554 | 13? | 28·549 | 16? |
| | *p* | ... | 28·264 | 18 | 28·198 | 4 | | | | |
| | *v* | ... | 0·314 | 23 | 0·294 | 16 | | | | |
| | *t* | ... | 62·26 | 3 | 48·85 | 17 | | | | |
| | *h* | ... | 0·80 | 17 | 0·54 | 3 | | | | |
| *Royal Observatory,* BRUSSELS. *Lat.* + 50° 51′; *Long.* 4° 22′ *E.*; *Alt.* 190 *feet.* | B | 29·745 | 29·844 | (12) | 29·662 | (4) | 29·768 | (7) | 29·681 | (9) |
| | P | 29·421 | | | | | | | | |
| | V | 0·324 | 0·490 | (8) | 0·190 | (1) | | | | |
| | T | 50·41 | 64·78 | (7) | 35·60 | (1) | | | | |
| | H | 0·81 | 0·91 | (1) | 0·69 | (5) | | | | |
| | C | 0·62 | 0·74 | (1) | 0·52 | (9) | | | | |
| | R | 28·62 | 3·15 | (8) | 1·98 | (4) | | | | |
| | *b* | ... | 29·754 | 22 | 29·734 | 4 | 29·753 | 10 | 29·786 | 16 |
| | *v* | ... | 0·329 | (1) | 0·303 | 16 | | | | |
| | *t* | ... | | | | | | | | |
| | *h* | ... | 0·92 | 16 | 0·72 | 2 | | | | |
| | *c* | ... | 0·67 | 1 | 0·52 | 12 | | | | |

| | | α | β | γ | δ | ε | ζ | η | θ | ι |
|---|---|---|---|---|---|---|---|---|---|---|
| *Mag. and Met. Observatory,* PRAGUE.* *Lat.* + 50° 5′; *Long.* 14° 25′ *E.* | B | 29·268 | 29·363 | (12) | 29·211 | (4) | 29·325 | (9) | 29·238 | (10) |
| | P | 29·001 | 29·214 | (12) | 28·831 | (7) | | | | |
| | V | 0·267 | 0·426 | (7) | 0·141 | (1) | | | | |
| | T | 48·17 | 67·19 | (7) | 28·15 | (1) | | | | |
| | H | 0·75 | 0·84 | (1) | 0·67 | (7) | | | | |
| | C | 0·62 | 0·78 | (3) | 0·46 | (7) | | | | |
| | R | 14·91 | 2·29 | (6) | 0·75 | (9) | 0·97 | (11) | 0·52 | (2) |
| | *b* | ... | 29·284 | 21½ | 29·250 | 4 | 29·276 | 11½ | 29·278 | 16½ |
| | *t* | ... | 53·24 | 2½ | 43·65 | 18 | | | | |
| *Mag. and Met. Observatory,* BOMBAY. *Lat.* + 18° 58′; *Long.* 72° 56′ *E.* | B | 29·800 | 29·922 | (1) | 29·635 | (6) | | | | |
| | P | 29·002 | | | | | | | | |
| | V | 0·798 | 0·926 | (6) | 0·617 | (2) | | | | |
| | T | 79·40 | 84·25 | (5) | 74·40 | (2) | | | | |
| | H | 0·79 | 0·84 | (5) | 0·74 | (2) | | | | |
| | C | 0·36 | 0·71 | (8) | 0·01 | (1) | | | | |
| | R | 75·20 | | | | | | | | |
| | *b* | ... | 29·857 | 21½ | 29·755 | 4 | 29·800 | 10 | 29·772 | 16 |
| | *p* | ... | 29·046? | 22? | 28·935 | 4 | | | | |
| | *v* | ... | 0·811 | 22 | 0·807 | 1 | 0·320 | 4 | 0·770 | 17 |
| | *t* | ... | 85·00 | 1 | 75·00 | 18 | | | | |
| | *h* | ... | 0·96 | 16½ | 0·88 | 0½ | | | | |
| | *c* | ... | 0·42 | 18 | 0·28 | 9½ | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Girard College*, PHILADELPHIA. | B | 29·929 | 30·024 | (2) | 29·842 | (5) | 29·997 | (8) | 29·906 | 10½ |
| *Lat.* + 31° 56′; *Long.* 75° 12′ *W.* | P | 29·578 | | | | | | | | |
| | V | 0·356 | 0·645 | (7) | 0·149 | (1) | | | | |
| | T | 51·53 | 73·27 | (7) | 28·77 | (1) | | | | |
| | H | | | | | | | | | |
| | C | 0·61 | 0·77 | (3) | 0·45 | (6) | | | | |
| | R | 37·25 | 7·8 ± | (7½) | 1·0 ± | (10) | 4·9 ± | (11) | 0.8 ± | (2) |
| | *b* | ... | 29·960 | 22 | 29·897 | 4 | 29·939 | 12 | 29·926 | 15 |
| | *p* | ... | | | | | | | | |
| | *v* | ... | 0·381 | 5 | 0·334 | (16½) | | | | |
| | *t* | ... | 58·33 | 3 | 46·00 | 17 | | | | |
| | *h* | ... | | | | | | | | |
| | *c* | ... | ... | 1½ | ... | 13½ | | | | |
| *Observatory*, U. S. WASHINGTON. | B | 30·051 | 30·147 | (1) | 29·953 | (6) | 30·133 | (10) | 30·060 | (12) |
| *Lat.* + 38° 54′; *Long.* 77° 31′ *W.* | P | 29·582 | | | | | | | | |
| | V | 0·469 | 0·715 | (6) | 0·224 | (2) | | | | |
| | T | 53·75 | 75·10 | (7) | 31·23 | (1) | | | | |
| | H | | | | | | | | | |
| | R | 41·21 | 4·5 ± | (1) | 2·6 ± | (3) | 4·0 ± | (4) | 2·9 ± | (12) |
| MADRID. | B | 27·815 | 28·003 | (3) | 27·701 | (5) | 27·907 | (9) | 27·624 | (12) |
| *Lat.* + 40° 25′; *Long.* 3° 42′ *W.* | P | 27·686 | | | | | | | | |
| | V | 0·129 | 0·236 | (7) | 0·076 | (11) | | | | |
| | T | 60·66 | 82·72 | (8) | 40·53 | (12) | | | | |
| | H | 0·62 | 0·83 | (1) | 0·48 | (8) | | | | |

* These results, deduced from the observations made at the Imperial Observatory, Prague, differ very materially from those given by Herr Karl Firtsch as resulting from the discussion of observations taken in the University Observatory. —(*Grundzüge einen Meteorologie für den Horizont von Prag.*)

| | | α | β | γ | δ | ε | ζ | η | θ | ι |
|---|---|---|---|---|---|---|---|---|---|---|
| *Office of Ordnance Survey,* DUBLIN. | B | 29·722 | 29·793 | (5) | 29·601 | (11) | | | | |
| *Lat.* 53° 22′; *Long.* 6° 5′ *W.*; | P | 29·417 | | | | | | | | |
| *Alt.* 154 *feet.* | V | 0·305 | 0·413 | (7) | 0·229 | (1) | | | | |
| | T | 48·4 | 58·2 | (7) | 40·5 | (1) | | | | |
| | H | 0·86 | 0·89 | (11) | 0·81 | (5) | | | | |
| | R | 29·08 | 3·1± | (11) | 1·5± | (3) | | | | |
| *Radcliffe Observatory,* OXFORD. | B | 29·710 | 29·743 | (5) | 29·627 | (11) | 29·763 | (12) | 29·687 | (2) |
| *Lat.* +51° 52′; *Long.* 1° 15′ *W.* | P | 29·404 | | | | | | | | |
| | V | 0·306 | 0·441 | (7) | 0·218 | (2) | | | | |
| | T | 48·60 | 61·30 | (7) | 37·0 | (1) | | | | |
| | H | | | | | | | | | |
| | R | 26·50 | | | | | | | | |
| *E. J. Lowe, Esq.* (BEESTON), NOTTINGHAM. | B | 29·774 | 29·846 | (3) | 29·764 | (6) | 29·868 | (9) | 29·680 | (1) |
| *Lat.* +52° 57′; *Long.* 1° 8′ *W.*; | P | 29·473 | | | | | | | | |
| *Alt.* 174 *feet.* | V | 0·301 | 0·438 | (7) | 0·211 | (1) | | | | |
| | T | 47 9 | 60·5 | (7) | 38·4 | (1) | | | | |
| | H | 0·82 | 0 88 | (12) | 0.76 | (5) | | | | |
| | R | 26·40 | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sir T. M. Brisbane's Observatory,* MAKERSTOUN. *Lat.* 55° 35′; *Long.* 0° 10′ *W.*; *Alt.* 213 *feet.* | B | 29·615 | 29·718 | (5) | 29·684 | (8) | 29·737 | (9) | 29·547 | (1) |
| | P | 29·330 | 29·436 | (5) | 29·241 | (8) | 29·438 | (12) | 29·235 | (1) |
| | V | 0·285 | 0·393 | (8) | 0·198 | (2) | | | | |
| | T | 46·03 | 57·00 | (7) | 36·05 | (1) | | | | |
| | H | 0·85 | 0·90 | (0½) | 0·79 | (6) | | | | |
| | C | 0 70 | 0·77 | (7) | 0·61 | (12) | | | | |
| | R | 26·35 | 2·95 | (10) | 1·36 | (4) | | | | |
| | *b* | ... | 29 623 | 22 | 29·608 | 4 | 29·622 | 9 | 29·605 | 16 |
| | *p* | ... | 29·344 | 11½ | 29·311 | 2½ | | | | |
| | *v* | ... | 0·301 | 1 | 0·267 | 16 | | | | |
| | *t* | ... | 51·19 | 2 | 42·07 | 16 | | | | |
| | *h* | ... | 0·92 | 15 | 0·75 | 2 | | | | |

(247.) The student who wishes to obtain a deeper insight into the subject of Meteorology than can be conveyed in the limited space we can devote to it, will find ample information in the following works, which however form only a small portion of the immense literature of the subject:—

*Æpinus* de distributione Caloris.

*Albany Institute.* Annual reports of its Regents to the Senate—Do., Report of the Committee for Term Observations, trans. ii.

*Anderson.* Description of an Atmometer, Ed. Phil. Jour., ii. 64.

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*Chladni.* Ueber Feuermeteore—Nouveau Catalogue des Chutes de Pierres, ou de Fer, des Poussieres, &c. &c.—Annuaire du B. des Long. Par., 1825.

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*Cordier.* On Temperature of Interior of the Earth, Mem. Acad Sci., 1827.—(Transl. Ed. P. J., Nos. 10, 11.)

*Correspondence* Met. de l'Obs. Centrale Physique de Russie.

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*Crosse.* Account of an Apparatus for Ascertaining and Collecting the Electricity of the Atmosphere.

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*Dalton.* On Rain and Dew, Manchester Mem. v.—On the Constitution of Mixed Gases, Do.—Met. Obs. and Essays, Lond. 1793—On Constitution of the Atm., Phil. Tr., 1826—
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