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PRACTICAL METEOROLOGY:

BEING

A Guide to the Phenomena of the Atmosphere,

AND THE

PRACTICAL USE OF INSTRUMENTS FOR REGISTERING AND RECORDING ATMOSPHERIC CHANGES

BY

J. ~~B.~~ SCOFFERN, M.B.,
AUTHOR OF "ELEMENTARY CHEMISTRY,"

AND

J. E. LOWE, Esq., F.R.A.S., F.G.S., M.B.M.S.,
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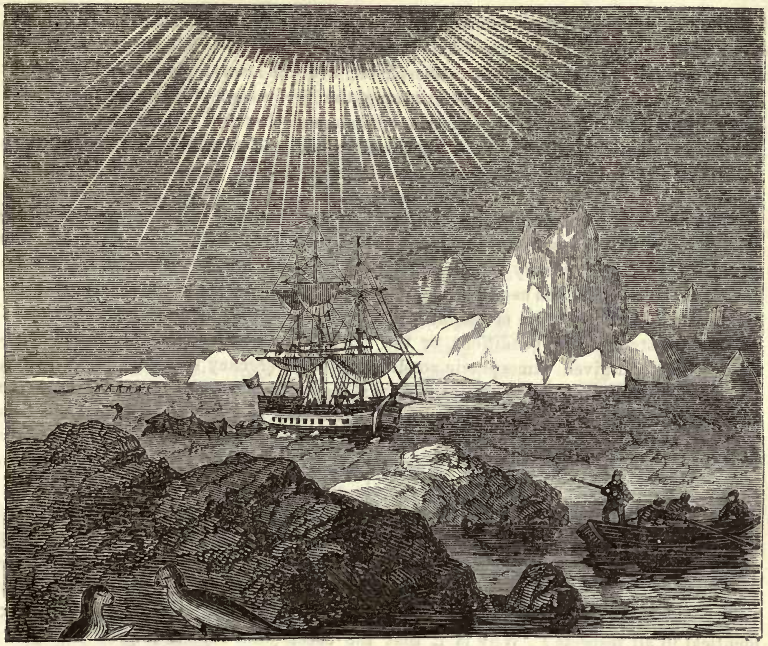


METEOROLOGY.

Definition and Limitations.—The term Meteorology, from *μετεωρος* elevated, was applied by Aristotle to signify phenomena occurring in elevated regions. It may be considered synonymous with the study of atmospheric phenomena, though all which concerns meteors proper is very nearly allied with astronomy.

In many respects Aristotle's opinions on meteorologic subjects display the usual acumen of that deep thinker; his remarks on the subject of dew are particularly interesting. Deprived, however, of the barometer and thermometer—deprived of optical instruments—the nature of electricity yet undeveloped, and the composition and functions of the atmosphere unknown, ancient speculations on meteorologic subjects were necessarily unsatisfactory and vague.

The meteorological writings of Theophrastus, Aristotle's pupil, were more diffuse than those of that great philosopher, and were long recognized as constituting a text-book. They constituted the groundwork of the *Διοσημεια*, or prognostics of Aratus, and were embodied in a versified rendering by Cicero in his youthful days. Portions of these attempts at versification are still in existence, and do but little credit to the great Roman orator in a poetical capacity.

Meteorology, in its most common and restricted sense, may be considered synonymous with *knowledge of the weather.* It therefore involves a full acquaintance with the nature and composition of the atmosphere; with the laws of gaseous and vapourous elasticity; with the conditions determining the production of fogs, dew, snow, and hail; also with the laws of atmospheric, optical, and electrical phenomena. It is the province of meteorology also to study the phenomena of aërolites, and the relations which subsist between atmospheric conditions and the development of organic species.

The above is a general outline of the scope and limits of meteorology. Its successful study will be seen to involve a pre-acquaintance with many sciences, more especially those of chemistry and electricity. There does not, indeed, exist any science having limits so undefined as meteorology. From a consideration of the theory of shooting stars to a contemplation of the mutual alliance subsisting between certain forms of disease and atmospheric conditions, or the relation between certain animal and vegetable tribes and given atmospheric conditions, the divergency is wide. Nevertheless, all these branches of study are intimately allied with meteorology; and perhaps the most delightful part of botanical science is that which seeks to establish connections between the localization of certain vegetable families in districts characterized by some peculiarity of meteorologic condition. Horticulturists have been too ready to overlook the influence of remote atmospheric conditions on certain vegetable families. Too frequently it has been considered that a vegetable surrounded by an atmosphere of temperature similar to that of its native region, and planted in a soil of similar chemical composition, must necessarily thrive. There are, nevertheless, meteoric conditions beyond these. Why is it that many species of the palm tribe refuse to grow very far away from their native regions, although transplanted to localities seemingly identical in all respects? Why is it that the cocoa-palm refuses to grow in regions very far distant from the sea? These questions involve meteorologic considerations of great interest; and not less interesting to a meteorologist is the partiality evinced to a restricted region by the cinchona tribe. An atmosphere very much rarefied and perpetually moist are so essential to their existence, that they cannot live without it.

The natural approach to meteorology is the study of the atmosphere, which admits of being contemplated under many aspects. It may be contemplated either as the atmosphere proper or theoretical, composed of two gases, oxygen and nitrogen; or as the practical atmosphere or mixture of the gaseous theoretical atmosphere with numerous vapours, extraneous gases, and fleeting undetermined miasmata. The atmosphere, too, admits of being regarded statically, *i.e.* at rest, and dynamically, *i.e.* in motion, the latter involving a study of the causes of winds. The atmosphere, lastly, may be considered in relation to the imponderable agents, to heat, light, electricity, and magnetism. I shall begin by investigating the nature of our atmosphere regarded chemically.

Chemical Constitution of the Atmosphere.—By the ancients air was considered to be an elementary substance. Chemistry at length demonstrated it to consist of two gases, oxygen and nitrogen combined, or rather mixed in the proportions of about eighty parts, by measure, of nitrogen, and twenty of oxygen; or, in other words, one volume of oxygen to four of nitrogen.

Considerable difference of opinion once existed on the question, whether the atmosphere be a chemical or a mechanical compound. To adduce evidence bearing on this discussion, would be foreign to the subject of meteorology. The generally received opinion is in favour of the mechanical constitution of the atmosphere. The law of the diffusion of gases perfectly accounts for the intimate mixture with oxygen and nitrogen in the atmosphere, without having recourse to the assumption of chemical union. An outline of the law in question it will be proper to give.

Gaseous Diffusion.—If two glass vessels be taken, as represented in the accompanying diagram (Fig. 1), the upper one being filled with hydrogen gas, the lower one with oxygen gas, placed in communication with each other by a capillary tube passing through the cork stopper of both, and allowed to remain at rest for about half an hour, perfect mixture of the oxygen and hydrogen gases will have ensued. Inasmuch as no chemical union takes place between the two gases thus circumstanced, and inasmuch as hydrogen gas filling the upper vessel is Lighter about sixteen times ~~heavier~~ than oxygen gas filling the lower vessel, some new cause of admixture has to be sought; it depends upon the mutual tendency of the two gases to become diffused through each other.

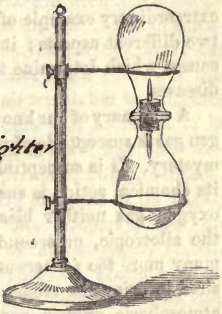


Fig. 1.

The above is an individual case exemplifying a general principle; any two gases might have been selected and mutual diffusion would have ensued. Oxygen and hydrogen gases have been here chosen because of the facility wherewith the circumstance of these having become diffused may be determined. It is well known that neither oxygen nor hydrogen gas, taken separately, will explode on the application of flame, whereas a mixture of the two readily explodes; hence the propriety of selecting these two gases for illustration of the principle in question will be obvious.

Faraday appears to have been the first to direct attention to the mutual diffusibility of gases. He noticed that bottles filled with gases, and corked or stoppered, or vessels filled with gases and inverted over mercury, in either case occluded to all appearance accurately, nevertheless almost always permitted mutual admixture of the air without and the gas within. Döbereiner, Mitchell, and Graham, more especially the latter, have since investigated this class of phenomena more narrowly, and Graham has succeeded in determining the law which regulates this diffusion. He finds that the relative diffusiveness of any two gases is expressed by the reciprocals of the square root of their densities. Thus, the density of air being one, its diffusiveness is one also. The density of hydrogen being 0·693, its diffusiveness is $\frac{1}{\sqrt{0{\cdot}063}} = \frac{1}{0{\cdot}2633} = 4{\cdot}56$; the density of ammonia being 0·5898, its diffusiveness is $\sqrt{\frac{1}{0{\cdot}5898}} = \frac{1}{0{\cdot}7681} = 1{\cdot}30$; and generally representing the density of a gas by d, its diffusiveness is $= \sqrt{\frac{1}{d}}$. Applying this rule to practice, it appears that, supposing hydrogen and ammonia placed under circumstances promoting their mutual diffusion, 456 volumes of hydrogen will become mingled with 1·30 of ammonia.

It will be remarked that the atmosphere has hitherto been treated of, in a theoretical sense, as a mere mixture of nitrogen and oxygen gases. Practically, however, the atmosphere is far more complex. It invariably contains portions of carbonic acid (about one part in a thousand), also extraneous gases, besides aqueous and other vapours. A mixture of all these things may be termed, distinctively, the actual or *practical* atmosphere. They will hereafter come under our notice *seriatim;* but even a theoretical mixture of oxygen and nitrogen gases is subject to remarkable variations of property, its chemical composition remaining unchanged; portions of its oxygen are subject to be converted into *ozone.*

The change of common oxygen into ozone, furnishes an illustration of one of the most remarkable discoveries of modern science. It displays what is, perhaps, the most extraordinary example of the condition of *allotropism*, or the existence of one body under two different aspects; it promises to render evident some of these occult atmospheric causes which determine the progress of epidemics, and promote the existence of endemic diseases.

A summary of our knowledge relative to ozone may be briefly stated as follows:—Oxygen gas is susceptible of undergoing a change, the nature of which is altogether veiled in mystery. It is susceptible of becoming odorous, corrosive, and irritating when breathed; its chemical action is susceptible of being exalted and modified, so that whilst ordinary oxygen gas neither bleaches nor corrodes silver, nor decomposes iodide of potassium, the allotropic, or second form of oxygen gas, will accomplish all these results, and many more too numerous for mention here. The general conclusion to which it is desired to bring the reader is this: if causes can be proved to exist capable of changing atmospheric oxygen gas in its ordinary state to oxygen gas in its extraordinary state, how vast, how complicated must be the meteoric results determined thereby! That such natural causes do exist will be readily inferred from a consideration of the artificial methods to which the chemist has recourse for changing ordinary oxygen into ozone.

Methods of Ozonising Oxygen Gas.—The most ready method of ozonising oxygen gas is as follows:—Take a few sticks of phosphorus, scrape them free from all superficial contamination, place them in a wide-mouthed bottle containing a little water but not enough to cover the phosphorus. Let the whole remain at rest for about ten or fifteen minutes, and a considerable portion of the atmospheric oxygen will have been converted into ozone. The ozonized air thus generated will be at present mixed with vapours of phosphorous acid; washing will free the air from these, however, without removing the ozone. That the air thus treated has become considerably modified in some way, will, in the first place, be rendered evident by the smell; atmospheric air, when pure and in its ordinary state, is devoid of smell. But the atmospheric air, the product of the experiment just detailed, will be found to have a very peculiar odour. It will be found, moreover, to be capable of removing the colour cf sulphate of indigo, and other vegetable and animal colouring bodies. All this is due to the modification which ordinary oxygen gas assumed—due to its assumption of the allotropic state—to its conversion into ozone.

Another ready method of generating ozone is this:—Moisten the interior of a bell-glass receiver, or a large-mouthed bottle, with ether; then take a glass rod, heat it in the flame of a spirit-lamp, and plunge it into the bottle or bell-glass; under these circumstances ozone will be formed, provided the glass rod has not been heated to an inordinate temperature, for the circumstance has to be mentioned that ozone is reconverted into ordinary oxygen gas by contact with any body heated above a certain, but not very well-determined, point.

We have seen that the ordinary method of generating ozone consists in promoting the contact of phosphorus with atmospheric air (or oxygen) under certain conditions.

Many other substances besides phosphorus are capable of generating ozone by contact. Oil of turpentine, and many other essential oils, will accomplish this; and the fact in question cannot be too forcibly remembered by the painter, who may discover in the philosophy of ozone the reason why certain pigments fade, or are bleached, thus destroying the general effect which he desired to produce. Meteorologically considered, however, the most important source of ozone remains to be described; I refer to the production of ozone by means of electricity. Every person who has been much accustomed to work with the electrical machine must have noticed the generation of something powerfully odorous during the friction of the cylinder, or plate, against the rubber. This odour has, in point of fact, been called the *electric smell.* Now, if this electric smell be compared with the smell of the atmospheric air which has been treated with phosphorus, as just described, and washed, the two odours will be found to be identical, which is a presumptive evidence that electricity has in some way been concerned in the formation of ozone—an idea which extended experiment fully comfirms.

It has already been stated that the most prominent quality of ozone is its highly developed oxidising power. By taking advantage of this property, we are supplied with an easy means of recognizing it, by means of a test-paper, imbued with a mixture of iodide of potassium and starch. The chemical reader need not be informed that iodine colours starch blue, whereas oxide of potassium does not; therefore test-paper, imbued with iodide of potassium and starch, may occasionally be resorted to for indicating the presence of certain bodies which have the faculty of decomposing iodide of potassium, and liberating free iodine. Ozone is one of these, which fact remembered will render the following experiment intelligible :—If a piece of paper, imbued with iodide of potassium and starch, be held between the prime conductor of an electrical machine and the knuckle or a metallic ball, and electrical sparks transmitted through it, spots of blue discolouration will be seen on the paper, corresponding to each electrical spark.

The method of detecting the presence of atmospheric ozone is now readily indicated. If a strip of paper, imbued with solution of iodide of potassium and starch, turns blue, the existence of ozone is demonstrated. The experiment is very striking when performed near the sea. During the prevalence of a land wind, the test-paper will generally afford slight indications, or none at all; during the prevalence of a sea wind, however, ozone can generally be detected.

The reader will now be prepared to form some idea of the natural causes which may generate ozone. We need assume no other agency than that of electricity, to be assured that the production of ozone must be universal, and, looking on the world as an aggregate, continuous; and when we consider the potent nature of ozone, the irritation it produces when breathed, the facility with which it bleaches, corrodes, and destroys, we shall not be at a loss to understand that the consequences to living beings of its excess or diminution must be all-important. A most important function of ozone has yet to be indicated, it removes almost more rapidly than chlorine itself the bad odours resulting from the decomposition of animal or vegetable bodies. If a piece of putrid flesh be immersed for a few minutes in a bottle of ozonized air, the odour of decomposition is totally destroyed. With these facts before us, we may form some idea to ourselves of the important functions which ozone is designed to accomplish. Lessen the amount of atmospheric ozone, lower it below given limits, and increase the atmospheric temperature to the degree most congenial to organic decomposition, and the air will soon be charged with disease-bearing putrid odours.

It is in accordance with all that philosophy has been able to teach us in relation to the laws of epidemic and endemic maladies, that the presence of such gaseous odours of organic decomposition as are here assumed, must be the fruitful source of disease ; and it is not possible, after having studied the qualities of ozone, to refuse assent to the proposition that the existence of this agent in competent amount must be followed by the destruction of the pestiferous odours of organic decomposition. If, however, ozone be naturally formed at any time in excessive amount, it is not difficult to foresee that other serious consequences must result to animal life. The inhalation of an irritating gas cannot but produce injurious effects on organs so delicate as the lungs, and perhaps many of the now anomalous and inexplicable effects of change of air to patients suffering from chest diseases may hereafter receive their solution in a more intimate acquaintance with the laws of ozone.

Physical Properties of Gaseous Bodies.—The word gas is of German origin, and was first employed by Van Helmont to signify the vapour which escaped from liquids undergoing vinous fermentation. At later periods the term was applied to designate every invisible substance disengaged from bodies by the application of fire. Macquer, a celebrated French chemist of the eighteenth century, extended the meaning of the term gas to signify every kind of air besides atmospheric air; and modern chemists have extended the meaning of the term still further to indicate elastic fluids, whatever their colour may be, which are not readily condensible. At one time it was erroneously imagined that gases did not admit of condensation; in accordance with this belief a gas was defined as being *a permanently elastic* fluid, thus distinguishing this class of bodies from mere vapours, which, so far from being permanently elastic, are very readily condensible. Modern discovery has proved this distinction to be untenable. All the known gases, except oxygen, nitrogen, hydrogen, nitric oxide, carbonic oxide, and coal gas have been liquefied, and a great number of them solidified, by subjecting them to extreme cold and pressure.

Law of Marriotte—The Volumes of Gases are inversely to the Pressure applied.—This is a very celebrated law, and one that intimately concerns the meteorologist; it may be otherwise termed the law of compressibility of elastic fluids.

It will be recognized that the law in question, according to the exposition of it just given, is a general law applying to a vast number of gaseous and vaporous bodies. For a long time its absolute truth remained unquestioned, but more recently M. Regnault and others have demonstrated it to be not of such universality.

Even atmospheric air and nitrogen do not rigorously conform to the law; and carbonic acid, and liquefiable gases generally, are so little amenable to the law, that, as applied to them, it cannot be regarded as approximately correct. Even the rate of compressibility of hydrogen is not strictly accordant with the law, although the deviation in this case is in the opposite direction to the deviation when atmospheric air is concerned; for it suffers less compression than, according to the law, should take place. Carbonic acid and nitrogen, when compressed by a force of forty-five atmospheres, only fill seven-tenths of the space they ought to occupy according to the law.

Now, inasmuch as the philosophy of estimating the height of mountains barometrically, is intimately associated with the law of Marriotte, it is well to indicate that this law is not quite correct; nevertheless, as regards atmospheric air, it is so nearly correct that we may accept it without demur.

The experiment by which the law of Marriotte was deduced is as follows:—Into a strong glass tube, of equal diameter throughout, bent on itself (as represented in Fig.

2), open at the long and closed at the short extremity, a little mercury is poured in such a manner that it shall be perfectly level in the two legs, as represented by the line A B. Under these circumstances it will be evident that the air inclosed between B C and A D will be equally compressed. Let us assume the amount of compression to be represented by the weight x. Let us furthermore assume that the weight of a column of mercury between O and D to be $= x$, and let us call it m. If, then, on filling the long arm of the syphon with mercury, the column of air originally extending from B to C be diminished to the column extending from B′ to C, that is to say, to one-half,

then we have $x + m = \frac{1}{2}$ B C, or $2\,x = \frac{1}{2}$ B C;

proving that the compression of air within the limits of the experiment is inversely to the pressure applied. In like manner, when the pressure is triple, the volume of gas is reduced to one-third; when quadruple, to one-fourth, etc. M. Arago has experimentally determined that the law rigorously applies to atmospheric air up to a pressure of twenty-seven atmospheres.

The Atmosphere as a Ponderable Agent.—Owing to the equality of pressure which the atmosphere exercises on every side, we are not ordinarily conscious of its possessing weight. Nevertheless, its weight is no less definite, under proper limitations of demonstration, than the weight of any solid or liquid. The weight of the atmosphere may be contemplated under two conditions: firstly, as the equivalent weight of an atmospheric column of known sectional area but unknown height; secondly, as the equivalent weight of a known atmospheric volume under proper limitations, presently to be indicated. Both these investigations will now have to be considered.

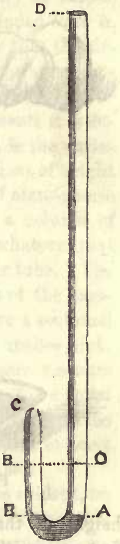


Fig. 2.

Determination of the Weight of an Atmospheric Column of known Sectional Area but unknown Elevation. The Barometer.—*Experiment* 1.—If a piece of glass tube be taken equal in bore throughout, having a length of some thirty-three or thirty-four inches, closed at one extremity and open at the other; if it be filled with mercury, then closed temporarily by the thumb, and inverted in a basin of mercury, as represented in the accompanying sketch (Fig. 3), we shall obtain a barometer of perhaps the most simple form this useful instrument can assume. We will proceed to study its philosophy. Firstly, let it be observed that though the tube *was* quite full of mercury, it does not remain quite full. No sooner is the restraining thumb removed, than a portion of the mercury sinks into the basin. If, instead of holding the inverted tube in the hand, as represented, some permanent support be devised

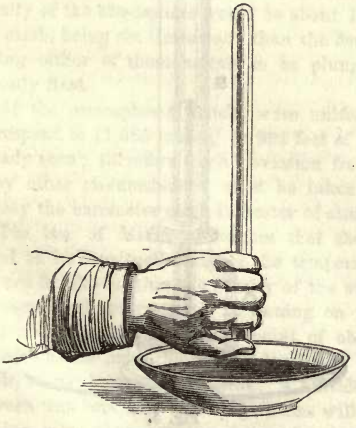


Fig. 3.

for it; if the point corresponding with the present elevation or level of the mercury be marked on the tube; and if the tube be examined from day to day, the observer will soon find the level to fluctuate; some times it will rise, at other times fall. He will find, moreover, that the mercury will become depressed previous to stormy weather.

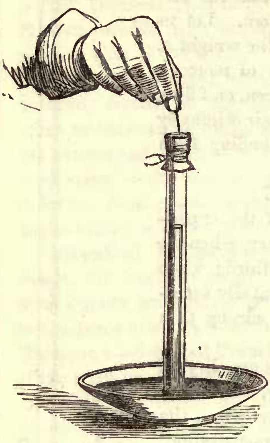


Fig. 4.

The instrument thus roughly extemporized is, in point of fact, a measurer of the weight of an atmospheric column of known sectional area (*i.e.*, the area of the interior diameter of the tube), but of unknown elevation. It is a barometer; and collaterally—inasmuch as depression of the mercurial column usually precedes stormy weather—the roughly-extemporized instrument is a weather-glass.

Demonstration.—It is desirable occasionally, when treating of natural phenomena, to violate the mathematical rule of accepting no fact until it has been demonstrated.

Thus, in the present instance, I have taken the fact for granted that the cause operating to maintain a mercurial column in the closed tube, is atmospheric pressure; and the cause to which variations of the height of that column is referable, is fluctuation of atmospheric pressure. The first proposition shall now be demonstrated, when the second will be accepted by inferential reasoning.

Experiment 2.—If, instead of a tube closed at one extremity, an open tube be taken and one end be occluded by tying securely over it two or three strong pieces of moistened bladder: if the tube thus prepared be filled with mercury, as before, and inverted in a basin of mercury, we shall be in a position to demonstrate the proposition that it is owing to atmospheric pressure—and that alone—that the mercurial column is supported. The operator has simply to prick the bladder, and let in air, when the whole column suddenly descends to the level of the mercury in the basin (Fig. 4).

There is another form of demonstration, as follows; but it is not so simple as the last, inasmuch as it requires the aid of the air-pump:—

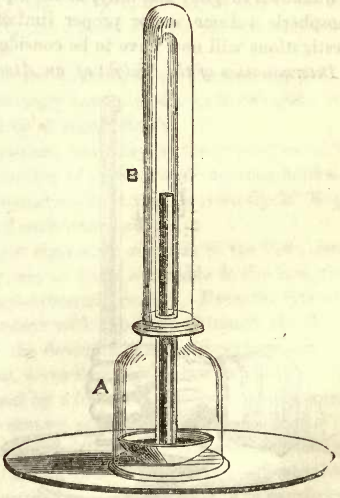


Fig. 5.

A is a glass air-pump receiver (Fig. 5), through the neck of which the tube B passes, inclosed in an exterior tube, which may be regarded as a prolongation of the receiver. C is the plate of an air-pump, on which the receiving jar is laid.

Let us assume that the barometer tube has been filled with mercury as before, plunged in the basin containing mercury underneath, the receiver A slipped over it, and finally extension made by the long glass sheath. Let us assume now that the air-pump is worked, and exhaustion gradually effected. Under these circumstances, the mercurial columns will be seen to fall, and it will fall by jerks, each jerk corresponding with a stroke of the pump-handle. Hence, by the two preceding experiments it is demonstrated that to atmospheric pressure, and atmospheric pressure alone, is the variation mercurial column due. It is also proved, inferentially, that the fluctuations of height witnessed from day to day in a barometric column are due to variations of atmospheric pressure. It appears, then, that by the barometer we actually weigh a column of atmospheric air equal in length to the whole elevation of the atmosphere, whatever that may be, and equal in area to the internal sectional area of the barometer tube. The barometer, however, gives us no information in terms of cubic dimensions of the barometric mercury. Thus, supposing the barometric tube employed to have a sectional area of one square inch, and supposing the mercurial column to be thirty inches high, then we should be correct in averring the pressure of an atmospheric column a square inch in sectional area, and extending the whole height of the atmosphere, to be equal to the weight of thirty cubic inches of mercury. Now the weight of thirty cubic inches of mercury will be about fifteen pounds; hence the atmosphere is said to exert a mean pressure of fifteen pounds on every square inch at the level of the sea.

Influence of Elevation on the Barometric Column.—It will be evident, on reflection, that the atmospheric pressure must decrease with every increment of elevation above the level of the sea. Founded on this principle, the barometer is frequently employed to determine the height of mountains; and, reversing the application, it might also be employed to determine the depth of mines and wells. At the elevation of about thirty-six miles, the pressure of the atmosphere cannot amount to more than 0·001 of an inch of the barometric column; and conversely, at a depth of about sixty-six miles, the density of the atmosphere would be about 100,000 times greater than at the surface of the earth, being six times more than the density of gold and platinum; so that, supposing either of these metals to be plunged into such an atmosphere, they would actually float.

If the atmospheric density were uniform, a barometric fall of one inch would correspond to 11,065 inches, or 992 feet of air. But it is not uniform, as we have already seen; therefore such deviation from the standard of uniformity, and indeed many other circumstances, must be taken cognizance of before we are enabled to employ the barometer as an indicator of atmospheric elevations.

The law of Marriotte teaches that the dilation of a volume of air is proportional to its density, so long as the temperature to which it is exposed is constant; whence it follows, that the density of the atmosphere diminishes from below upwards in geometrical progression. Reasoning on this basis, it appears that, assuming any particular elevation above the point of observation, its numeral exponent may be regarded as the logarithm of the density of the lowest atmospheric layer, or, in other words, of the barometric column. A consideration of the mutual relation subsisting between numbers and their logarithms will render this evident, for logarithms are nothing more than numbers increasing by arithmetical progression, corresponding to other numbers, the increase of which is also in geometrical progression. Being possessed of a table of logarithms expressing the densities of atmospheric layers, one might calculate the height of a mountain by two observations made at two stations; but the same result may be arrived at by using a common table of logarithms, and multiplying them by a constant factor. According to Deluc, the factor is 10,000.

Many other considerations have yet to be taken cognizance of before the barometer can be accurately applied as a measure of mountain elevations—they are temperature, latitude, relation subsisting between the specific gravities of air, and mercury $= \frac{1}{1046}$, and dilation of mercury for each degree of the thermometer $= 0 \cdot 0001$ for each degree of Fahrenheit's scale. All these general considerations have been embraced in tables.

Although the circumstances necessary to be taken cognizance of when employing the barometer as an indicator of mountain elevations are numerous and complicated, nevertheless the results obtained are susceptible of a considerable degree of accuracy. Subjoined is a table of comparative results between trigonometric and barometric observations. The difference, it will be seen, is only trifling.

COMPARISON OF TRIGONOMETRIC AND BAROMETRIC MEASUREMENTS OF MOUNTAIN HEIGHTS.

Observers.	Place of Observation.	Latitude.	Longitude.	Trigonometric height in feet.	Barometric height in feet.
Webb . .	Gunna Nath, Stockdale	29° 45′ 56″	79° 30′ 29″	6,828	6,831
Borda . .	Bagha Ling, Temple .	29° 47′ 30″	80° 2′ 27″	7,646	7,635
Von Buch.	Teneriffe	28° 30′ 0″	16° 13′ 0″	12,188	....
	Ditto	....	....	....	12,131
Buckle .	Sugar-loaf, Sierra Leone	8° 29′ 40″	13° 15′ 0″	2,493	....
Sabine .	Ditto ditto .	....	....	....	2,521
Sabine .	Spitzbergen	73° 0′ 0″	10° 0′ 0″	1,644	1,640

When an approximate result is alone required, and the height is inconsiderable, a fall of $\frac{1}{10}$th of an inch may be allowed for every ninety feet of elevation, or $\frac{1}{1000}$th of an inch for every foot. This rule suffices for the small differences of elevation at which barometers are hung, and enables the observer to institute a comparison between them. Correction for temperature must, however, not be omitted. The ratio of expansion for mercury, glass, and brass—the materials employed in the manufacture of barometers—will be pointed out hereafter; meantime I may as well indicate that perhaps, after all, it is well in practice to ignore these complex elements, and to consider $\frac{3}{1000}$ths of an inch as the allowance for mercurial expansion for every degree above 32, and *vice versa*. Applying the above corrections for temperature and pressure to practice, let it be required to know the altitude at the level of the sea and at 32° Fah. of 29·565 inches of mercurial column at a place 150 feet above the level of the sea, and at temperature 55° Fah.

	Inches.
Actual height of mercurial column	29·565
Deduct for 23° of temperature above 32 $\frac{3}{1000} \times \frac{23}{1} = \frac{69}{1000}$ = . .	·369
Altitude of mercury . . . = . .	29·496
Add for elevation ·001 × ·150 . . . . = . .	·150
Altitude at level of sea, at temperature 32° Fah. . . = . .	29·649

The reader will remember that the previous remarks have reference to the barometer as affected by air at rest, this being the simplest atmospheric condition which theory can assume. Hereafter we shall discover that the barometer, when influenced by the atmosphere in motion—by winds, in other words—is subject to influences from that cause.

Further Improvements of the Barometer.—The barometer in its simplest form, as already described, is a more perfect instrument than many in which simplicity of form is departed from, in deference to portability; nevertheless it is not quite correct. To be absolutely correct it is indispensable that the mercurial level in the basin should bear a constant ratio to the mercury remaining in the tube, a condition which evidently cannot be obtained in the instrument just described. In proportion as mercury descends out of the inverted tube, the level of the mercury in the basin will be elevated, and to the extent of such elevation the indications of the instrument will be prejudiced. Various means are had recourse to for lessening, or absolutely removing, this evil. It may be lessened by increasing the width of the basin to such extent that the ratio of elevation of the mercurial surface may be so greatly diminished that it will practically cease to impart errors. It may be absolutely removed by one of two devices. One consists in mounting the receiving basin on a screw, which, by elevation and depression, regulates the quicksilver to any desired level. Such is the contrivance of M. Fortin, whose construction of a barometer is here subjoined (Fig. 6); but more usual is it to attach to the barometer a long scale having a slide motion, so that the lower end or commencement of the scale may be made to coincide with the level of the mercury in the basin. Practically, however, the basin is usually dispensed with, the reservoir for mercury being a mere extension of the barometric tube, in some cases bulbed, and in others quite plain. Both these forms of construction are annexed (Figs. 7, 8).


Fig. 6.

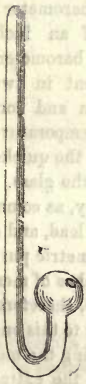


Fig. 7.


Fig. 8.

The Weather-glass.— The primary and only *direct* function of the barometer is as I have described. Its mercurial column indicates, by rising and falling, the varying weight of the superincumbent atmosphere. Very frequently this direct function is taken no account of; variation in the state of the weather being all which the observer desires to make himself acquainted with. Subserviently to this intention, all direct rise and fall of the barometric column is lost sight of, and the indications of a dial-plate with moveable hand substituted. Such an instrument is termed the dial weather-glass, the construction of which is as follows:—T (Fig. 9) is a barometer tube, W is a small float attached to one end of a cord, the other extremity of which is attached to a small weight, N. From this arrangement it will be seen that every rise and fall of the real barometric column in the long arm of the tube, will correspond with a parallel fall and rise of the mercurial column in the short arm. It will be seen, moreover, how the small float, *w*, is raised and lowered, how the pulley M will be caused to revolve, and the index-hand to traverse the dial plate of the instrument. The exterior of the wheel barometer is represented in Fig. 10.

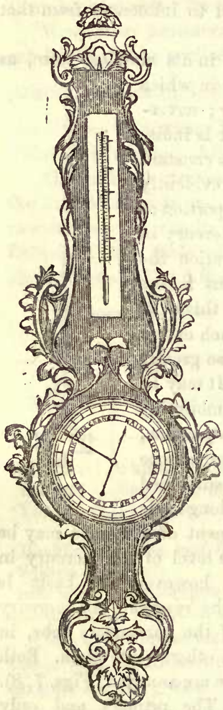


Fig. 10.

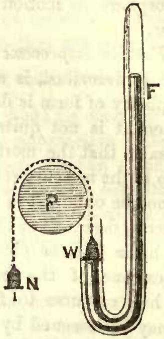


Fig. 9.

I need scarcely indicate that the wheel barometer is considered, *barometrically*, a very imperfect instrument. Not only is the varying ratio between the mercurial column and the level of the mercury in the reservoir here a necessity, the very index motion depending upon it; but the presence of the float, *w*, tends also to embarrass the free ascent and descent of the column of barometric mercury.

Manufacture of a Correct Barometer.—Not to render the principles concerned in the barometer complex, I have hitherto assumed that the act of charging a tube with mercury is simple and free from difficulties. Practically this is not so; many precautions have to be taken, otherwise the resulting barometer will be anything but correct. Firstly, the tube selected must not be too small; many instruments are rendered incorrect owing to neglect of this precaution. The internal diameter of the barometer tube should scarcely be less than a quarter of an inch; it may be even more with advantage. A small barometer tube prejudices the correctness of the instrument in two respects. Firstly, the variations of expansion and contraction of the mercury, due to variations of temperature, are more considerable; secondly, the motion of the quicksilver up and down is impeded by friction against the glass.

The Mercury must be Pure and deprived of Atmospheric Air.—Mercury, as commonly existing, is generally impure. It contains uncertain quantities of tin, lead, and sometimes zinc. Of course these admixtures damage the mercury for barometric purposes. The observer desires to read off his atmospheric pressures in terms of inches of mercury, not in terms of inches of a mercurial compound. It is indispensable, therefore, that the impurities be discharged or extracted. Various processes are used to this end, but the process usually followed by makers of barometers consists in agitating the mercury to be purified with dilute nitric acid, which gradually dissolves out the extraneous metal and leaves the mercury pure.

Far greater difficulties are encountered in discharging atmospheric air from the mercury employed. This is accomplished by boiling the mercury after it has been poured into the tube. The operation requires great delicacy, and the instrument is frequently broken in the operation.

Method of Reading off Barometric Indications correctly.—It is not possible to read off by referring to a common scale of inches and parts of inches the various small elevations and depressions of a barometric column. Two methods are had recourse to for obviating this difficulty: one is the diagonal tube, a contrivance altogether peculiar to the barometer; the other is the vernier or nonius scale, employed for the general purposes of facilitating the reading of minute scale divisions.

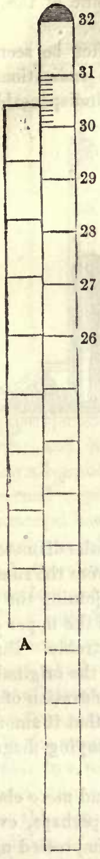


Fig. 12.

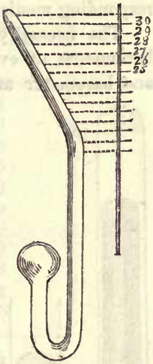


Fig. 11.

The diagonal-tubed barometer is represented by the accompanying diagram (Fig. 11).

The Nonius or Vernier Scale.—This is an ingenious contrivance for measuring small linear divisions by means of larger divisions, and consequently more easily recognizable by the eye than larger divisions would be. Thus, for example, by means of a vernier graduated in divisions of an inch and one-ninth we can read off tenths of an inch, as will be seen by reference to Fig. 12.

Let A be a scale sliding in proximity to B. Let each of the divisions on B be = one inch, and each of the divisions on A = one inch and one-ninth. From these considerations it follows that nine divisions on A are equal to ten divisions on B. Directing the eye to the upper limit of A, it will be seen that its edge corresponds to thirty inches, and *something more* on B. In this case the observer would have no difficulty in recognizing the amount over and above thirty inches on B to be equal to four-tenths of an inch. Our scale divisions are so large that a vernier scale is not required for conveying that information. But assume the tenths division between 30 and 31 to be obliterated, still we should be able to discover the overplus beyond 30 inches to be four-tenths by means of the vernier scale A, inasmuch as the number of tenths will be equal to the number of whole parts on the vernier scale A above the first line of coincidence between it and the scale B. Now the line of coincidence in question is at 26, counting upwards, from which, to the extremity, we have four divisions, which indicate a fraction of four-tenths of an inch over and above 30 inches.

Fig. 13.

Correction of the Barometric Column for Capillarity.—If mercury be poured into a glass vessel, it will not furnish a perfectly level surface, but will be elevated, as in the accompanying diagram (Fig. 13); or, in the language of philosophy, it will constitute a meniscus; and if the line V be dropped perpendicular to the line B, joining the two corners of the meniscus, the line V will constitute, in the language of trigonometry, the versed sine of the meniscus. The convexity of the meniscoid surface of mercury will vary in proportion as the diameter of the tube or other vessel containing the mercury varies. Hence the allowance to be made for diminution of the height of a mercurial column, owing to capillarity, is determined by two considerations—the diameter of the tube, and the length of the versed sine of the corresponding meniscus.

The necessity for such allowance does not apply, as will hereafter be seen, to barometers of every form; neither is it imperative, so long as the indications of one barometer are to be compared amongst themselves; but it is indispensable if we would compare the indications of barometers with each other.

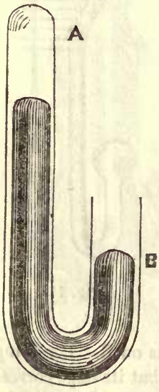


Fig. 14.

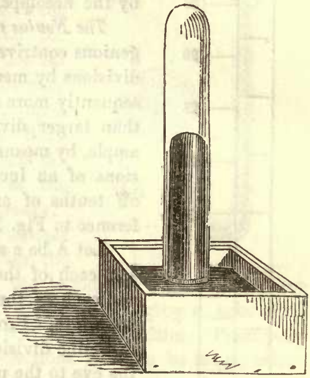


Fig. 15.

First, let us consider the cases to which the correction for capillarity does not apply. It does not apply to any barometer, the reservoir of which constitutes part of the tube itself. The accompanying diagram (Fig. 14) represents a barometer of great tubular diameter. Two meniscoid surfaces of mercury are there apparent—one at A, another at B. Now it is evident that the columnar interference at A will be exactly equal to the columnar interference at B, provided the tubular diameter be equal throughout. Hence, whether the degree of elevation be counted from the summit of the lower to the summit of the upper meniscus, or from the base line joining the two corners of the lower meniscus to the base line joining the two corners of the upper one, the two resulting columnar estimations will be strictly equal and comparable. But it is different when the observer has to do with barometers constructed on the original, or Toricellian, plan of a separate reservoir; in this case the meniscoid elevation of the mercury in the reservoir is practically ignored, being so inconsiderable that it amounts practically to nothing, as will be seen by reference to the accompanying diagram (Fig. 15).

Annexed is a small table of depressions due to capillarity. Larger and more elaborate tables have been calculated, but the one given will suffice for, perhaps, every occasion. The meteorological student cannot have the fact too strongly impressed upon him, however, that the barometer is confessedly a very imperfect instrument; therefore correct results from barometric observations are to be looked for as the mean resultant of a number of accumulated observations, rather than from any elaborate mathematical tabulations of principles, correct enough in themselves theoretically, but which do not admit of being realized in practice.

In the record of some barometrical observations, we find cognizance taken of thousandths of inches. Until the errors which attach to the principle of the barometer greatly diminish, a record of thousandth of inches cannot be otherwise regarded than as a kind of philosophic affectation.

DEPRESSION DUE TO CAPILLARY ACTION.

Diameter. Hundredths of inches.	Depression in Decimals of Inch.		
	Ivory.	Young.	Laplace.
5	·2949	·2964	....
10	·1404	·1424	·1394
15	·0865	·0880	·0854
20	·0583	·0589	·0580
25	·0409	·0404	·0412
30	·0293	·0280	·0296
35	·0212	·0196	·0216
40	·0154	·0139	·0159
45	·0112	·0100	·0117
50	·0082	·0074	·0087
60	·0043	·0045	·0046
70	·0023	....	·0024
80	·0012	....	·0013

Thermal Expansion.—I have already adverted casually to the condition of thermal expansion as an interfering cause in all estimations of true barometric columnar heights; and, by anticipation, I have already furnished an approximative means of making allowance for it. We will now proceed to examine more narrowly the function of thermal expansion, which not only intimately concerns the barometer, but is the fundamental basis of the thermometer, and besides it enters as an element into so many meteorologic calculations, that a thorough investigation of its laws cannot be omitted. I shall, therefore, embody the laws of thermal expansion in a few propositions for successive demonstration.

Heat may be regarded in the two senses of signifying temperature, or that sort of heat which is recognizable to the sense of touch, and which affects the thermometer; and heat which is devoid of these manifestations, which neither creates the sensation of warmth nor is amenable to thermometric demonstration. The former we may express by the term sensible heat, and the second by the term latent or insensible heat.

On the supposition that all the functions of heat, sensible as well as insensible, are referable to a real physical agent, the term caloric has commonly been applied as the representative of such agent; but though the term be in general use, it is perhaps objectionable—modern science leading us to infer that the functions of heat are due to a condition of matter, rather than to a separate agency. It is to evident heat, recognizable to the touch, that I shall now direct the reader's attention.

I. *Heat affects the Volume of all Bodies.*—The general effect of heat on bodies is to cause their expansion. So general is this rule, that we shall do well to consider it as universal; treating all deviations from it hereafter as so many exceptions.

II. *The Volume of all Solids is increased by increase of Heat.*—This proposition is demonstrated by so many instances commonly occurring, that specific experiments are hardly required. The wheel-wright takes advantage of this property to bind tightly together the wood-work of his carriage-wheels. He heats the annular tire, by which he expands it; he then slips the tire over and around the wood-work, and, allowing the tire to cool, the wood-work is tightly braced together by an indomitable force.

Some years since the walls of the *Conservatoire des Arts et Metiers*, at Paris, were found to be diverging from the perpendicular. They were restored to their original lines by the following beautiful expedient:—They were perforated transversely, copper bars were thrust through the perforations, each bar at either extremity being supplied with a nut and screw. Every alternate bar was now heated by means of a spirit-lamp flame; being heated the bars expanded, and the screw-nuts being now turned close up to the wall on either side, the bars were allowed to cool. By cooling they contracted, pulled the walls to some extent together, leaving the ends of the unheated bars protruding; their screw-nuts were now turned close up to the wall on either side, and the heating process repeated. Thus little by little the walls were restored to their original position.

An exemplification of the expansion of iron by heat sometimes occurs to the laundress. Occasionally she is surprised to find that the heater of her Italian iron will not enter its corresponding sheath when red hot, though it enters readily enough when cold. This is attributable, as the student will perceive, to the effect of thermal expansion on the iron (Fig. 16).

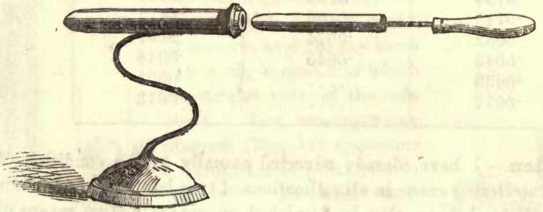


Fig. 16.

Thousands of familiar instances might be cited, all illustrative of the same property. I shall leave their consideration to the reader, concluding my remarks on this part of the subject by bringing before his notice a common lecture experiment, illustrative of solid thermal expansion. Let G (Fig. 17) be a guage, into which the metallic bar, A, accurately fits, whilst cold; it will be found that when the bar A is heated—moderate heating will suffice, such as may be accomplished by means of the flame of a spirit-lamp, or a basin of hot water—the heated bar will no longer fit into the guage. In this way the student may demonstrate the fact that each different solid possesses its own definite rate of expansion for equal degrees of temperature.

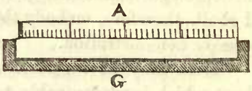


Fig. 17.

Investigations of the law regulating the thermal expansion of bodies under every condition are attended with extreme difficulty. They have been conducted by Regnault, Rudberg, and others, with great industry and much success; but, as in most cases where the investigation of natural phenomena through long ranges are concerned, the results are merely approximate. To give the reader a general notion of one of these difficulties, let it be assumed that A B C D stand for successive equal intervals of thermometric graduation. Let it be assumed that the rate of expansion of a substance from A to D be known to be equal to a quantity expressed by Y. It by no means, however, follows—nor do philosophers believe—that because the rate of expansion of the body between A and D is equal to Y, therefore the rate of expansion of the same body between A and B is equal to $\frac{Y.}{3}$

Further consideration of this matter may, however, be omitted in a treatise on meteorology. We merely want to be acquainted with approximate results of the law, in order to allow for practical discrepancies between the apparent and the actual indications of the instruments employed in the course of our researches.

To convey a general notion of this kind of knowledge to the meteorological observer, the student's attention may be directed to the fact that, supposing a barometer-scale to be made of brass, and supposing the tube to be filled as usual with mercury, then the amount of expansion of mercury by heat, and for which allowance has to be made, will be determined by the ratio $\frac{M}{B}$, if M stands for the co-efficient of expansion of mercury, and B with the co-efficient of expansion of brass. By the term co-efficient of expansion is meant the number indicating the amount of expansion peculiar to any body for given ranges of temperature.

III. *The Volume of all Liquids is increased by increase of Heat.*—Investigations prosecuted for demonstrating this law are attended with a difficulty which does not apply to the previous case. Liquids require vessels to hold them, and these vessels are themselves amenable to expansion. This difficulty has been very ingeniously avoided by MM. Petit and Dulong, who determined the expansion of liquids by a method founded upon the well-known hydrostatic principle, that the vertical heights of two fluids communicating by a horizontal tube are in inverse ratio to their densities. The accompanying apparatus (Fig. 18) was employed in their experiments. A, B, C, D is a tube bent twice at right angles, and enlarged at either extremity; the two vertical tubes are connected inferiorly by a horizontal tube of exceedingly fine bore. By virtue of the hydrostatic law just mentioned, it follows that if any liquid of homogeneous density be poured into the vertical leg of one side, it will rise to a corresponding elevation in the vertical leg of the other; and if the fluid in one vertical leg be now heated, and consequently expanded, its height will be in excess of the columnar height of the other by a definite quantity. By an easy train of mathematical reasoning, the expansion due to heat can be deduced from a consideration of the different levels and the different temperatures of the two vertical tubes. Our diagram represents each vertical tube surrounded with a cylindrical vessel. These vessels are for the purpose of commanding variations of temperature, one tube being filled with ice, whilst the other is filled with hot water.

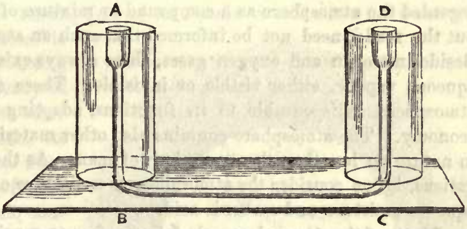


Fig. 18.

By an experiment of this kind, the co-efficient of thermal expansion of mercury from 0 to 100 of the centigrade scale is $\frac{100}{5550}$; whence, assuming its rate of expansion equal throughout, the expansion for every centigrade degree will be $\frac{1}{5550}$, or for every degree of Fahrenheit $\frac{1}{9990}$; in decimals = 0·000101; or, expressed in round numbers, one ten-thousandth part of its bulk.

IV. *The Volume of all Gases is increased by increase of Heat.*—Though the consideration of this law is not related, like the two preceding, to the *construction* of the barometer, it is intimately connected with the functions of that instrument, more especially as regards its application to the measuring of elevations; we shall do well, therefore, to consider it at once.

It has already been remarked, that the rate of expansion of all solid bodies for given increments of temperature is various; and a similar remark applies to liquids. The rate of expansion of gases was first closely investigated by the immortal Dalton, who arrived at the conclusion that all gases were equally affected by equal increments of heat, expanding to $\frac{1}{480}$th parts of their volumes at 32° Fah. for each of the 180°, between 32° Fah. and 212° Fah. As regards temperature above 212° Fah. and below 32° Fah., it was imagined by Dalton that the same law of expansion held good. Various theoretical reasons exist of a nature to create a doubt as to the large generalization of Dalton, and these doubts have been fully substantiated by M. Regnault. He finds that all gases do not dilate to the same extent between equal limits of temperature, neither is the dilatation of the same gas between the same limits independent of its primitive density. These are interesting facts: they prove that to assume one co-efficient of dilatation for all gases is obviously incorrect; nevertheless his experiments go to prove that such an universal gaseous co-efficient of dilatation may be adopted for convenience, without appreciable error, within the theoretical limits of ordinary experiment. We must not, however, continue to adopt $\frac{1}{480}$th as our working gaseous co-efficient of dilatation for every degree of Fah. between 32° and 212°, nor $\frac{1}{483}$, as subsequently adopted by MM. Petit and Dulong, but $\frac{1}{491}$.

The Atmosphere Actually or Practically Considered.—We have hitherto regarded the atmosphere as a compound or mixture of nitrogen and oxygen gases only, but the reader need not be informed that such an atmosphere is altogether theoretical. Besides nitrogen and oxygen gases, there always exists a portion of carbonic acid, also aqueous vapour, either visible or invisible. These are invariable components of the atmosphere, indispensable to its functions, adapting it to the purpose of this world's economy. The atmosphere contains also other materials, the results of local operations in nature no less than the operations of man. As the subject of our present investigations, let us consider the atmosphere as a mixture of the theoretical atmosphere *plus* aqueous moisture and carbonic acid.

Limits of the Atmosphere.—It follows, from a consideration of the laws of elasticity, that the atmosphere must vary in density for every difference of elevation. The atmospheric layer nearest to the earth must be pressed upon by the superincumbent atmosphere above it; whence the deduction follows, that when we speak of 100 cubic inches, or *any* definite measure of the atmosphere, weighing a certain number of grains, certain conditions and limitations are implied. Some of these have reference to the composition of the atmosphere chemically considered, others have reference to the atmosphere merely regarded as an elastic medium. To the latter consideration alone the reader's attention will be now directed.

Seeing that the atmosphere, in accordance with the laws of elasticity, must necessarily expand the higher we ascend above the normal level of the surface of our globe—or, in other words, the level of the sea—the first question which arises is this—To what extent do the atmospheric limits reach? does the expansion go on *ad infinitum* to the farthest realms of space, or are these limits definite? and if definite, what is the cause, or what are the causes, of limitation? Two theories have been adopted in reference to this question. According to one theory the atmosphere is illimitable; according to the other it is limited. Some of the arguments for and against I shall now proceed to give.

If the atmosphere be really illimitable, let us see what should follow, to be in accordance with recognized laws, to which all ponderable matter, or matter subject to gravitating influences, is amenable. Gravitation being directly as the mass of gravitating bodies, it should follow that, were the atmosphere illimitable, each of the heavenly bodies should be surrounded with an atmosphere proportionate to its mass—an assumption which astronomy disproves. Thus astronomy furnishes strong proof in favour of the finite extension of the atmosphere. A consideration of the laws of the atomic constitution of matter lends further, and perhaps stronger, proofs. Chemistry is full of evidence in favour of the atomic constitution of matter; or, in other words, is full of proofs that all material substances are composed of molecules or particles; to which extent they can alone be divided, and not beyond. The mathematical reasoning which has been employed against this atomic theory, as chemists term it, is specious at a first glance, but really untenable. To argue that the theoretical space occupied by any material particle may be supposed capable of division, and sub-division, *ad infinitum*, is really not to the point. Space is one thing, the matter occupying such space is another. The mathematical objection touches the space alone, not the matter; therefore the chemical evidence in favour of the atomic constitution of matter is unanswered, and is apparently unanswerable. Let us now regard the consequences of this assumption as it relates to atmospheric air. The late Dr. Wollaston was the first person who directed attention to the limitation which should theoretically be imposed on atmospheric expansion, supposing the assumption of its atomic constitution to be correct. The atmosphere, like other ponderable material bodies, is subject to gravitating influences, thus imparting a tendency of descent towards the earth. On the other hand, the atmosphere being elastic, its particles are mutually separated from each other by the operation of this force. Now, assuming the atomic constitution of the atmosphere to hold good, there must be some finite distance from the earth's surface, at which the force of elasticity would be counterbalanced by the force of gravitation, which distance would correspond with the farthest limits of the atmosphere. The mean distance of this limit is assumed to be about forty-five miles, though it must differ for every point north and south, being greatest over the equator, and least at either pole, as indicated by the accompanying diagram (Fig. 119).

Fig. 19.

The reason of it being greatest at the equator is immediately referable to the diurnal rotation of our globe on its axis, thus generating a centrifugal force, which has determined the oblate spheroidal form of the earth. Material bodies will be affected by this centrifugal force, *cæteris paribus*, directly as their attenuation, whence it follows that the atmosphere, being a gas, must be affected to an extreme degree. It will be sufficiently evident, however, that the atmosphere is only affected by the earth's diurnal rotation intermediately, or by friction, the velocity of motion imparted to it by the earth being less considerable than the velocity of the earth itself. We shall hereafter find, when we come to treat of the trade winds, that these permanent aërial currents are not altogether referable to atmospheric motion, but in some degree depend upon the diurnal motion of the earth.

Determination of the Weight of a given Volume of Atmospheric Air.—Nothing can be more easy than the theoretical means of solving this problem; and though certain practical difficulties do interpose, we had better, for the sake of theoretical explanation, consider them absent.

The case under consideration is general, not specific. The determination of the weight of a given volume of atmospheric air is accomplished similarly to the determination of the weight of a given volume of any other gas; nor does it differ in principle from the process had recourse to when solids or fluids are concerned.

If, to take the simplest practical case, without reference to cohesive state, it were desired to ascertain the weight of a given bulk of copper or brass—say one hundred cubic inches—the operator's first care would be to obtain a solid of copper or brass having these cubic dimensions, which having been obtained, no vessel for the purpose of weighing it in would be necessary. This is the simplest case of bulk-weighing which can occur; nevertheless, a condition has to be regarded which the superficial observer might forget, or perhaps not be aware of. The copper or brass alters its dimensions for every variation of temperature. If heated, it will expand; if cooled, it will contract; so that, practically, under no two degrees of temperature has the mass of brass or copper the same size. Practically, so long as solids are concerned, these variations of size, dependent upon variations of temperature, are not of much consequence in ordinary operations of weighing. It is necessary, however, to estimate them for other reasons, and to tabulate these variations. We shall have occasion to refer to this tabulation hereafter.

Let it now be assumed that the problem before us is to determine the weight of a given bulk of liquid—say water. In this case we must have recourse to some vessel of capacity for the purpose of holding the water to be weighed, and further elements of complexity, in addition to that of temperature, are introduced. Firstly, the vessel employed has its own laws of expansion and contraction; secondly, the water, when poured into the vessel, will not have a perfectly flat surface; so that, except the mouth of the vessel be small, an error of considerable magnitude will be imparted; neither must it be too small, or the functions of capillary attraction will come into play, and the water will present a higher level than properly belongs to it.

The chief source of inaccuracy, however, which the operator meets with in operating upon solids and liquids, is that dependent on the variations in bulk referable to thermal increments and decrements; any alteration due to variations in pressure being practically ignored. So far as atmospheric pressure is concerned, which is the only kind of pressure we need take cognizance of as affecting our subject, it exercises so little influence on the dimensions of solids and liquids, that we may put it altogether out of consideration. Far different, however, is it when gases are concerned. Their attenuation and elasticity are such, that variations of atmospheric pressure exercise the most powerful influence over them; so that the degree of atmospheric pressure operating at the time of the experiment is, at least, of equal consequence with the degree of temperature.

We are now in a position to trace the theoretical steps necessary to be followed in effecting the weight of a given volume of any gas.

Necessarily, as in the previous case, a vessel of capacity is required; but, inasmuch as a gas does not admit of being poured into the vessel like water, some practical expedient for accomplishing this must be devised. We had better omit all consideration of this for the present, and assume that the vessel (which will be a globe or flask having a neck with stop-cock attached) already filled with the gas to be weighed, at a definite temperature and definite pressure. This accomplished, the operator has only to weigh his flask full of gas, deduct the weight of the flask from the total weight of flask and gas, and the result is gained. Practically, however, many points have to be considered.

The Gas must be pure.—Whether gas, or liquid, or solid, any body, the weight of which we desire to know, must be pure; but this precaution applies in the highest degree to gases.

The Gas must be either dry or its amount of moisture must be definite.—The property which gases have of taking up vapours, especially aqueous vapour, is well known; and it will readily be seen that to the extent of the presence of such vapour will the weight of a given bulk of gas and vapour mixed fluctuate. One of two processes has now to be followed: either the gas must be artificially dried by exposure to one of the hygroscopic bodies used by chemists for that purpose; or, it must be saturated with moisture to the fullest capacity at some given temperature.

The further steps of the calculation are based upon a consideration of the ratio between the specific gravity of steam or vapour, and the specific gravity of dry gas; and, lastly, the amount of vapour which a gas absorbs at a definite temperature. According to Gay Lussac, the ratio between the specific gravity of aqueous vapour and air under similar conditions of temperature and pressure is

$$\frac{0{\cdot}620}{1} = \frac{\text{vapour}}{\text{atmospheric air}}.$$

The amount of aqueous vapour which an unit volume of gas can absorb at given temperatures, has been ascertained and tabulated.

Applying this knowledge to practice, let us assume that 100 cubic inches of moist air, at 60° Fah. and 30 inches barometer, weigh 31 grains, it is required to know how much 100 cubic inches of dry air would weigh.

We begin by turning to a table indicating the quantity of vapour present in a gas saturated with vapour at any given temperature. Dalton's table gives this quantity for 60° Fah. as 0·524. We next perform the following calculation—

30 : 0·524 : : 100 : 1·747 = the volume of vapour in 100 cubic inches of moist air at 60° Fah.

And as 100 cubic inches of aqueous vapour weigh 19 grains, 1·747 cubic inches weigh 0·3368th of a grain.

Weight of 100 cubic inches of moist air . .	31
Deduct	0·3368
	30·6632

Therefore the weight of 100 — 1·747 = 98·253 cubic inches of dry air = 30·6632 grains, and 98·253 : 30 6632 : : 100 : 31·214 grains.

Whence it follows, according to the foregoing calculation, that the weight of 100 cubic inches of dry air at 30 inches barometer and 60° Fah. is 31·214 grains.

Such, then, are the practical operations by which the weight of a known volume of gas is determined. I have chosen atmospheric air as the subject of illustration, but the processes are identical whatever the gas may be.

Although the result of the calculation just effected gives 31·214 grains as the weight of 100 cubic inches of atmospheric air at 30 inches barometer and 60° Fah., and although the number may be accepted for all purposes of meteorologic calculation, nevertheless it must not be viewed in an implicit sense. In point of fact, the exact weight of atmospheric air is not yet made out. Probably the determinations of MM. Dumas and Boussingault are most reliable. According to their experiments 1 litre or 61·02791 cubic inches of air at 0° centigrade and 0·76 metres barometer weigh 20·065 grains; whence it follows that 100 cubic inches, under the same conditions, must weigh 31·093 grains at 60° Fah.

Barometric Pressure at the time of Experiment must be an Element of the Calculation.—A consideration of the laws of pressure, as influencing the volume of gases and vapours, will have made the student aware that due allowance requires to be made for variations referable to this cause. Now we are acquainted with amount of expansion and contraction dependent on variations of pressure. This information is conveyed by a study of the law of Marriotte, which proves that a rule of proportion will furnish the information required. Thus, for example, suppose we have 100 measures of any gas at a pressure of 29 inches of the mercurial barometric column, and it is required to ascertain what volume the gas will fill at 30 inches of the same—this being the normal pressure to which all calculations as to the volume of gases are reduced—then we say

As 30 : 29 : : 100 : 96·66

In other words, the 100 volumes of gas under those conditions would contract into 96·66.

Temperature must be an Element of the Calculation.—When it is considered to what extent gases and vapour suffer expansion and contraction by variations of temperature, the necessity of this calculation will be obvious. I have already explained the ratio of thermal expansion to which gases and vapours are subjected by variations of temperature. *Practically*, we have seen at page 466 that this ratio may be considered identical for all of this class of bodies, and to be equal to $\frac{1}{491}$th part of their bulk at 32° Fah. and 30 inches barometer for every degree of temperature between 32° Fah. and 212° Fah. Let us now apply this information to practice.

If the temperature of the gas be above 32° Fah., multiply its total volume by 491, and divide the product by 491 *plus* the number of degrees that the temperature of the gas exceeds 32° Fah. The numeral result of this operation gives us the correct volume the gas in question would occupy at 32° Fah.

For example, we have 100 cubic inches of gas at 50° Fah.; it is required to know what volume this gas would occupy if raised to 60° Fah.: thus

$$\frac{103 \times 491}{491 + 18} = 96{\cdot}46 = \text{the volume at } 32^\circ \text{ Fah.}$$

And $$96{\cdot}46 + \frac{96{\cdot}46 \times 28}{491} = 101{\cdot}56 = \text{the volume at } 60.$$

Recapitulation and Deductions.—It appears, then, that the operation of weighing a gas demands in all cases that due allowance should be made for variations of heat and of pressure; and if the gas be charged with vapour, due allowance has to be made for moisture also.

The Thermometer.—In the course of our preceding investigations relative to the atmosphere, we have seen that temperature is an important element. Not only are the chemical functions of the atmosphere intimately related with temperature, but without being able to take cognizance of the expansion produced by increments of heat, the meteorologic observer is unable to comprehend some of the most ordinary physical conditions of the atmosphere. We have already seen that the general effect of heat, as regards alteration of dimensions, is expansion. If the amount of this expansion be determined for any particular range between fixed points, and the linear extension or space thus intercepted be divided into smaller spaces, each of these becomes a representative of heat or temperature. Supposing we assume the temperature at which water freezes to be our starting point or first limit, and the temperature at which water boils to be our other limit; and supposing, furthermore, we assume the space between the two to be divided into any given number of parts—say for example 180—then we may describe any third body the temperature of which is between the temperature of freezing and the temperature of boiling, to be one, two, or any number of parts above the former or below the latter. Thus, by applying these principles, we should have constituted the thermometer or heat-measurer. If the rate of expansion of any one body for given increments of temperature were regular and well determined, there would be no theoretical difficulties in the way of making a thermometer; practical difficulties there would be, but the hypothetical part of the task would be sufficiently easy. It so happens, however, that the number of expansive agents capable of employment for this purpose is limited.

The earliest thermometer was that of Sanctorini. Its construction is represented in the annexed diagram. A glass stem, open at one extremity, is terminated at the other by a bulb (Fig. 20). Into the bulb and a portion of the tube is poured a coloured fluid, which being done the stem is inverted into the lower vessel. By virtue of the ordinary laws of hydrostatics, the level of the fluid in the stem will remain constant for every constant temperature; but inasmuch as every increment of heat will cause the air contained in the bulb to expand, so will it necessarily cause the coloured fluid—which latter merely serves as an index—to descend in such manner that were the ratios of successive equal linear measures of descent equal, the instrument would be a no less delicate measurer of variations of temperature than it is a delicate indicator of the same. For certain reasons, now to be described, it is not a delicate heat-measurer. Its successive lineal columnar measurements are not comparable among themselves; whence it follows that the instrument is not a thermometer or heat-measurer, but a thermoscope or heat-indicator.

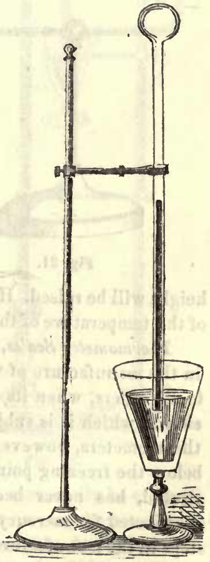


Fig. 20.

Concerning the reasons wherefore the instrument just described is not a perfect instrument, they readily admit of being made evident. They are immediately referable to the fact that the coloured fluid, which, according to the necessities of the experiments should be dynamically passive, is really active. Its activity, moreover, is a variable quantity. If the coloured fluid were merely an index having no dynamical power of its own, then the total increments of expansion and contraction of the air contained in the bulb and part of the stem, would be proportionate to the increments of heat and cold within so small a deficit of the truth (see page 458) that the error need not enter into calculation; but examination of the structure of the instrument will show wherefore this cannot be so. *Actually* the total expansion of the air in the bulb is the resultant of two forces—the force of aerial elasticity due to heat, and the force of pressure or downward tendency of the columnar liquid. Inasmuch, therefore, as the columnar height of the liquid in question varies for every temperature; and inasmuch, moreover, as the rising and falling of the liquid in the reservoir or lower receiving vessel also confuses the result, the reason will be sufficiently evident wherefore the heat-determining instrument of Sanctorini is not a correct measurer of temperature.

The Differential Thermometer.—Although various forms of air-thermometers are occasionally used in conducting certain specific experiments, their use is rare. Almost the only form of air-thermometer in frequent use is the differential thermometer, an instrument the function of which is to determine the difference between the temperature of any two adjacent bodies, or of the adjacent parts of any one body, without informing the observer concerning the actual temperature of either.

The differential thermometer is represented by the accompanying diagram (Fig 21). It consists of a glass tube having a bulbular expansion at each extremity, and joined by a stem bent on itself twice at right angles, so that the two bulbs look upwards. During the process of manufacturing this instrument, whilst one of the bulbs was yet unclosed, liquid was poured into the instrument just enough in quantity to reach a little way up the vertical part of the stems; each of these vertical parts were now supplied with a scale-division of equal lengths or degrees. Looking at this instrument, the observer will readily see that, supposing the tension or expansive force of the atmosphere in each bulb to be equal, the index fluid in the stem will stand at precisely the same elevation in both vertical stems; but supposing the air in one bulb to become heated to a higher degree than the air in the other; supposing, in other words, its expansion to be greater, the corresponding columnar height will be diminished, and necessarily the opposite columnar height will be raised. Hence the difference between the two columnar heights will be that of the temperature of the two bulbs expressed in equal parts of columnar measurement.

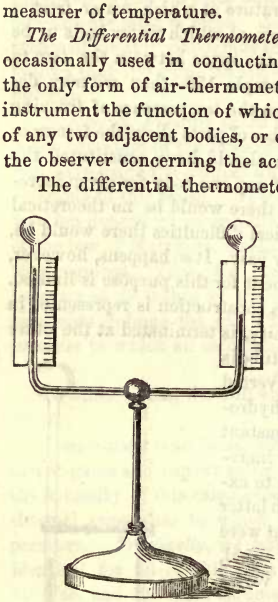


Fig. 21.

Thermometer Scales, and Ordinary Thermometers.—The liquids ordinarily employed in the manufacture of thermometers are mercury and alcohol. The former is preferred to all others, when its use is practicable, on account of the comparatively equal expansion to which it is subject for equal grades of temperature. In the manufacture of thermometers, however, intended to be employed for the measurement of temperatures below the freezing point of mercury, that fluid is necessarily inapplicable. Spirit, or alcohol, has never been frozen by the most intense cold yet produced, therefore it is substituted for mercury on such occasions. I shall now proceed to detail the successive steps in the manufacture and graduation of thermometers.

Under the head of *Barometer* the inconvenience was pointed out of using a glass tube of small diameter, because of the interference resulting from the expansion and contraction of mercury by heat. Now that which is a cause of embarrassment in the barometer, is the function on which the action of the thermometer depends. It follows, therefore, that in proportion as the bore of a thermometer tube is more small, so is the resulting instruments more delicate, because greater linear increments of expansion will be generated for given amounts of temperature. Necessarily, however, it happens in practice that if the diameter of the tube and the diameter of the mercurial column contained in the tube be smaller than certain limits, it is difficult to be seen. It is hardly necessary to indicate, moreover, that the length of linear expansion may be increased to any given limit by increasing the dimensions of the corresponding bulb, or mercurial reservoir. Practice alone can determine the proper relation which should subsist between the bore of a thermometer tube and its corresponding bulb.

The following directions for the manufacture of a thermometer are not intended to cause the meteorological student to usurp the functions of the mathematical instrument-maker; on the contrary, they are intended to make known to him the defects which he should look for in a thermometer, and which, if discovered, should cause the thermometer to be rejected.

The tube must be equal in bore throughout.—If the bore or diameter of a thermometer tube be not equal throughout, it is evident that the amount of linear expansion cannot be equal, and that the instrument will be absolutely worthless. A very easy means of guaging this equality is the following:—Having selected a piece of thermometer tube open at both ends, tie on to one extremity a rigid bottle of india-rubber, and dip the other end in mercury, thus (Fig. 22). Pressing the bottle, a portion of the atmospheric air will be expelled; then allowing the bottle to expand, some mercury will enter, forming a mercurial column, the length of which admits of being measured. Let it be measured by means of a pair of compasses; then let the mercury be driven to various parts of the tube, and the measurements repeated. If the tube be of equal bore throughout, the mercurial column will necessarily be of equal length throughout: this is evident. If the tube stand this test, it may be considered good. Instead of the india-rubber bottle the breath might be employed, but it would be attended with the disadvantage of moistening the tube. However, it is possible to use the breath without prejudice, if the operator take the precaution of blowing through some material absorptive of moisture. The next step in the manufacture of a thermometer consists in fusing one end of the tube, and blowing it into a bulb; this, again, should be effected by means of the caoutchouc bottle, lest moisture be introduced. Mercury has now to be introduced, which is accomplished as follows:—


Fig. 22

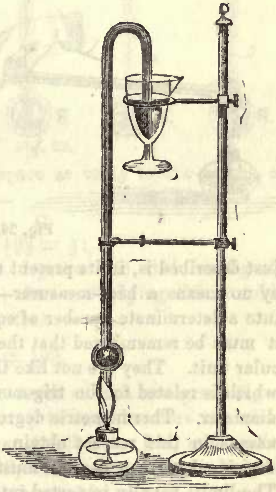


Fig. 23.

The thermometer tube having been bent as represented (Fig. 23), its open extremity is immersed in a vessel of mercury. Heat being now applied to the bulb, the air therein contained is expanded, and the heat being removed a partial vacuum results, to fill which mercury rushes in. By repeating the operation, the mercury already contained in the bulb is vapourized, and the vapour expanding drives out all the remaining atmospheric air, so that on the removal of heat the whole—tube, bulb, stem and all—becomes filled with mercury. The bent part of the tube is now broken off, and the final quantity of mercury duly apportioned to the tube. The amount of this apportionment can be only determined by practice; but, in general terms, it may be described as being such a quantity that, at the boiling point of mercury, it shall nearly extend to the extremity of the tube.

The next process is one of extreme delicacy. It has for its object the sealing or melting the open extremity of the thermometer tube, without admitting the slightest portion of atmospheric air, the presence of which would materially interfere with the delicacy of the instrument. The operation is conducted as follows:—The open end of the tube having been melted in the blow-pipe flame, is drawn out to a fine termination, thereby diminishing still further the internal bore of the tube, and rendering the final occlusion of its orifice more easy. The mercury in the bulb is now heated once more, and at the very instant when it is seen to fill the tube and to be in the act of overflowing the capillary extremity, the tube is closed by the fine jet of blow-pipe flame *b* (Fig. 24). It only now remains to graduate the thermometer.

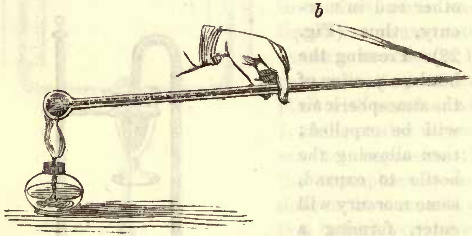


Fig. 24.

Graduation.—The instrument just described is, in its present condition, a thermoscope, or indicator of heat; but it is by no means a heat-measurer—to convert it into which it requires to be graduated into a determinate number of equal parts. These parts are usually called degrees; but it must be remembered that the so-called degrees have no ratio whatever to any particular unit. They are not like the degrees on the circumference of a circle, each one of which is related to the trigonometrical ratio, or the ratio of the circumference to the diameter. Thermometric degrees are altogether arbitrary, except in so much as certain usages in this respect obtain. This much is, however, invariable and universal—the divisional parts or degrees must be established between certain limits fixed by nature. The limits usually imported into the manufacture of thermometers are the boiling and the freezing of water, which phenomena always, under similar conditions, take place at similar respective temperatures. Founded on the bases of these limits three principal scales of graduation have been devised. They are the centigrade scale, or scale of Celsius, the scale of Reaumur, and the scale of Fahrenheit. The latter is mostly used in this country; the former is chiefly adopted on the Continent.

Let us commence our illustrations with the centigrade scale, as being most easy. The term centigrade seems to be significant of a hundred divisions. In point of fact, the centigrade scale has for its 0, or zero, the temperature at which water freezes, and for its 100 the temperature at which water boils; the intermediate space being divided into 100 equal parts. And if it be desired to carry the graduations above or below the guage limits, this is accomplished by measuring off equal parts by means of a pair of compasses.

Reaumur's scale has also its zero point at the elevation of mercurial column corresponding with the freezing point of water, but at the other extremity of its scale the boiling point of water is considered to indicate 80; hence the intermediate space is divided into 80 equal parts. The appended diagram (Fig. 25) will render evident the peculiarities of the ordinarily employed thermometric scales.

Conversion of One System of Graduation to Another.—This conversion of thermometric scales is frequently necessary. The rules for effecting the conversion are evident on reflection; nevertheless it is well to reduce these rules to general formulæ. If all these scales counted their zero from the same point, the method of converting one scheme of graduation into another would be still easier than we find it. Actually, some little confusion at first arises from the circumstance that Fahrenheit's zero is placed not at, but below the freezing point of water.

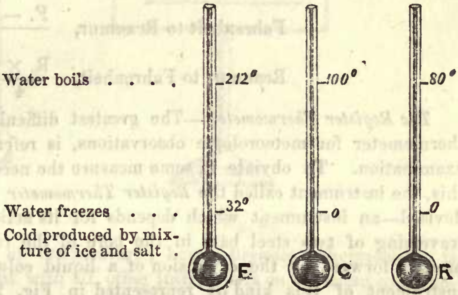


Fig. 25.

Conversion of Fahrenheit to Centigrade Degrees.—The proposition is evident that one Fahrenheit degree is equal to five-ninths of a centigrade degree, inasmuch as the number of Fahrenheit degrees between the freezing and the boiling point is to the number of centigrade degrees for the same space as unity to five-ninths, as is seen to be established by the following proportion:—

$$\overset{\text{F.}}{(212 - 32) = 180} : \overset{\text{C.}}{100} :: \overset{\text{F.}}{1} : \overset{\text{C.}}{\tfrac{100}{180}} = \tfrac{5}{9};$$

whence it appears that we may convert Fahrenheit degrees into their centigrade equivalents by first subtracting 32°, which leaves 180; then multiplying this number by five, and dividing by nine, as in the following proportion:—

$$212 - 32 = \frac{180 \times 5}{9} = \frac{900}{9} = 100.$$

Conversion of Centigrade to Fahrenheit Degrees.—Inasmuch as each centigrade degree is longer than a degree of Fahrenheit in the ratio of $\frac{9}{5}$ to one, therefore the former may be reduced to the latter by multiplying by nine, dividing by five, and adding thirty-two. The truth of this operation may be readily demonstrated by working on the number 100, which should give, if the rule just enumerated be correct, 212:—

$$\frac{100 \times 9}{5} = 180 + 32 = 212^\circ \text{ F.}$$

The examples just given illustrate the process of calculation when positive degrees or degrees above zero, thus (+), are concerned. Exactly the same rule has to be followed when negative degrees (—) are in question, although the rule, when stated in common terms, appears to be different, inasmuch as following the diction of arithmetic the operator must be told to subtract 32. An example will render this more evident. Suppose we require to represent 5° below zero, or — 5° of C., by its equivalent F. Now the number 32, with 9 subtracted, gives 23° for remainder. Viewing all the steps of the calculation involved algebraically, it will be found that the rule of adding 32 has been implicitly followed; a negative 5 however (— 5) yields in the following operation a negative 9 (— 9), which, being added to + 32, is equivalent to subtracting a positive 9 (+ 9). For example—

$$\frac{-5 \times 9}{5} = \frac{-45}{5} = -9 + 32 = +23.$$

The various steps for the reduction of one system of thermometric degrees to another, are comprehended in the appended formulæ:—

Fahrenheit to Centigrade, $\frac{F. - 32 \times 5}{9} = C.$

Centigrade to Fahrenheit, $\frac{C. \times 9}{5} + 32 = F.$

Fahrenheit to Reaumur, $\frac{F. - 32 \times 4}{9} = R.$

Reaumur to Fahrenheit, $\frac{R. \times 9}{4} + 32 = F.$

The Register Thermometer.—The greatest difficulty attendant upon the use of the thermometer for meteorologic observations, is referable to the necessity of frequent examination. To obviate in some measure the necessity for this, the instrument called the *Register Thermometer* has been devised—an instrument which depends for its action on the traversing of two steel bars in the bore of the tube, each pressed forward by the expansion of a liquid column. An instrument of this kind is represented in Fig. 26. The register thermometer is accurate enough in its indications for some rough purposes, but it is by no means adapted to supersede the use of thermometers of ordinary construction.

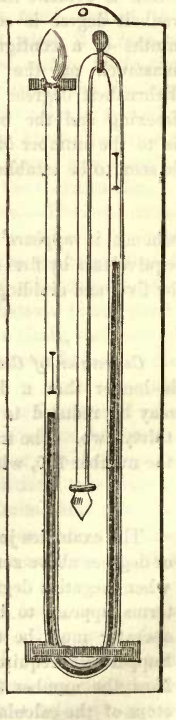


Fig. 26.

The Thermometer of Breguet.—A very delicate thermometer has been invented by M. Breguet. It differs from all which I have hitherto described, in the fact of its dispensing altogether with mercury, or other expansive liquid, and utilizing the expansion or uncoiling of a compound metallic bar.

Fig. 27.

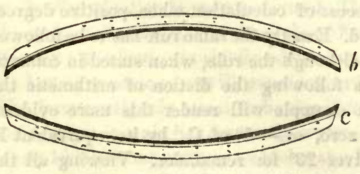


Fig. 28.

The illustration of the different rates of expansion by heat of two different metals (for instance, iron and brass) is often made by the following contrivance:—*a* (Fig. 27) is a compound bar of this kind, perfectly straight when cold; but if this same bar be heated, it becomes curved, as represented by Fig. 28. Breguet's thermometer is merely an amplification of the preceding experiment; instead of a straight compound bar, a compound bar twisted into the spiral form is employed. One end of the spiral is fixed, the other end is free, and is attached to an index. The mode of action of the instrument will be obvious. Variations of temperature producing variations of curve, will cause the spiral to unfold, or contract, according as the variations are towards the direction of increased heat or increased cold. The metals employed in making the spiral of Breguet's thermometers are platinum, gold, and silver. Experiment has demonstrated that the needle of this instrument travels over equal arcs for equal increments of temperature; hence Breguet's thermometer is not only comparable with itself, but with all other instruments on the same construction. Unfortunately this delicate instrument has no great range of application, its indications being limited between the freezing and the boiling points of water (Fig. 29).

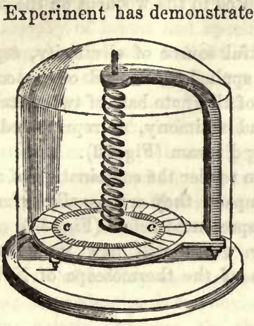


Fig. 29.

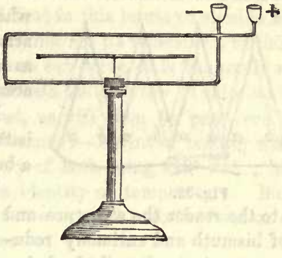


Fig. 30.

The Thermoscope of Nobili.—By far the most delicate indicator of minute increments and decrements of temperature is an instrument founded on principles totally different to any already described. The electrical thermoscope of Nobili admits of being thus described :—The action of the instrument is based upon the fundamental fact of electro-magnetism, viz., that a magnetic needle, freely suspended and placed in

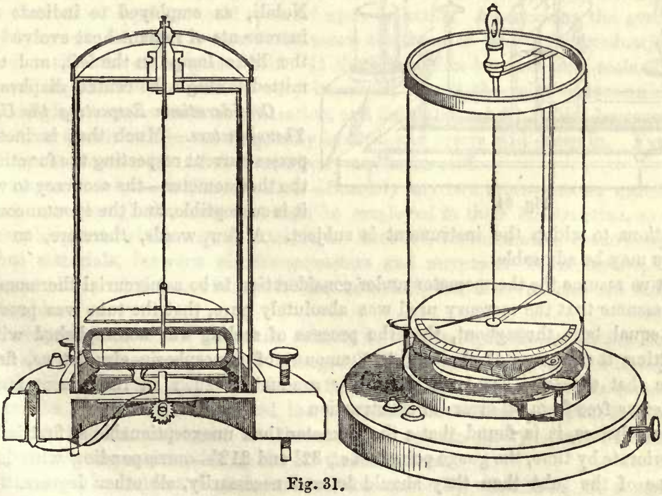


Fig. 31.

the vicinity of an electric current, finally arranges itself at right angles to that current. Hence the deflection of a magnetic needle becomes indicative of the existence of such current. Founded on the consideration of this fact, we have the instrument termed the galvanometer, which, in its simplest form, is represented by Fig. 30; and a still more delicate construction of which is represented in the woodcut on the previous page (Fig. 31).

It remains now to remark that heat is a fruitful source of electricity, especially when heat is applied to one end of a mechanical arrangement of alternate bars of two metals, such as bismuth and antimony, as represented in the accompanying diagram (Fig. 32).

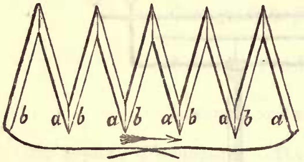


Fig. 32.

In order to render the combination of metallic bars more compact, they are usually arranged in a bundle as represented below (Fig. 33).

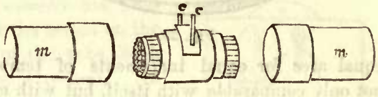


Fig. 33.

Very few words will now render comprehensible to the reader the structure and functions of the thermoscope of Nobili. A bundle of bismuth and antimony reduplications, as just described, being placed in communication with a galvanometer, the magnetic needle of the latter is ready to be deflected on the first occurrence of an electric current, and such electric current is a direct consequence of the application of heat to one extremity of the system of compound metallic bars. The annexed diagram (Fig. 34) represents the thermoscope of Nobili, as employed to indicate small increments of radiant heat evolved from the little lamp on the left, and transmitted through the central diaphragm.

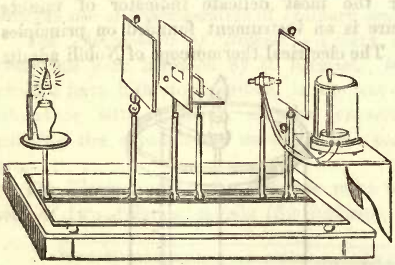


Fig. 34.

Considerations Respecting the Use of Thermometers.—Much that is incorrect passes current respecting the functions of the thermometer—the accuracy to which it is susceptible, and the spontaneous deteriorations to which the instrument is subject. A few words, therefore, on these matters may be advisable.

Let us assume the thermometer under consideration to be a mercurial thermometer; let us assume that the mercury used was absolutely pure, that the tube was proved to be of equal bore throughout, that the process of sealing was accomplished without permitting the ingress of the slightest amount of atmospheric air; let us, finally, assume that the tube has been accurately graduated—such an instrument may be regarded as free from all errors of construction.

Nevertheless, it is found that a thermometer thus unexceptionable at first is liable to deteriorate by time, the guage points—*i.e.*, 32° and 212°—corresponding with higher portions of the tube than they should do, and necessarily, all other degrees. Most probably this result is referable to a gradual contraction of the sides of the tube and of the bulb, the contraction being determined by continuous atmospheric pressure.

Looking at this contraction, the propriety is suggested of retaining thermometer tubes filled some time previous to graduation.

The Kind of Heat indicated by Thermometers.—The term heat is commonly held to be synonymous with *temperature;* but philosophy accepts it in a more extended sense, as comprehending not merely one effect (temperature), but the cause of many effects. The philosophy of latent and specific heat is almost too purely physical for extended examination here; hence a slight reference to these conditions will suffice. The thermometer is not adapted to take cognizance of heat in this latent or specific form. It is only indicative of evident heat or temperature; nor are its indications in this narrow field so complete, nor the information it conveys so extensive, as is frequently supposed. The thermometer does not even profess to indicate the *quantity* of calorific heat, but only its *degree;* terms which are totally distinct, as will soon be perceived. Let us take the following as an illustration of the difference:—A pint of boiling water is as hot as a quart of boiling water, the temperature of both being 212° Fah.; hence the thermometer, if appealed to, will indicate this identity of temperature. But, necessarily, a quart of boiling water must contain twice as much calorific heat as a pint of the same: the deduction is too obvious for comment.

Again, strictly speaking, the thermometer cannot be said to present us with the *correct* temperature of anything, inasmuch as the degree of columnar expansion is not the degree corresponding with that of the thing with which the barometer is brought into contact, but the mean of the thing touched, and the bulb which touches it. This objection attains its minimum when the atmosphere itself is the medium, the temperature of which we desire to investigate; but it becomes of practical importance in al other cases, and its consideration teaches the thermometric observer the necessity for employing instruments the bulbs of which are as small as compatible with well-marked amounts of columnar expansion. This remark especially applies to cases in which the bulk of liquid or solid operated upon is small. As concerns the graduation of thermometers, the most correct instruments are those of which the graduations are effected on the tube of the glass itself. If the graduation be made on a scale of brass, the resulting indications will be very incorrect, except the relative expansibility of brass and glass be taken into consideration, and duly allowed for; this, however, is so troublesome that it will be too frequently evaded, and errors will creep in. Far better than brass is box-wood; and slate and ivory are better still.

Correspondence between Thermometers.—Scarcely any two thermometers exactly correspond, even though the same materials be employed in their construction, so numerous are the points which require attention. Between thermometers constructed with different materials, between air thermometers and mercurial thermometers, for instance, or either of these, and spirit thermometers, the discrepancies are still more considerable.

The experiments of M. Regnault relative to the discrepancies subsisting between mercurial and air thermometers are amongst the latest on this important subject. He found that between 32° and 212° Fahrenheit, there is an almost absolute coincidence between the degrees of the air and the mercurial thermometer. From 212° to 482° Fahrenheit, the mercurial and air thermometers remain pretty equal; but after the latter point the mercurial gains on the air thermometers.

Hitherto I have treated of the atmosphere, statically considered, in a condition of repose; but perfect atmospheric quiescence is unknown in nature—it is always agitated more or less; hence we are led to the consideration of atmospheric currents or *winds.*

So variable are winds in these northern latitudes, that their incertitude has passed into a proverb; primary atmospheric currents, nevertheless, are constant in their direction, and are referable to variations of temperature simultaneously existing in different parts of the world.

Heat in its non-latent condition, or, in other words, that condition of heat which is recognizable by the thermometer, has a tendency to equalize itself. Hence, if two bodies *a* and *b*, of which *a* is hotter than *b*, be situated in proximity to each other, there is an immediate tendency to equalization of temperature as between the two; but the thermal conditions which regulate the production of winds will be most readily appreciated by reflecting on what takes place when a heated solid is suspended in the atmosphere by a small chain or wire; we shall find, on investigation, that a heated solid thus circumstanced gradually becomes cool by the operation of three distributive influences—*conduction*, *radiation*, and *convection*.

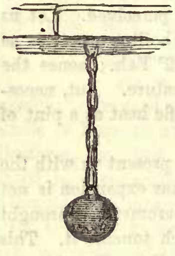


Fig. 35.

Conduction.—If the chain by which the heated cannon-ball is represented to be suspended in the annexed diagram (Fig. 35), be examined from time to time by the thermometer, or even by the fingers, it will be found to increase in heat evidently because it removes a portion of temperature from the heated cannon-ball by conducting it away. This function of heat is so well understood and so commonly exemplified, that no further consideration of it will be necessary here.

Radiation.—If a thermometer be held even at the distance of some feet from the heated cannon-ball, the mercurial column will be sensibly affected, thus demonstrating the transmission of heat. But how transmitted? By contact with the atmosphere? Clearly not, inasmuch as the result just indicated still occurs if the cannon-ball be placed in the vacuum of an air-pump. By experiment it has been determined that the temperature, in the case under consideration, has been given off in the condition of rays, precisely as light is evolved, and hence the propriety of the term radiant heat.

Convection—Independently of the two processes of heat-distribution already described, there is yet a third. Referring to the suspended hot cannon-ball, we shall find that, if suspended in a room from the ceiling, the air near the ceiling becomes hotter than the air below: hence a portion of the temperature of the hot cannon-ball must have become accumulated there, by reason of some cause besides those of conduction and radiation, both of which distribute the temperature equally in all directions, through a homogeneous medium—such as the atmosphere for example, in our assumed experiment. The process of heat-distribution known as convection, is the necessary result of the expansion of liquids and fluids by heat; for when expanded they are specifically lighter; and, when specifically lighter, they must necessarily ascend. It is by virtue of the process of heat-distribution, termed convection, that the child's soap-blown bubbles ascend instead of at once falling to the surface of the earth.

Temperature and pressure being equal, breath evolved from the lungs is heavier than atmospheric air, because it holds more carbonic acid. Nevertheless, inasmuch as it is evolved from the lungs hotter than the surrounding atmosphere, soap-bubbles blown with it ascend. Presently, however, they descend, because the heat acquired from the lungs being evolved, and equalization of temperature with that of the surrounding atmosphere having ensued, the great specific gravity of the gas wherewith the bubble is blown causes the latter to sink to the surface of the earth.

It is to the process of heat convection, that we owe the salutary draughts in our chimneys, and also unsalutary draughts in our apartments. No sooner is fuel lighted in a fire-place, than the superincumbent air becomes higher and specifically lighter; it therefore ascends, and cold air rushes in to fill its place. Thus we have, in point of fact, a local wind; and the causes which determine that wind are exactly comparable to the causes of winds which take place in the grand economy of nature, as will soon be rendered manifest.

The Trade Winds.—Applying the facts just developed, let us now regard the surface of our globe in the aggregate, with reference to the localities of maximum and minimum temperature, and the consequence of such difference of temperature in originating an aerial current. It is evident that the hottest portions of our globe's surface are comprehended within the tropics, and the coldest portions are the arctic regions—north and south.

These circumstances being premised, we are now in a condition to anticipate the direction of the aerial currents or winds which must necessarily ensue. Firstly, an ordinary current of heated air should rise aloft in the tropical regions, then diverge and pass north and south to either arctic circle, thus constituting what may be termed the upper trade current. This current, as it proceeds north and south, gradually becomes cold, in which condition it is rendered specifically heavier, falls to the surface of the earth, and floats along towards the equator, thus generating two principal currents—one north, the other south. Whilst yet in the frigid and the temperate zones these primary currents encounter so many interferences that their primary or fundamental direction is masked or veiled; but still proceeding north and south, the persistent directive tendency of the trade winds is at length developed. But the currents no longer flow directly north and south. By the operation of a cause which will presently be rendered evident, the directive tendency of either current has acquired a certain impulse towards the west; or, in other words, both currents come more or less from the east. But at length they blow almost from due east, and finally cease altogether; so that the equator, and a certain space north and south of the equator, are comprehended within what is termed the region of calms. The north trade wind meeting the south trade wind, they are mutually destructive of each other. Two conflicting aerial forces by mutual impact come to rest, just as two billiard balls, each rolling gently from an opposite point, become quiescent.

No part of the earth's surface, however, is subject to such capricious and such violent tempests as the so-called region of calms. This is a result which theory would lead us to suspect. The cause has now to be explained wherefore the trade winds do not blow directly north and south. If our globe were at rest, or if its only motion were motion in its orbit, such would be the result; but it revolves on its axis also from west to east, and this circumstance fully explains the deviation from northness and southness of the trade winds. If the lower or returning aerial current which constitutes the trade winds ceased to exist altogether, then our globe's diurnal rotation would generate a current in the apparent direction of east to west. I say *apparent direction*, because, in point of fact, we may regard the atmosphere under these circumstances as being tranquil or passive, and our globe revolving in the midst of it, in the direction of west to east. Inasmuch as the force representing this apparent east wind, and the force representing the north and south atmospheric currents, flowing towards the equator from either pole, are simultaneously operating, there occurs a resultant, which is the trade wind. The appended diagram (Fig. 36) roughly illustrates the points which have been described. Towards the extreme north and extreme south the great aerial currents, ultimately destined to become the trade winds, are represented fluctuating and variable; gradually, however, they acquire a northern and a southern directive tendency respectively; lastly, they come from the point of almost due east, and then cease altogether.

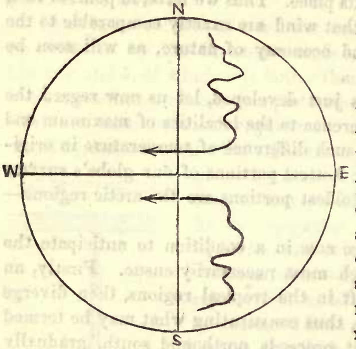


Fig. 36.

A consideration of the influences which determine trade winds leads to a facile explanation of many aerial currents of less extent. The heating influence referable to the geographical position of the tropics is not the only influence of this kind. A peculiar condition of the earth's surface, taken conjointly with a favourable condition of the sun's rays, may bring about similar results. In this manner the Mediterranean etesian winds, or aerial currents from the north, may be accounted for. Looking at the geographical condition of localities south of the Mediterranean, we find the Sahara, or Great Desert, a region whose surface is strewed with masses of pebbles and sand, and almost totally devoid of vegetation. Such a surface must necessarily become elevated by the solar rays to a high temperature, an atmospheric column must ascend, travel to the north, then fall, and at length return from the north to the Sahara, whence it came.

Land and Sea Breezes.—Many countries near the sea are subjected to winds of diurnal periodicity, known as land and sea breezes. About eight or nine A.M., an aerial current begins to flow from the sea towards the land, and persists until about three P M., when a current in the reverse direction, or from the land towards the sea, takes its place, and continues throughout the night until sunrise next morning, when it ceases, and a calm ensues until the completion of a period of twenty-four hours from the occurrence of the preceding land breeze. These currents, in reverse directions, can be easily accounted for when we consider the heating agency of the sun. Necessarily land becomes hotter than water under an equal power of luminous rays; whence it follows, that the surface of the ground becoming heated after sunrise, determines the ascent of an atmospheric current vertically; thence, proceeding oceanward, the same current returns from the sea to the land. No sooner does the sun set, than this current is reversed.

In the preceding explanations of the cause of winds as being referable to inequalities of temperature, it will be observed that reference has alone been made to the calorific effects of the sun's rays. This is, in point of fact, the only source of heat which has to be taken cognizance of in meteoric considerations; for, although the earth's own temperature gradually increases as we pierce downwards below the surface, so imperfect are the conducting powers of the materials of which the crust of our planet is composed, that all consideration of them may be safely omitted in accounting for the present phenomena.

Process of Reverse Atmospheric Currents.—Although the existence of atmospheric currents proceeding in a direction reverse to those we meet with on the earth's surface is forced upon the mind by inferential reasoning, and the fact must be accepted, even though no further evidence of it could be adduced, nevertheless direct proofs are not wanting. The direction of upper layers of clouds afford their testimony to the truth of the opinion. Where the trade winds prevail, the higher strata of clouds may be seen taking a direction opposite to that of the wind itself; and travellers, during their ascent of high mountains, have frequently proved the existence of a superior wind pursuing a course opposite to the wind below. This has been especially obvious on the Peak of Teneriffe, a mountain situated in the belt of the trade winds. Here, on the summit of this peak, it has been always found that a south-west wind prevails, whereas the trade wind at the base of the same mountain blows from the north-east.

A similar remark has been made by travellers who have ascended Mona Kea, in Owyhee, the height of which is 18,000 feet. But perhaps the most striking illustration is the following:—The island of Barbadoes lies eastward of St. Vincent, and between the two the trade wind continually blows, and so forcibly that it is only with difficulty, and by making a long circuit, that a ship can sail between the latter and the former. Nevertheless, on one occasion, during an eruption at St. Vincent, dense clouds formed over Barbadoes, and large quantities of ashes fell on the island. A similar result was observed after an eruption of the volcano of Cosoguina, on the shores of the Pacific, in Guatemala, in January, 1835, some of the volcanic ashes falling in Jamaica, more than 800 miles in a direct line distant, and directly opposed to the prevailing lower current. At the same time another portion of ashes was carried westward, or in an opposite direction, falling on Her Majesty's ship "Conway," in the Pacific, more than 1200 miles distant.

The trade winds are, for the most part, only recognizable at sea; the solid material of land developing local aerial currents of their own. The extent of prevalence of the trade wind is various. In the Atlantic it prevails from 8° to 28° or 30°, but in the Pacific only to 25° N. L. In the southern hemisphere, the extent of the trade wind has been less accurately determined. When first the phenomena of trade winds were noticed by Columbus and his associates, they caused the greatest consternation. Accustomed to the fluctuating and irregular breezes of Europe, they regarded the continuance of a wind from the east as emblematic of their perpetual banishment from their native shores. The early Spanish navigators, however, very soon learned to appreciate the value of trade winds, by the aid of which treasure-laden galleons could, setting out from Acupulco, manage to arrive at Manilla almost without changing a sail.

As respects the upper current proceeding from the equator to either pole, it varies, as might be anticipated, in different localities. Travellers, who have ascended the Peak of Teneriffe, inform us that this upper current is found in that locality at an elevation of 9000 feet; but Humboldt, during his explorations on the Andes, discovered the eastern trade wind to be blowing at an elevation of 8000 feet above the level of the sea. As the upper, or equatorial current loses its heat, its specific gravity becomes greater, and it sinks lower and lower, no longer manifesting any well-marked directive tendency.

On the ocean, and between 30° and 40°, there is a prevalence of westerly winds, especially in the southern hemisphere. In the Atlantic a similar tendency is manifest; whence it follows, that the voyage from Europe to America occupies more time than a voyage in the reverse direction. It is difficult to say what may be regarded as the prevailing wind in these isles—probably, however, a south-western wind, as stated in the following table:—

Table Representing the Relative Prevalence of Winds in different Countries for a Period of 1000 *days.*

Countries.	N.	N. E.	E.	S. E.	S.	S. W.	W.	N.W.
England . .	82	111	99	81	111	225	171	120
France . .	126	140	84	76	117	192	155	110
Germany . .	84	98	119	87	97	185	198	131
Denmark . .	65	98	100	129	92	198	161	156
Sweden . .	102	104	80	110	128	210	159	106
Russia . .	99	191	81	130	98	143	166	192
North America .	96	116	49	108	123	197	101	201

The direction of winds is found, taking the average of many years, to vary according to the season. In Europe south winds are more prevalent than any others during winter; east winds belong more especially to the spring; west and north winds to the summer, and towards October the wind usually veers round to the south. Usually the wind is more strong in February and March than at any other, and at all seasons the wind is usually strongest at noon.

Storms.—Whenever the air, from any cause, is thrown into violent commotion, the result will be a storm. The philosophy of storms, notwithstanding the attention which has been devoted to the subject, is by no means well understood. In point of fact, the causes of storms are numerous and complex. If we reflect on the agency of temperature on the air, one prevalent cause of storms will at least become manifest. If one portion of the atmosphere be suddenly heated, violent commotion must arise—there must follow a storm. The laws of latent heat demonstrate that whenever water is suddenly condensed, the surrounding air must be raised in temperature; and thus we have one of the most frequent local causes of storms. According to modern observations storms are, for the most part, circular whirlwinds progressing in a north-eastern direction from the south to the north of the tropic of Cancer. In proportion as a locality is devoid of mountains and near the sea, so is it more liable to be subject to storms. Perhaps the most violent of all European storms are those which occur in the south of France during the prevalence of the north-east wind termed *mistral;* but the most violent storms occur in and near the tropics, and are termed *tornadoes*, *trovadoes*, *hurricanes*, *typhoons*, &c. Hurricanes are essentially tropical; the West Indies suffer from them more than any other region. Hurricanes are of yearly occurrence in the West Indies, but the islands of Trinidad and Tobago, being protected by mountain elevations, usually escape them altogether. The wind, during a hurricane, frequently makes an entire circuit, blowing from every point of the compass; and it is by no means an unusual occurrence for the wind to cease awhile altogether, and then commence blowing again. Perhaps the most violent hurricane on record is the one which occurred in 1780. It destroyed the fleet of Lord Rodney, and a vast number of merchant ships. It killed no less than 9,000 individuals in Martinique alone, and 6,000 in St. Lucia. It totally destroyed the town of St. Pierre in Martinique, and almost as completely the town of Kingston in St. Vincent, only fourteen houses of the latter being left unmolested. Not a few of the West Indian hurricanes extend their ravages northward to the United States; usually, however, with a violence greatly diminished.

The eastern, western, and southern coasts of Africa are also subject to storms of almost equal violence with the West Indian hurricanes; these storms, however, in the localities under consideration are called tornadoes. At Sierra Leone and the adjacent parts two or three tornadoes usually usher in the dry season; they are sometimes accompanied with rain, and sometimes without; when of the latter kind, they are called white tornadoes. The eastern coast of Africa, especially towards the south, is also very subject to tornadoes. One of the most violent storms on record occurred in the Mozambique Channel in 1809, extending to the islands of Bourbon, Mauritius, and Rodrigues. The violence of storms at the Cape of Good Hope is proverbial; the early Portuguese navigators, therefore, called the southern cape of Africa the Cape of Storms.

Typhoons may be described as hurricanes of the Chinese and Japanese seas; like hurricanes, they have a rotatory motion, but they are more localized in their action, having no distinct rectilineal progression.

Hot Winds.—Although heat may be regarded as primarily the cause of all winds, it does not follow that all winds must be hot; indeed, we know that the result is the direct opposite—that many winds are very cold. The temperature of a wind is for the most part totally independent of the temperature which caused it, and is determined by the nature of the surface over which it blows. The principal hot winds are those denominated the simoom, the harmattan, the chamsin, the sirocco, and the solano. The term simoom, or *samiel*, means poisonous, and is derived from a belief of the Arabs that the devastating effects of this wind are attributable to some poisonous emanation which it bears. There is no foundation, however, for this notion. The terms chamsin and harmattan are little else than Egyptian and negro appellations respectively for the simoom. The Egyptian term *chamsin* means fifty, and has reference to the duration of the wind fifty days—from April 27 to June 18. The simoom is the terror of desert caravans. At its approach the horizon grows dark, the sun's rays scarce penetrate with lurid gleam the atmosphere charged with particles of burning sand. The wind blows with fitful violence, scattering death and desolation in its track, withering the trees and shrubs which it encounters, suffocating animals, and burying them under waves of sand. The camels no sooner perceive the advent of the simoom, than rushing to the nearest tree or bush, or seeking the spur of some projecting rock, they place their heads in the direction opposite to which the wind blows, and endeavour to screen themselves from its violence. The traveller throws himself on the ground on the lee-side of the camel, and screens his head from the fiery blast within the folds of his robe. Too frequently all these precautions are unavailing, both man and beast falling a prey to the terrible simoom. The idea, however, of the wind being poisonous is not founded on fact. In the western parts of Asia, more especially in Arabia, the simoom only blows in the summer months, and with maximum violence in July. It occurs only in the day time, and for the most part only lasts a few hours. In Lower Egypt, the direction of the simoon is from the south-west; in Mecca, it comes from the east; in Surat, from the north; in Bassora, from the north-west; in Bagdad, from the west; and in Syria, from the south-east; in every case proceeding from the neighbouring desert where the air has suffered rarefaction. The simoom, far from being poisonous, is in some localities beneficial to health, by drying up aqueous exhalations, which, if not removed, would give rise to fevers and other diseases. This is particularly the case on the western coast of Africa. It is, nevertheless, always injurious to vegetation.

The Italian sirocco and the solano of Spain may be regarded as European continuations of the harmattan or simoon of Western Africa. The sirocco, although usually restricted to Malta, Sicily, and southern Italy, sometimes extends into Germany and Switzerland: in the latter locality it is denominated the *föhn.* The föhn, although prejudicial to trees, develops to a surprising degree the vegetation of young plants, and can hardly be regarded as a calamity. It is most prevalent in Switzerland, near the Lake of the Four Cantons. Its period of duration does not usually exceed a few hours, though sometimes this period is exceeded, and it rarely occurs in winter.

The southern part of Australia is subject to a hot north wind, presenting such a marked resemblance to the sirocco that geographers are led to the natural inference that the unknown interior of the Australian continent is a desert of sand and rock, like the Sahara and the wilds of Arabia Petræa.

Cold Winds.—These winds are less noticeable and fewer in number than those already mentioned. Their low temperature is usually referable to the circumstance of their passing over mountain ranges covered with snow. The most considerable winds of this kind exist in Mongolia, Beloochistan, and the Russian steppes. To this class also belongs the *mistral,* a north-east wind prevalent in southern France, and which is exceedingly prejudicial to vegetable life.

Whirlwinds.—When two violent winds meet, the result is a whirlwind, so called from its rotatory character. If a whirlwind occurs at sea, or over water, it elevates a large column of water aloft, sometimes to the height of many hundred feet, thus giving rise to the meteoric phenomenon termed a *water-spout.* If a whirlwind occurs on land it lifts up dust, boughs, the roofs of houses, and other solid matters, producing a column of well-defined shape. These whirlwind columns, whether they consist of water or solids, present the same general formation and contour. They consist of a hollow cone, sometimes straight, but more frequently curved or horn-shaped, its upper portion proceeding from a cloud; its lower part consisting of an aggregation of water or of sand and dust, according to the locality. The upper and lower portions of these columns are so much denser than the remainder, that they are generally opaque, whereas the middle portion is generally transparent. The tint of these colours is various — sometimes gray, sometimes brown or nearly black, and occasionally fiery red.

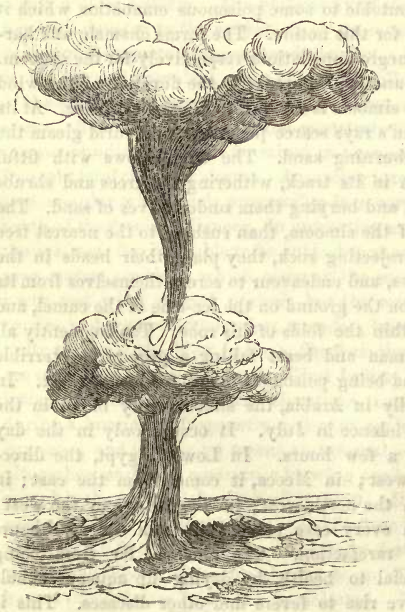


Fig. 37.

Independent of the circular or axial motion of these whirlwind columns, they pursue an onward course, sometimes straight, at other times curved. The velocity of this course differs within wide limits. Sometimes a man on foot can readily keep pace with it, whilst at other times they proceed at the rate of nine or ten miles an hour, sometimes more.

Whirlwind columns, whether they eventually become water-spouts or not, always originate on land, or in the vicinity of land where the winds and temperature are mutable. They are usually attended with thunder, lightning, and other electrical phenomena; and they constitute the centre of an aerial commotion, all around the focus of which a profound calm prevails. Bodies which they have taken up are not readily deposited, but carried along in their onward course. Sometimes they are quite in the clouds, at other times on the surface of the earth or water, and their formation may be prevented. Even when already formed, they may frequently be destroyed by some violent aerial commotion, such as that produced by the discharge of a piece of ordnance—a fact well known to seafaring men. The size and height of these whirlwind currents is various; occasionally they present a diameter of no more than two feet, while the diameter of some has been estimated at two hundred, or even more. Again, the height of some is no more than thirty feet, whereas others have been known the height of which was no less than three thousand feet.

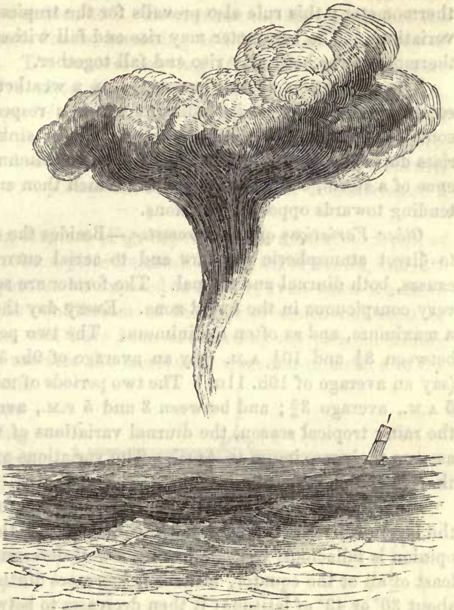


Fig. 38.

Water-Spouts.—Of these columnar whirls the water-spout is less damaging than the dry whirl, probably because the weight of fluid which it carries diminishes the violence of its rotatory motion. Not the least extraordinary amongst the many curious circumstances relative to water-spouts, is the well-attested fact that, although occurring at sea, they have been occasionally known to break and deluge a ship with a torrent of fresh water.

Influence of Wind on the Barometer.—Although the barometer has hitherto been considered in reference only to the pressure of a tranquil column of air, its variations are influenced by many other circumstances, which we must not omit to consider. Amongst the most important of these are winds. Having regard to the ultimate cause of winds, it will be evident that the existence of a wind bespeaks the condition of different temperature in two different places. Hence, every wind necessarily varies to some degree the temperature which would have subsisted at any given place under a perfectly tranquil atmosphere. Now, inasmuch as the atmosphere expands by heat and contracts by cold, varying to a corresponding degree its density or specific gravity, so it follows that the height of the barometric column will be influenced by winds. In Europe it will be generally found that a fall of the barometer corresponds with a rise in the thermometer; this rule also prevails for the tropics, nevertheless it is subject to many variations. The barometer may rise and fall without any corresponding change in the thermometer or both may rise and fall together.

The application of the barometer as a weather-glass is altogether collateral and secondary, nevertheless its indications in this respect are, for the most part, worthy of confidence; generally the barometric column sinks the day before rain occurs, and rises during its prevalence. The barometric column is much agitated during the existence of a storm, owing to the conflict which then ensues between atmospheric currents tending towards opposite directions.

Other Variations of the Barometer.—Besides the elevation of barometric mercury due to direct atmospheric pressure and to aerial currents, there exists other fluctuating causes, both diurnal and annual. The former are scarcely noticeable in temperate, but very conspicuous in the torrid zone. Every day the barometric column twice attains a maximum, and as often a minimum. The two periods of maximum elevation occur between 8½ and 10½ A.M. (say an average of 9h. 37m.); and between 9 and 11 P.M. (say an average of 10h. 11m.) The two periods of minimum elevation are between 3 and 5 A.M., average 3¾; and between 3 and 5 P.M., average 4h. 5m. During winter and the rainy tropical season, the diurnal variations of the barometer are least, and they assume their maximum in April. The variations are much less on elevated mountains than in the plains below.

Mean Barometric Condition of a Place.—It was formerly assumed that everywhere at the level of the sea the barometric condition for the same time was identical. This opinion is fallacious, latitude having a well-determined influence in this respect. It is least of all at the equator, whence it increases north and south, attaining its maximum about 30° or 43° of latitude; it then decreases to between 60° and° 70. Within the polar circle it would appear to reascend, but further experiments for this locality are a *desideratum.*

Longitude also appears to exert some influence over the elevation of the barometric current. It is greater in the Atlantic than in the Pacific, by a small but readily perceptible quantity.

Causes of Periodical Barometric Variations.—Various opinions have been advanced to account for these periodical barometric variations. To say they are attributable to difference of temperature is to advance a cause too remote from the result. Many philosophers have attributed these variations to the existence of veritable atmospheric tides; but the most plausible explanation of diurnal barometric variations would seem to be that of Dove, who assumes them to depend upon the varying amount of aqueous vapour. Aqueous vapour and atmospheric air are possessed of different specific gravities, and the barometric height of a column of mercury for any time will be the sum of pressure of dry atmospheric air and associated moisture; as the relative amount of the two varies, so will vary the height of the barometric column.

Atmospheric Moisture and its Derivatives.—When treating at page 469 of the means to be employed for weighing a gas, the facility wherewith gaseous bodies absorb moisture was adverted to. Some idea then may be gained of the amount of moisture present in the atmosphere, seeing that the latter is ever in contact with large expanses of water. The atmosphere, in point of fact, is never dry, or in any way near dryness. Even when the air seems parching hot, drying the skin and withering vegetables, it is easy to demonstrate, by the aid of chemical agents, the existence of aqueous moisture; without the presence of which neither the functions of animal or of vegetable life could be maintained. Even when the air approaches the condition of dryness, within very remote limits, breathing is difficult and symptoms of feverish restlessness speedily sets in. The natural craving of the lungs for moisture is demonstrated by the presence of a close stove in a small room. The sensations, which are very unpleasant, can always be alleviated by placing a small dish of water on the stove, so that evaporation may go on continuously. It is of the utmost importance, then, to be enabled not only to demonstrate the existence of atmospheric moisture, but to determine its quantity. A few experiments for effecting this demonstration I shall now detail.

Experiment 1.—The accompanying diagram (Fig. 39) represents a balance or pair of scales, into one pair of which there has been placed a small dish of oil of vitriol, and into the other a counterpoise. If the apparatus be exposed to the air, even when the earth is hottest and dryest, nevertheless the equilibrium of the pair of scales will soon be destroyed. Some ponderable increase will have been acquired by the pan containing the oil of vitriol, and analogy demonstrates the increase in question to be due to the absorption of water. Founded on this property, oil of vitriol is frequently employed by the chemist for desiccating substances which could not be heated without damage. Accordingly, if a pan of oil of vitriol and a moistened sheet of paper be enclosed together, under an inverted glass, the paper will in course of time become dry. Far more rapid and powerful is the operation of the oil of vitriol when, instead of being placed together with the substance to be dried, and in a mere bell-glass, the two are placed under the receiver of an air-pump, and the air exhausted. Under these circumstances an atmosphere of aqueous vapour alone soon fills the air-pump receiver, and the absorptive operation of the oil of vitriol being continuous, the water is speedily evaporated.

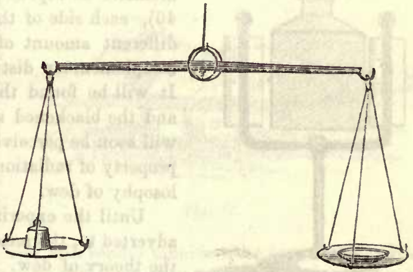


Fig. 39.

Experiment 2.—Instead of oil of vitriol, carbonate of soda, or chloride of calcium, and, in an inferior degree, common salt (chloride of sodium) may be used; for these bodies are all hygrometric—that is to say, they have the property of absorbing water from the air. Of the three bodies mentioned, chloride of calcium is the most hygrometric, and is of constant application by the chemist. Founded on the hygrometric quality of common salt, and other saline materials contained in sea water, is the property which certain sea weeds have of becoming moist in damp weather, and of indicating by their dry crispness an opposite atmospheric condition.

Although aqueous vapour be always present in the atmosphere, it is not always visible. Frequently it is quite transparent, and only demonstrable by the process of getting it out; but at other times it aggregates, becoming vesicular, and forming clouds, fog, dew, rain, snow, hail, or sleet.

Dew.—Although the philosophy of dew is now perfectly well understood, no atmospheric phenomenon before the happy researches of Dr. Wells was more imperfectly explained and involved in greater mystery. The formation of dew is immediately referable to the function of radiation, concerning which it will be proper to make a short explanation in addition to that which has been already stated at page 480.

In that place the general indication only has been made that a heated body—for example, a cannon-ball—if suspended in space, darts off heat cognizable on temperature under the condition of rays. It remains now to be stated that the function of radiation is determined as to its extent by the surface of bodies: rough metallic surfaces radiate more than those which are smooth; glass surfaces radiate more than metallic surfaces; plants radiate more than the earth; grass and leaves more than bushes and trees; loose gravelly land more than hard soil.

To demonstrate the effect of surface on radiation, many instructive experiments may be performed by means of the differential thermometer and a cubical canister of tin plate. If such a canister be taken, and one side of it scratched, another polished smooth, another painted white, and the fourth black, a mixture of lamp-black and size being used by preference for the latter purpose—if the canister be now filled with hot water and held between the two bulbs of a differential thermometer as represented in the accompanying diagram (Fig. 40), each side of the canister will represent and indicate a different amount of radiating influence, as shown by the complementary disturbance of the two mercurial columns. It will be found that the polished side has the minimum, and the blackened side the maximum, radiating effect. It will soon be perceived that these deductions concerning the property of radiation are intimately connected with the philosophy of dew.

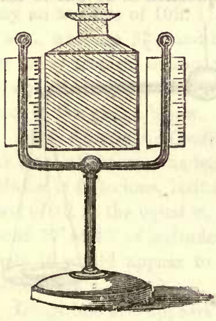


Fig. 40.

Until the experiments of Dr. Wells, which will be soon adverted to, the most erroneous notions prevailed concerning the theory of dew. According to some it fell from the sky, according to others it rose from the ground, both which theories are altogether untenable.

It is a sufficient answer to the proposition that dew falls from the sky, to say that dew never occurs when nights are cloudy; and it is a sufficient answer to the statement that it rises from the ground, to remark that a slight screen thrown on the ground, or elevated above the ground, is incompatible with the formation of dew.

The theory of dew is hardly explained by a consideration of the laws of radiant heat. The starting point of the investigation is the atmosphere. Now the atmosphere always contains moisture, as I have already explained, and the amount of this moisture will, *cæteris paribus*, be correlative with the degree of atmospheric heat at the time. If, then, the atmosphere being raised to its fullest point of saturation for any given degree of temperature, that temperature should by any chance fall, the result will necessarily be a deposition of moisture. Let us now apply these principles to the conditions of a heat-radiating surface of the earth and a clouded sky. In this case no dew occurs, nor, according to theory, should any occur, inasmuch as the clouds perform the functions of a second radiating surface. The earth radiates heat owing to the clouds; but the clouds in their turn radiate heat back again to the earth; whence it follows that the earth practically does not lose heat, and its temperature not falling below the temperature of the circumambient atmosphere, no atmospheric moisture can be deposited; in other words, no dew can occur.

For these facts we are indebted to the late Dr. Wells. They are demonstrated by thousands of natural conditions, and bear the test of any properly-devised experiment.

The following diagram (Fig. 41) is intended to show the manner in which a screen will prevent the occurrence of dew. Two plates of glass are represented as supported over an expanse of grass. Underneath the glass plate not the slightest dew will be found, though the grass around will be dewed heavily.

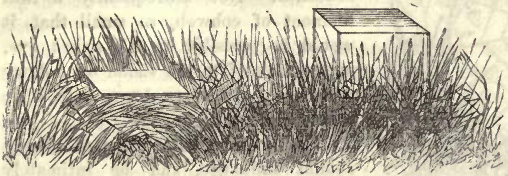


Fig. 41.

A very pretty illustration of the conditions which regulate the formation of dew, will frequently be supplied by a sheep lying down on the grass, on a clear, tranquil, cloudless night, when, to use a popular but incorrect expression, dew is falling; it will be found that the upper part or aspect of the wool of a sheep, is completely drenched with dew, although the under part or aspect of the animal is dry, as represented in the accompaning diagram (Fig. 42).

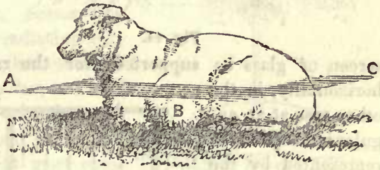


Fig. 42.

The explanation of this phenomenon will be so obvious that no further remark concerning it is necessary.

Consideration of the laws of radiant heat will render manifest the reason wherefore some surfaces are more bedewed than others. The amount of dew will depend, *cæteris paribus*, on two circumstances—firstly, on the kind of surface; and secondly, at its angle

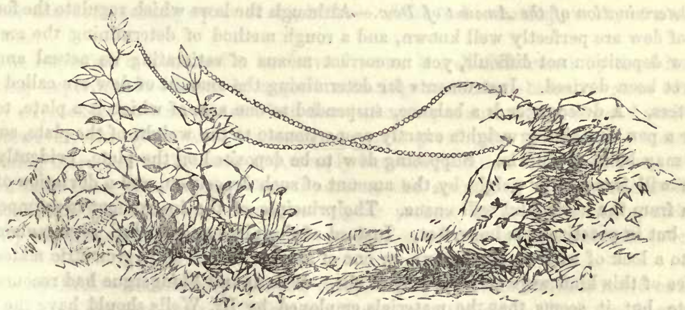


Fig. 43.

of inclination. Reference has already been made to the comparative facility wherewith certain bodies found in nature favour the deposition of dew upon them, and the most casual observer cannot fail to be struck with the difference. In all cases, the bodies which indicate heat are the most favourable to the deposition of dew upon them. Few, if any, objects naturally occurring are so solicitous of dew as spiders' webs; and no object present the phenomena of dew under a guise so beautiful. Not unfrequently a thin filament of cobweb, so small that it would be invisible to the naked eye, presents itself to the vision on a dewy morning as if it were strung with little pearls (Figs. 43, 44).


Fig. 44.

That angular inclination of a body should influence, and be intimately connected with, the function of dew formation directly follows from a consideration of the laws of radiant matter; and it may be readily illustrated by a diagram. Let us be assured that a screen of glass be supported over the radiating surface of the earth—in one case horizontally, in the other case at an angular inclination, as represented by the accompanying diagrams (Figs. 45, 46).

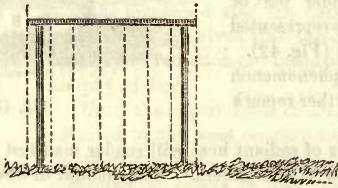


Fig. 45.

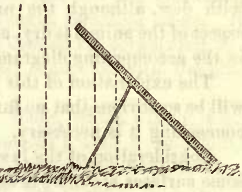


Fig. 46.

It will be evident that the horizontal glass in Fig. 45 will radiate back more heat than the diagonal glass in Fig. 46.

Determination of the Amount of Dew.—Although the laws which regulate the formation of dew are perfectly well known, and a rough method of determining the amount of dew deposition not difficult, yet no correct means of estimating its actual amount has yet been devised. Instruments for determining the amount of dew are called drosometers. A drosometer is a balance, suspended to one arm of which is a plate, to the other a pan containing weights exactly proportionate to the weight of the plate, so that both may be in equilibrio. Supposing dew to be deposited on the plate, evidently the latter will increase in weight by the amount of such deposition, and a deviation of the beam from the horizontal will ensue. The principle of the instrument is unimpeachable, but in practice it is imperfect. Instead of the plate as described, recourse may be had to a lock of wool or eider-down, or one of a large choice of hygrometric materials. Bodies of this kind were employed by Wells. Wilson and Flangergue had recourse to a plate, but it seems that the materials employed by Dr. Wells should have the preference.

A very instructive experiment relating to dew formation, and one which may be regarded as presenting a summary of the whole matter, is as follows:—

If on a clear, cloudless night, when dew is being deposited, a glass ball (Fig. 47) be suspended in the open air some height from the ground, dew-drops will form on the ball; not, however, equally on all portions of its surface. Firstly, its upper aspect will be bedewed, then its sides; but only rarely, and in extreme cases, the inferior aspect of the glass globe becomes covered with dew-drops, and when they do occur they are very small; indeed, a complete gradation of size is manifest, the dew-drops decreasing in size as the upper aspect of the globe is departed from.

Generalizations.—The following generalizations relating to the phenomena of dew may now be appended; they will, for the most part, be seen to be directly deducible from a consideration of the laws of radiant heat:—Clouds and brisk winds are both inimical to the formation of dew; the former, because of their own radiating power; the latter, because of the removal of cool air, its place being supplied by air already warmed. If the night be cloudy, and the wind still, very little dew results. If clouds and wind occur together, dew is totally absent. Screen-like objects interposed between the sky and the radiating surface produce an effect identical with clouds, hence bodies freely exposed to the atmosphere, *cæteris paribus*, are most freely bedewed. Morning and evening are not the times, as commonly supposed, when dew is formed most copiously. It is deposited at all hours of the night, but most copiously rather after midnight. It sometimes occurs even before night, late in the afternoon. Dew is not deposited with equal readiness in all parts of the world, but attains its maximum in warm lands near the margin of the sea, rivers, or lakes; as, for example, near the Red Sea, the Persian Gulf, the coast of Coromandel, at Alexandria, and in Chili. It is quite absent in very arid regions, in the interior of continents—such, for example, as central Brazil, the Sahara, and Nubia; neither does it frequently occur at sea, because of the bad radiating quality of a surface of water.

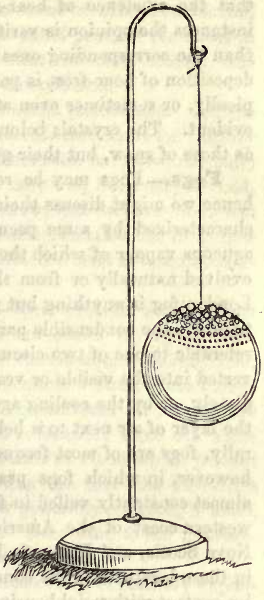


Fig. 47.

The imperfect radiation of a surface of water is well illustrated by the following striking experiment:—Glass is a good radiating surface; whence a piece of glass freely exposed in an atmosphere when dew is forming soon becomes covered with dew. If, however, the glass have its surface wetted previously to exposure, instead of becoming more wet it becomes dry, simply because radiation is impeded, and evaporation takes place unchecked. *Cæteris paribus*, the amount of dew produced will be proportionate to the amount of aqueous vapour present in the atmosphere, and thus readily explains the fact that a copious production of dew is frequently the precursor of rain.

Honey-Dew.—Occasionally a sweet, damp, sticky moisture attaches itself to leaves during the night, and does not disappear throughout the day. The term honey-dew has commonly been applied to it, though, in point of fact, it is not dew at all, being merely an excretion from certain insects termed *aphides.*

Hoar-Frost.—Hoar-frost differs only from dew in the circumstance of temperature. One is deposited and remains uncongealed; the other, becoming consolidated by the agency of freezing cold, is converted into ice. Every meteorological observer knows that the existence of hoar-frost is held to be indicative of coming rain, and in most instances the opinion is verified. The phenomena of hoar-frost are even more beautiful than the corresponding ones of unfrozen dew. Upon leaves and vegetable stems the deposition of hoar-frost is particularly beautiful. If hoar-frost be examined microscopically, or sometimes even attentively by the naked eye, a crystalline structure will be evident. The crystals belong to the same crystallographic system (the rhombohedric) as those of snow, but their general appearance is somewhat different.

Fogs.—Fogs may be regarded as clouds which form close to the earth's surface; hence we might discuss their peculiarities under the general head of clouds. They are characterized by some peculiariaties, however, chiefly dependent upon the vesicular aqueous vapour of which they are composed, embracing and retaining volatile particles evolved naturally or from the operations of man. In this way it is well known that London fog is anything but pure aqueous matter. One of its very important constituents is the condensible part of smoke. As regards the production of fog it is usually referable to one of two circumstances: either non-visible aqueous vapour may be converted into the visible or vesicular form by decrease of atmospheric temperature immediately, or by the cooling agency of the earth's surface depressing the temperature of the layer of air next to it below the dew point. In this country, and in Europe generally, fogs are of most frequent occurrence in spring and autumn. There are regions, however, in which fogs prevail throughout the year. The coasts of California are almost constantly veiled in fog; and the same remark applies, in a minor degree, to the western coast of the American continent, even so far south as Peru. Newfoundland, Nova Scotia, and Hudson's Bay, are all subject to frequent and dense fogs, attributable in these localities to the condensation of vapour which arises from the hot gulf-stream by contact with neighbouring and colder air. Fogs do not occur so frequently on level plains as on mountainous regions. In Arabia and the arid table-land of Persia they are almost altogether wanting. London and Amsterdam have acquired a somewhat evil character for fogs; but this meteoric condition applies to many other European localities with an almost equal amount of propriety. At Antwerp fogs are very prevalent, and the navigation of the lower and middle Rhine is sometimes impeded for weeks together by the occurrence of this pest of the sailor. Neither can Paris boast of much immunity from fogs; they are somewhat less dense and less frequent than our own London fogs, it is true, but are, nevertheless, far from contemptible. Amongst the regions which are likely in future to be celebrated for the prevalence of fogs, the Black Sea may be enumerated. Until recent events that locality was comparatively unknown to us; and since the conveying of stores to our troops in the Crimea has necessitated its continuous navigation, the embarrassment of fogs has only been too apparent.

Dry Fogs.—Under this name has been described a dull opaque appearance which the atmosphere of certain regions occasionally assumes, deadening the fiery beams of the sun, and dulling that luminary so that he may be looked at without pain by the naked eye, and embarassing respiration.

The dry fog is most common in certain parts of North America, during the period known as the *Indian Summer*. It also occurs in Germany, and more rarely in England. There can be no doubt that many atmospheric opacities, different in character as well as in cause, have been summarily classed under the denomination of *dry fog*. When the phenomenon occurred locally, it can generally be traced to such causes as the burning of extensive districts of turf or of forests. When its prevalence is more general, the most rational explanation would seem to be that which attributes it to volcanic eruptions. Some meteorologists have invoked electricity as the cause of this phenomenon, but it is not easy to see in what way the assumed cause could produce the effect in question. Electricity has long been to meteorologists what the class *radiata* was to Cuvier; namely, the receptacle for things unknown or unexplained.

Clouds.—Clouds are perhaps the most beautiful of all aerial phenomena. All the charms of changeful variety of colour, of form, and of motion are theirs; nor is their utility inferior to their beauty. Without clouds there would be neither rain, nor snow, nor hail; the consequences of this deprivation may be anticipated, or they may be readily learned, by turning to the geography of countries where rain, and snow, and hail are unknown. All regions thus circumstanced, provided irrigation be impossible, and that the altogether exceptional condition of copious dews be absent, are, despite the most favourable conditions of climate and of soil, barren wastes.

Notwithstanding the thousandfold varieties of clouds—their protean shapes, their manifold colours, and other distinctions—when the observer comes to regard them with a scrutinizing eye, he will not fail to recognize broad distinctions between them, admitting of being made the basis of a philosophic classification. Thus, some clouds are devoid of outline, their edges merging away into circumambient air; some are black and massive, almost conveying the idea of a hard substance; some are white and fleecy; others extended like a pennon. All these are forms of cloud which present manifest distinctions amongst themselves. Mr. Howard was the first who effected a regular classification of clouds. This classification is now generally adopted, I shall, therefore, present the reader with an outline of his system. According to this meteorologist, there are three elementary and four secondary forms of cloud.

Primary Forms.—The first primary form is the *cirrus*, consisting of feathery expansions, and which is only seen in clear weather.

The second primary form of cloud is the *cumulus*, composed of large hemispheroidal masses superiorly and apparently resting below on a horizontal base. This form of cloud chiefly occurs in summer.

The third primary form of cloud is *stratus*, composed of horizontal layers, the smaller layers being underneath. It is this form of cloud, more than any other, which presents itself under a variety of beautiful colours. It chiefly appears at sunset.

Secondary Forms.—The secondary forms of clouds are—(1) *Cirro cumulus*. It is a mixture, as its name indicates, of cirrus with cumulus, and is made up of an aggregation of small white clouds, which have been compared to a flock of sheep. (2) *Cirro stratus*. A compound cloud, which is formed of the two primary clouds embodied in its name. (3) *Cumulo stratus*. This compound cloud chiefly appears towards night in dry windy weather, and is of a leaden colour. (4) *Nimbus, or rain cloud*. This cloud is seen in greatest perfection during a thunder-storm. All the varieties of clouds described are represented in the appended diagram (Fig. 48).

It will be readily anticipated that clouds are frequently so mingled and confounded, that they are not always susceptible of the precise classification just announced; nevertheless, a prevalence of one type of cloud over another will be generally seen to prevail.

Relation between Clouds and the Weather.—People who are in the habit of narrowly studying the phenomena of clouds, are enabled to draw conclusions of much accuracy respecting the coming weather. Thus cirro cumuli are for the most part indicative of serene fair weather; the prevalence of wind subsequently to the appearance of much extended and highly-coloured stratus clouds, is a matter of popular experience. The appearance of nimbus clouds proclaims the advent of rain; and the cirro stratus which sometimes colours the sky as with a veil, all well-defined form being absent, is almost a sure forerunner of bad weather.

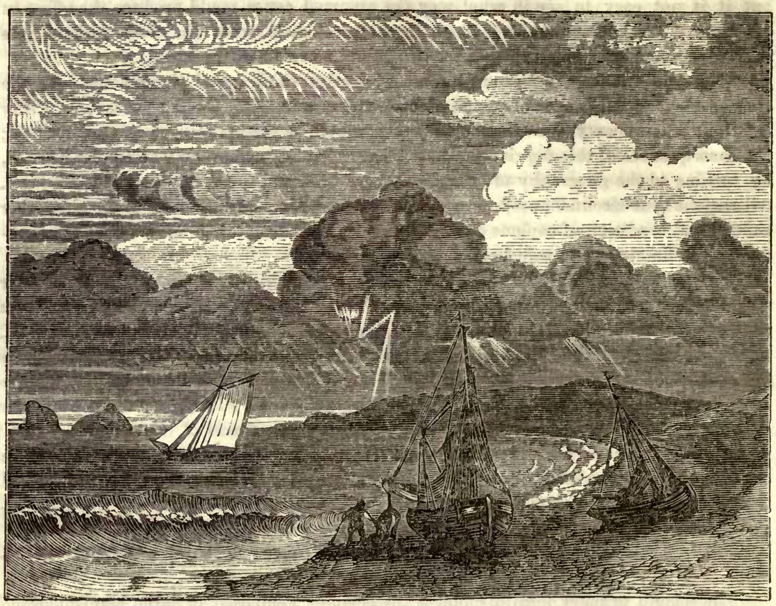


Fig. 48.

Composition of Clouds.—That clouds are composed of water in some condition does not require to be demonstrated; but some explanation must be given of the circumstances enabling water, a material so much heavier than atmospheric air, to remain suspended frequently in very elevated regions, where the atmosphere, thin though it be on the earth's surface, is still more attenuated. This is a matter which it must be confessed is still veiled in considerable obscurity; but perhaps the most rational explanation of cloud formation is the following:—Firstly, aqueous vapour is diffused, or rather absorbed, invisibly throughout the air. The laws of the absorption or diffusion are perfectly well known. The amount differs, as we have already seen, for different temperatures, being proportionate to the temperature. Assuming, then, that the upper regions of the atmosphere at any time are saturated with atmospheric moisture in its invisible condition, let us now contemplate the effect of cooling that atmosphere by any cause. It is not difficult to furnish reasons for these cooling agencies; they are numerous and varied—such as sudden variations of electric condition, sudden variations in the direction of winds. If, then, from any cause the atmosphere is cooled below its capacity for holding vapour in the invisible form, aqueous deposition occurs. If this deposition take place on the earth's surface, the result is dew; if aloft in the air, we have a cloud.

Thus far th steps of each succeeding change are evident; but the remaining points of cloud-formation are more obscure, the circumstance of chief difficulty being to find an explanation of the aerial permanence of clouds, seeing that the material of which they are composed is so much heavier than air. Probably the most consistent explanation is this:—Atmospheric moisture, when it changes from the invisible to the visible form, assumes the physical condition of spheroids or vesicles—minute bubbles of water, in point of fact, each bubble filled with air. If these vesicles be exposed to the sun's rays, it is evident, from consideration of known laws, that they must become specifically lighter than the surrounding medium; and thus affected, they would float, for the same reason that a soap-bubble floats whilst it is yet warm, notwithstanding that the air which it contains is heavier than the surrounding atmosphere. We seem, therefore, in a position enabling us to account for the upper part of cloud strata. Directing our attention now to the lower part of these strata, it seems rational to assume that the vesicles of which they are composed should descend. Probably they do so; continuing their descent until they come in contact with an atmosphere sufficiently warm to dissolve their aqueous coating, and convert their water once more into the vaporous or invisible form. Thus it may be, and most probably is, that a cloud which looks permanent to the eye, is really exposed to the continued operation of resolution and reformation: or, rather, that the two opposing causes, which are here spoken of as producing active changes, balance themselves, and give rise to a condition of equipoise.

Although it has hitherto been taken for granted that clouds are formed of unfrozen water, we know that such is not invariably the case. If the temperature of a nimbus cloud sinks to freezing point, or 32° F., its contents freeze, and snow is the result. Many philosophers, indeed, but more especially Kaemtz, are of opinion that the cirrus—the cloud which soars in the highest regions, frequently at an elevation not less than 20,000 feet above the earth's surface—consists of particles of snow or ice. Assuming this to be the case, it is not easy to advance the reason of such molecules remaining aloft in a medium so attenuated as is atmospheric air in a position so elevated.

Position of Clouds.—It is somewhat remarkable that every known form of cloud assumes more or less the horizontal position. Vertical clouds are very rare; and if we choose to except water-spouts, not recognizing them as clouds, perhaps we may say unknown. The horizontality of clouds, warrants their being spoken of as composed of strata; generally, indeed, these strata are very well defined. MM. Paytier and Hoffard have carefully examined the thickness of these cloud-strata on the Pyrenees, and have found their average variation to be between the limits of 3400 and 1600 feet. The maximum observed thickness was 5000 feet, although this measurement is undoubtedly in some cases greatly exceeded.

Height of Clouds.—Several meteorologists, amongst whom Riccioli, Wrede, Kaemtz, and Arago must be particularly mentioned, have set themselves to the task of discovering the height of clouds. The methods by which these investigations were made have been various. Riccioli determined their height by placing two observers a certain and known distance apart; Wrede by making use of their shadows, and then reducing the computation of height to the solution of a problem in trigonometry. Riccioli states the maximum height of clouds to be 25,000 feet, and Lambert takes their minimum height at 13,000, whilst their maximum height, according to the same, another is from 15,000 to 20,000 feet. Gay Lussac, when he acquired in his balloon an elevation of 21,600 feet, perceived small clouds floating still much above him. Perhaps the statements of

Kaemtz, relative to the height of clouds above the earth, are the most trustworthy. He believes the usual range of cumulus to be from 3000 to 10,000 feet; of cirrus from 10,000 to 24,000 feet; of nimbus, or thunder-cloud, between 1500 and 5000 feet. That very accurate physicist Pouillet, as the result of certain experiments performed in 1840, states, that he has proved the existence of clouds at an elevation from about 22,300 to 38,000 feet, and probably, as the general result of all recorded trustworthy observations on the elevation of clouds, we may arrive at the conclusion that cirrus does not descend below 2000 or 3000 feet, whilst nimbus occasionally descends so low that it approaches the earth within a few hundred feet of surface. The maximum mean elevation of clouds seems, in low latitudes, evidently on account of the greater capacity of the atmosphere to absorb and dissolve aqueous vapour. It should here be remarked that the elevation of a cloud cannot be determined by reference to its apparent place in the sky; and, except the distance be known, neither can its actual size. These remarks are illustrated by the accompanying diagram (Fig. 50), where the same cloud will be seen at different times under very different angles by the same observer, as reference to the angles A E C and B E D will testify, whence the height would differ for two different statures.

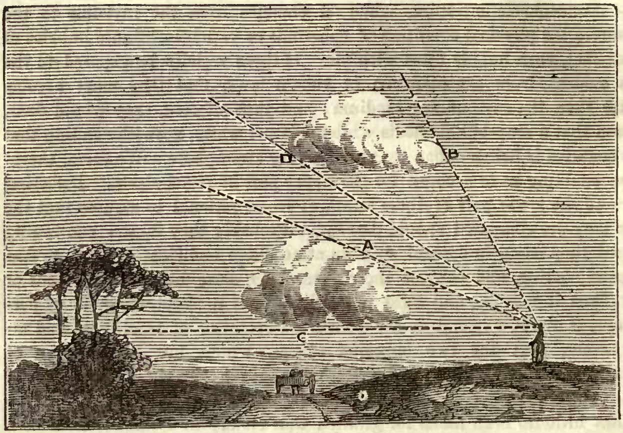


Fig. 49.

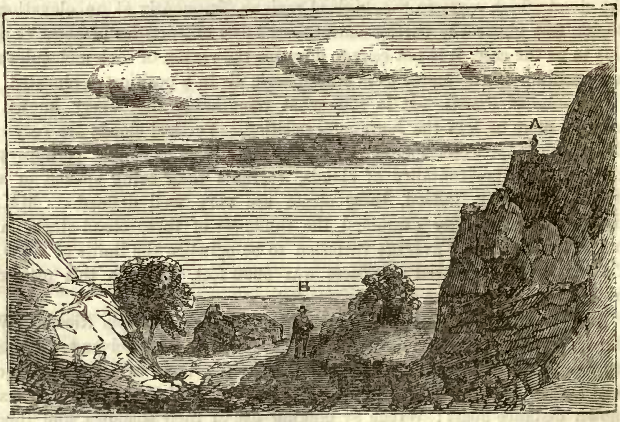


Fig. 50.

And again, in the subjoined diagram it is demonstrated that the observer at A will see clouds which are quite invisible to another observer at B.

Rain.—When from any cause cloud-vesicles aggregate into drops, and these drops fall, the result is rain. Rain would appear, therefore, to be necessarily dependent on a cloud; and in a large majority of instances we find this to be the case. Still, the phenomenon of rain without clouds is well attested. The amount of rain which falls at any place, and at any stated interval, may be readily estimated by means of an instrument termed a pluviameter, or rain-gauge. The principles on which this instrument is founded are of the simplest kind. If, for example, a cup or basin, of known cubic capacity and known orifice, be exposed so that it may receive the fallen drops of rain, the cup or basin would be a rough rain-gauge. Were it not that the collected water thus exposed would be continually evaporating, thus apparently diminishing the total fall of rain, no better rain-gauge need be desired; but in practice it is necessary to provide against such evaporation; and it is usually accomplished by forming an instrument of such construction that one part may be destined to collect the fallen rain, and another part to diminish, within the smallest limits, the amount of evaporation. In expressing the amount of rain which falls at any particular spot, it is necessary to express the height also at which the observation is made. The annual fall of rain increases as land acquires elevation; nevertheless, at one and the same place the amount of rain decreases with elevation, for the reason that each drop of rain throughout its descent goes on collecting moisture and becoming larger. Dalton appears to have been the first to notice this fact. He proved, on comparing two sets of observations,—one set made at the base, the other at the summit, of a high tower,—that the amount of rain at the top to that at the bottom was as two to three. Similar observations made at the Paris Observatory have led to similar results. This variation between the amount of rain at different elevations in one locality, is the more considerable as the point of aerial saturation is more nearly attained; for which reason it is less in summer than in winter. The heaviest rains usually occur in the tropics, and during the hot season. There the fall of rain is enormous, sometimes amounting to an inch per hour; nay, Humboldt has related that in South America no less than five inches of rain fell in one hour. In these islands we can hardly say that any one season merits the designation of the rainy season; but in tropical regions, except the belt of calms, and in the subtropical regions, the separation between the dry and rainy seasons is well marked. In the continental portions of the torrid zone, the rainy season sets in when the summer heat attains its maximum, and continues during four or five months, the atmosphere being clear and bright throughout the remaining portion of the year. Near the equator there are two wet seasons, sometimes separated from each other by a totally rainless period, but at other times demarcated only by periods of maximum and minimum fall of rain. Dutch Guiana furnishes the well-known illustration of a country having two well-marked rainy seasons: one, and that the chief, commences in April, and lasts till June; the other, or minor rainy season, commencing in the middle of December lasts till the middle of February. The drops of tropical rain attain a magnitude never seen in the tamer showers of these northern regions; their weight is so considerable, and the force with which they descend so great, that their splash or stroke leaves a smarting sensation on the skin. The region situated between the influence of the two trade-winds, and commonly known as the region of calms, is devoid of periodic rains, although the fall of rain there is frequent and heavy.

Rainless Portions of the Earth.—There are some localities in which rain never occurs: for example, Egypt, the Desert of Sahara, the table-lands of Persia and Mongolia, the rocky flat of Arabia Petræa, &c. Rain is generally the most abundant near mountain ranges; but there are exceptions, one of the most remarkable of which is presented by the part of Spain south of the Sierra Nevada.

Condition of Europe with regard to Rain.—Europe, considered in relation to the prevalence of rain, admits of being divided into three districts—the South European, the Middle European, and the Swedish. In Portugal and the larger portion of southern and central Spain, there is an almost total absence of rain during summer; but north of the Pyrenees, rain occurs at variable times throughout the whole year. All the portions of Europe north of the Alps and Pyrenees are subject to the Middle European and the Swedish pluvial conditions. The characteristic of the Middle European climate as regards rain is, that the latter chiefly occurs during westerly winds; whereas the Swedish climate is characterized by the prevalence of rain during both easterly winds and westerly winds, which bring rain to the whole of Central Europe, and deluge our isles with wet, leaving the bulk of their moisture by the mountainous Scandinavian range which separates Norway from Sweden. St. Petersburg and Moscow cannot be said to belong either to the Central or Northern European climate; these places lie on the confines of both; hence neither westerly nor easterly winds are there prevalent. In England, the maximum number of rainy days throughout the year occurs in Cornwall and Devonshire; passing thence east into Central Europe, the total number of rainy days per annum continually declines. If we assume the annual amount of rain which falls at St. Petersburg to be nearly three, the corresponding annual amount for the West of England will be 2·1; in Central England, 1·4; in Central Germany, 1·2. This statement assumes an average of some special localities to have been taken into consideration: special places present many deviations. In describing any place as subject to rain, or *rainy*, distinction must be made between the actual quantity of rain per annum which falls, and the total average number of rainy days. Understanding by the latter term every day on which rain, much or little, falls, the number of rainy days increases in Europe from south to north. The mean average for Southern Europe may be taken as 120, in Central Europe as 146, and in Northern Europe as 180. The following statement indicates the total number of rainy days per annum for a few places specifically named:—

Buda	112	Ratisbon	115
Warsaw	138	Rotterdam	187
Germany, average of	150	Paris	160
Carlsruhe	174	Poitiers	99
Tagernsee	170	St. Petersburg	168
Munich	149	Moscow	205
Stuttgardt	127		

Annual Distribution of Rain.—The time of year at which rain is most prevalent, is subject to much variation for different countries. Throughout Central Europe rains are most prevalent in summer, but in Southern Europe the preponderance is on the side of winter rains. Norway is subject to copious winter rains; whilst in Sweden they are almost entirely wanting. Sweden, in point of fact, although placed so near the sea, has a climate altogether like that prevalent in continental regions. The reason wherefore Norway is subject to winter rains, and Sweden is deprived of the same, hinges upon the explanation already made that western winds (which predominate in Scandinavia during winter) lose their moisture in passing over the Scandinavian range. Although summer rains are in many places rare, yet when they occur they are generally more copious than rains at any other period.

Rain which falls in summer at different places, taking the rain which falls on a winter's day at the corresponding place as unity:—

England	1·07	Germany	1·76
Western France	1·03	St. Petersburg	2·17
Central France	1·57		

from which statement it appears that the prevalence of summer rain increases towards the east.

Peculiarities of Rain-Water.—Fresh-falling rain-water, collected far from towns or other sources of local contamination, is very nearly pure; nevertheless, modern chemical observation has succeeded in discovering the presence in rain-water of many substances present in small quantities. Nitric acid and nitrate of ammonia are by no means unusual constituents; and iodine has been frequently recognized. As regards the sources of these and other extraneous bodies, much still remains to be discovered. Nitric acid is most probably formed in the atmosphere by the agency of electricity; and the ammonia may be referable to exhalations from decomposing matters on the earth's surface. Many of the extraneous bodies, especially salts, sometimes recognized in rain-water, are unquestionably due to the action of winds upon finely-divided ocean-spray.

Showers of Fishes, Stones, &c.—Instances are on record of whole shoals of fishes, and numerous collections of other animals—also stones, &c.—being cast on the earth by showers. At one time these phenomena were regarded mysteriously, and referred to occult causes. At present they are deprived of their mystery, and referred to the previous elevation of the fishes, &c. by aerial currents, whirlwinds, and water-spouts.

Snow.—If the temperature of a cloud should fall at any time to 32° F. or lower, instead of rain the result is snow. Much that is beautiful and beneficent is seen in this divided form of frozen water. In our own temperate clime we do not comprehend, except by reflection, the true value of snow in the economy of nature. Its fall amongst us is uncertain and exceptional; we know not when it is to come, or how long it is to remain. We therefore make no provision for it—regard it as a condition to be tolerated—regret that it interferes with our locomotion—that it impedes our railway trains, and wets our feet; and wish it away. Nevertheless, even in these isles, the farmer, from experience, is not insensible to the value of snow. He says it keeps his winter crops *warm;* and the thoughtless passer-by, wrapped in his own self-conceit, laughs at him for making a statement so apparently grotesque. The philosopher, however, who is aware of the low heat-conducting power of snow, and who can appreciate the evil consequences of frost on vegetation, indorses the farmer's statement.

If we would desire to recognise the full benefits of snow, we must direct our attention to northern climes—to Sweden, to Russia, and Canada. There the advent of snow is looked forward to as a blessing; and when it comes, the period of its duration admits of being predicted with tolerable accuracy. No sooner is the ground covered with sufficient snow, than wheeled-carriages, which but yesterday were sticking up to the axletree in mud and wet, are put aside, and sledges supplied in their stead. Market-places, which before the snow had fallen were naked and unworthy, now teem with good things brought from hundreds of miles away. Snow has all at once laid down a far-stretching railroad, over which the sledges glide almost with the ease and velocity of a railway-train.

Form of Snow Flakes.—In certain conditions of temperature snow falls as a pulverulent body, in other conditions as a flaky amorphous mass; but if very dry snow be microscopically examined before it has been broken up, indications of crystalline structure will be recognizable. Sometimes these crystalline snow-flakes attain such large dimensions, that they are quite evident to the naked eye. The crystalline forms thus developed are numerous, but they are all referable to one crystalline system, the *rhombohedric* or *rhombohedral;* the characteristic of which is that crystals belonging to it have three axes crossing each other at the angle of sixty, and one axis at right angles to these. Scoresby, who has minutely examined these snow-flakes, describes five principal forms of snow crystals:—1st, crystals having the form of thin plates, which are the most abundant; 2nd, surfaces or spherical nuclei, with ramifying branches in different planes; 3rd, fine points, or six-sided prisms; 4th, six-sided pyramids. The latter form is the least frequent of all. The accompanying diagram (Fig. 51) represents the principal crystalline varieties of snow-flakes.

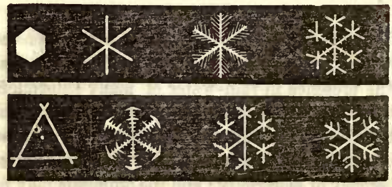


Fig. 51.

The Snow-line.—Inasmuch as the upper regions of the atmosphere are intensely cold, there is an elevation for every latitude at which atmospheric moisture is changed into snow. This elevation corresponds with what is termed the *snow-line.* At the equator the snow-line is elevated from 11,000 to 12,000 feet above the sea-level. As we proceed towards the north, the elevation of the snow-line will evidently be lower. Snow does not fall on level ground in Europe farther south than Central Italy; but in Asia and America the region extends nearer to the equator. Through Florence passes the isothermal line of 59° F., and it may be regarded as the southern limit of the region in which snow falls on level places. Snow does not usually fall at the time of maximum cold; some meteorologists say it never does—but this is an error. After snow has fallen the weather generally increases in severity. We are usually in the habit of assuming that the total quantity of snow which falls increases as we reach either pole—an assumption, however, which is only correct within certain limits. Thus, taking the northern hemisphere, for instance, the fall of snow increases from the isothermal of 59° F. to the isothermal of 41° F., which latter cuts the town of Drontheim, in Norway. Passing still further north, the quantity of snow goes on diminishing, evidently because in the polar regions the temperature of the air is too cold to retain much moisture, and atmospheric moisture must necessarily be the antecedent to either rain or snow.

The atmospheric condition during the fall of snow may vary from the limits of almost complete tranquillity, to the other extreme of most violent perturbations. In Germany, and other countries having a corresponding latitude, the fall of snow is usually tranquil, except during the months of February and March. In high latitudes snow usually occurs during violent tempest-gusts, almost equal sometimes to the West Indian hurricane or the Chinese typhoon. In Norway these storms are very frequent, also in Kamtschatka; in which latter region they are called *purga.* They are veritable thunder-storms, as is completely proved by the intense electrical condition of the atmosphere. On mountainous elevations snow-storms are commonly prevalent, irrespective of latitude.

Coloured Snow.—Red and green snow have been frequently described by travellers. The cause of these phenomena is now referred to the presence of minute algæ—the *protococcus nivalis* in the so-called red snow, and the *protococcus viridis* in the green variety.

Hail.—Frequently cloud-vesicles become aggregated and frozen into lumps of various sizes and shapes, sometimes opaque, sometimes transparent, and occasionally, though not very often, containing neuclei of solid foreign matters. Meteorologically, aggregations of this kind constitute hail. In most parts of the world where rain occurs hail is known, but certain localities are particularly subject to hail-storms. Generally hail falls by day; indeed an opinion prevails that hail-storms are unknown by night. This supposition is, however, erroneous. The form of hail is various, though for the most part they assume a spherical, spheroidal, paraboloidal, or pyriform contour; and still more frequently they are rounded, flattened, or angular. According to Delcross, the most common form of hail is that of a three-sided spherical segment, resulting from the comminution of larger spheres.

The diameter of hail-stones at a mean latitude is, according to Muncke, not usually greater than one and a-half or one and three-fourths of an inch, although on some occasions blocks of ice of enormous dimensions have fallen. For example, in 1719, there fell at Kremo, hailstones weighing not less than six pounds; and at Namur, in 1717, others weighing not less than eight pounds. Again, it is stated that, in 1680, masses of ice fell in the Orkneys twelve inches thick; and in 1795, hailstones fell in New Holland from six to eight inches long and two fingers thick. It is recorded, but on doubtful testimony, that there fell in Hungary, on May 28, 1802, a piece of ice three feet square by two feet thick, and the weight of which was 1100 pounds. But even this is much exceeded by a statement that, in the latter part of the reign of Tippoo Saib, a lump of ice fell at Seringapatam as large as an elephant. The *size* of the elephant, however, is not mentioned.

With regard to foreign substances existing in hailstones, they are described as various. In 1755 there fell in Iceland hailstones containing sand and volcanic ashes; others which fell in Ireland in 1821 contained a metallic nucleus, which proved, on analysis, to be iron pyrites (sulphide of iron); a similar phenomenon occurred in Siberia in the year 1824. The presence of small pieces of straw in hail has been frequently demonstrated.

The largest hailstones fall in summer during thunderstorms. Storms of this kind are most frequent in June and July; they are more rare in May, August, and September, and still more so in April and October. They usually occur at the close of long periods of calm, sultry weather. Hail-clouds are much lower in the sky than rain-clouds; and are generally recognisable by a peculiar ragged or jagged contour, and by their lower portions being marked with white streaks, the other portions of the cloud being inky black. Previous to the occurrence of hail, the barometer sinks very low; and, what is unusual before rain, the thermometric column suffers a corresponding depression. The thermometer during a hail-storm has even been known to sink through 77° F. A peculiar rustling sound in the air is also indicative of speedy hail, by a darkness resembling that dependent on an eclipse of the sun. Hail-storms are very seldom of long duration, usually lasting a few moments only—seldom longer than a quarter of an hour. The rapidity with which hail-storms travel is very great: one which occurred in Central France in 1788 travelled at the rate of forty miles an hour. The force of hailstones is sometimes dangerously great, not only breaking windows and shattering tiles, but killing herds and men and animals, cutting off branches of trees and herbage, and, in short, desolating all save the largest vegetable growths. The hail-storm in France of 1788, already adverted to, extended its devastations over 1039 parishes, destroying property to the amount of 25,000,000 of francs. Although hail-storms often extend very far in a linear direction, their breadth is usually inconsiderable,—often but a few hundred, or at most a few thousand feet,—though the linear extension has been known to exceed four hundred miles.

It has been already mentioned that wherever rain-clouds rest, hail may occur; nevertheless, latitude and local conditions determine the frequency of the phenomenon. Rain seldom occurs on the level land of tropical countries; and it is rare in the extreme north. The hail-belt, pre-eminently so considered, is comprehended between 30° and 60°, and to elevations less than 6000 feet. Even within this belt, and below the limit of elevation just assigned, there are certain localities where the occurrence of hail is a very rare phenomenon. Certain of the Swiss valleys may be cited as a well-known illustration of this remark; more especially in the Valais and its allied dales. It has also been well determined that hail more rarely occurs at the base of mountains than in localities a short distance removed. Perhaps no country, upon the whole, is more subject than France to the ravages of hail-storms, and in no country are the effects more serious. It has been ascertained that the average annual number of hail-storms in France is about fifteen. They are especially prejudicial to the vine and the olive, sometimes laying whole districts under desolation. Having regard to the highly excited electrical condition of the atmosphere as the rule during the occurrence of hail-storms, great hopes were once entertained that they might be prevented, or their ravaging power diminished, by means of suspended conductors. The idea of using such conductors appears to have been first suggested by Guenaut de Montbeillard in 1776; and hail-conductors have been extensively tried, but hitherto without any amount of practical benefit to justify their longer continuance. In 1820 a peculiar kind of hail-preventor was suggested by La Postolle, and subsequently by Thollard. The instruments consisted of straw ropes in which a metallic wire was interwoven, and suspended by means of pointed rods similar to lightning-conductors; but, like instruments having a similar object, and which preceded them, they were found to be unavailing.

Methods of Determining the amount of Atmospheric Moisture.—Having described the numerous forms under which aqueous moisture may exist in the atmosphere, it now remains to indicate and describe certain instruments which have been devised by different experimenters for determining its amount. These instruments, founded on different principles, as will be seen, are termed hygrometers.

It is a matter of common experience that many bodies are affected as regards their dimensions, more particularly their linear dimensions, by mutations of atmospheric moisture. Wood is a very common example of this property; more particularly a stick of wood cut transversely to the grain. Founded on this property of wood, the late Mr. Edgeworth constructed a very ingenious toy, which, though it be not a hygrometer, inasmuch as it does not measure the amount of atmosphere prevalent in the air, is at any rate a *hygroscope.* It is related that the somewhat eccentric philosopher just named once laid a wager that a certain toy—a wooden horse—constructed by himself, should, after the lapse of some time, walk across his room. The horse was accordingly made, and placed at one end of a chamber; the door of the chamber was then locked, and the key deposited in safe keeping. In process of time the horse did indeed arrive at the other end of the room; and the manner in which this was accomplished will now be made evident.

Underneath each hoof was a claw, long enough to stick into the flooring, and there take hold. The horse itself was made out of a piece of wood cut transversely to the grain; the consequence was that when the weather was dry, the linear dimensions of his back contracted, and when the weather was wet his back again elongated. Now, bearing in mind the construction of the feet of this toy-horse, it is evident that these alternate contractions and expansions must necessarily result in a forward motion.

Again, the condition of human hair illustrates the effect of varying amounts of moisture in the atmosphere. Every lady knows that she cannot retain her hair in curl during wet weather so well as when the weather is dry, because of the moisture present, which causes the hair spirals to relax and unfold. In point of fact, each hair contracts and elongates alternately by every mutation of dryness and moisture; so that if only the exact ratio of contraction and expansion could be determined and applied, the meteorologist might construct a hygrometer, having for its basis of actuation a human hair. The hair-hygrometer of Saussure takes advantage of this principle.

To construct this hygrometer, a soft human hair is boiled for a short time in a solution of sulphate of soda, afterwards for a few minutes in pure water; it is then well washed to free it from all adhering salt, and dried in a shady place. Next, one extremity of the hair is fastened to the extremity of a little tongue, and the other end is wound round a small pulley having two grooves. The second groove is for the purpose of retaining a filament of silk, from which a weight is suspended for the purpose of retaining the hair in a constant state of tension. To the pulley is fastened an index, traversing a graduated arc, whenever the pulley turns in any direction by the contraction or elongation of the hair. The graduation of the instrument is thus effected:—It is placed in a receiver holding chloride of calcium, or concentrated oil of vitriol, the air is exhausted from the receiver, and the place where the index then stands is marked. This mark corresponds with the point of greatest dryness, or 0 of the scale. We have next to determine the point of greatest saturation, which is thus effected:—The instrument is next placed in a receiver containing a dish of water; so that as the hair elongates the index turns, and finally coming to rest, the point at which it stands is marked. This mark corresponds to the maximum of moisture, which of course may be indicated by any number arbitrarily selected; this number being usually 100. Finally, it remains to divide the interval between the two extremes into 100 equal parts, and the instrument is complete. Notwithstanding all the care which may be devoted to the construction of this instrument, it is, after all, scarcely deserving the name of a hygrometer—it is little better than a hygroscope.

Occasionally certain helical vegetable fibres have been used as hygrometers in a way which the accompanying diagram will render manifest.

Let A represent a circular card or other flat disc, and B a vegetable filament helically coiled—it is evident that the helix will unravel in a damp, and tighten its coil in a dry, atmosphere. An instrument of this kind has been sometimes employed for the purpose of determining whether a bed be moist or dry. The instrument is a very good hygroscope; but, inasmuch as the coiling and uncoiling of the helix is most comparable with equal arcs, the instrument can hardly be termed a hygrometer.

Fig. 52.

We are under obligations to the ingenuity of the Dutch for another hygrometer, or rather *hygroscope*—for, like the instrument just described, it is not a true indicator of the *quantity* of moisture present in the atmosphere. The instrument is of this kind.—A piece of catgut is suspended from one extremity, and to the other, or lower extremity, is fixed transversely a little horizontal bar. On one extremity of the bar, a lady in gay summer attire is represented, on the other a man dressed appropriately for a rainy day; finally, the catgut and its toy-appendages are surrounded with a case having two openings, and in such fashion that only one of the toy images can be visible at a time. Now, it is evident that the fibres of the suspended catgut will partially untwist under the influence of moisture, and re-twist as the atmosphere becomes dry; whence it follows that the lady will appear under the latter circumstances, and the man under the former. This instrument, though something more than ingenious, for it is a good ***hygroscope***, does not merit the dignified term of ***hygrometer***.

The Dew-point Hygrometer of Daniell.—If a wine-bottle be taken from its bin, it will frequently be found covered with moisture; and in proportion as the air is saturated with moisture, so will the depression of temperature be at which this moisture begins to be deposited on the bottle. In this manner, if we had the means of regulating the temperature of the bottle at our will, depressing it at pleasure, we might ascertain the exact temperature at which moisture would begin to be deposited; and thus noticing the variations of temperature at different times, we might establish and tabulate a correspondence between each particular temperature at which moisture was deposited, and the corresponding amount of moisture contained in the atmosphere. Now, the degree of temperature at which moisture begins to be deposited in this way, is called the *dew-point;* and hence the propriety of the appellation *dew-point hygrometer* which has been given to the instrument presently to be described. It consists of a doubly-bent exhausted glass-tube, each end terminating in a bulb. One bulb is covered with a coating of thin gold or platinum foil, the other with a fine linen rag. The former bulb is partially filled with ether, and holds a small thermometer, the graduated portion of which passes up the tube. If ether be dropped on the second bulb, evaporation rapidly ensues, and the bulb is cooled, thereby condensing the vapour of ether which it contains, and permitting a new evolution from the ether in the bulb. This evolution of ether cools the bulb, and causes dew to be deposited on its surface. The inclosed scale indicates the dew-point. The following reasoning explains how the determination of the dew-point can indicate the amount of aqueous vapour in the atmosphere:—In proportion as the temperature of the air is elevated, will it be capable of holding more moisture. Hence, by cooling the air, its power of holding moisture is diminished; a portion of moisture, therefore, becomes condensed in the form of dew-vesicles. The greater the moisture contained in air, the more readily will condensation ensue for a given reduction of temperature.

The dew-point hygrometer of Daniell, though a great advance upon the rude instruments just described, is attended with some imperfections. Its construction has been improved upon by Döberemer and by Regnault; but the instrument, in its most perfect form, still leaves much to be desired. Not only does its employment necessitate the use of a large amount of ether; but, what is of more consequence, when the weather is extremely dry the deposition only takes place with great difficulty. A far more effective instrument, though based on different conditions, is that now about to be described.

The Psychrometer.—The psychrometer consists of two thermometers mounted on the same frame, the bulb of one thermometer being naked, whilst the bulb of the other is enveloped in muslin or other similar absorbent texture, from which there extends a wick-like absorbent stem, terminating in a cistern of water. From a consideration of the structure of this compound instrument, it will be evident that the mercurial column of the naked or uncoated bulb will stand higher than the mercurial column of the second or wetted bulb. The reason of this is obvious. The process of evaporation lowers the temperature: and it follows, that under one condition, and *only one*, can the readings of the pair of thermometers which constitute the psychrometer correspond—namely, when the atmosphere is saturated with moisture to such an extent that it is unable to take up more. By an extension of this reasoning it will be now evident that the mercurial readings of the pair of thermometers will continually vary, according to the amount of dryness or moisture of the surrounding atmosphere. The variation, in point of fact, is in an inverse ratio to the amount of moisture; so that by means of formulæ we can easily connect the indications of the psychrometer with the dew-point.

Diurnal Variation of Atmospheric Moisture.—The amount of moisture present in air varies at different times of the day. There appears to be two maxima and two minima. The first maximum occurs about 9 A.M., the second at 9 P.M.; the first minimum shortly before sunset, the second about 4 A.M. Popularly, the air is said to be most damp at sunrise, and in the sense of dew or palpable moisture the popular expression is correct; but, provided the air be hot enough, we have already seen that it can absorb large quantities of moisture, retain it invisibly, and impart no sensation of moisture; indeed, pure steam is no more wet than a pure gas is wet.

Monthly Variation of Atmospheric Moisture.—The fact needs no comment, that all months throughout the year are not equally moist. It appears that at London, Paris, Geneva, and Great St. Bernard, the absolute amount of vapour in these places attains its maximum in January, and its minimum at the end of July or the beginning of August; but the relative moisture is greatest at London, Paris, and Geneva in December, and least in May.

Like the true aerial atmosphere, atmospheric aqueous vapour continually varies as to its amount of tension or elasticity. According to Dove, the amount of tension is less during north and south winds than during eastern and western winds, an observation which has also been confirmed by Kaemtz. Necessarily, too, the direction whence the wind blows must influence the quantity present of aerial vapour. North and north-east winds are, at least in these latitudes, less moist than winds blowing from the opposite direction.

Inasmuch as the aqueous vapour dissolved invisibly in air assumes the condition of vapour whenever the air is cooled below the dew-point, the influence which mountain ranges exercise in robbing winds of their moisture and producing rain will be readily evident. By an extension of the same reasoning, it will be also evident that winds which have reached into continents far distant from the ocean, and lost considerable bulks of water, must be necessarily dry. Such are the indications of theory, and observation fully confirms them.

The Meteorologic Relation of Imponderable Agents.—In our preceding investigations, the meteorologic relation of the imponderables has been almost unnoticed. Incidentally, some few of the leading properties of heat have been treated of, but no general statement of the meteorologic relations of these agents has been offered, this being a subject of such vast importance that it merits a treatment of itself.

The expression, imponderable agents, or imponderable forces, is now commonly applied to indicate the cause or causes, whatever they may be, which give rise to the phenomena of light, heat, electricity, magnetism; we must now also include actinism, or the radiant influence of the sun, being neither light nor heat, to the operation of which photographic pictures are due.

The imponderable agents have always presented a field of great interest to the student; but especially interesting is the study at this time, seeing that it is a tendency of modern philosophy to refer all these imponderable agencies or forces to various modifications of one grand cause. The correlations between light and heat, electricity and magnetism, is so intimate and so well marked, that assent can hardly be refused to the assumption that they must all be due to a modification of one common agent. Nevertheless, even though the cause of heat and light, magnetism and electricity, be granted as one and the same, the functions of these four results are so diverse that no generalization of treatment will include them all; they must be held distinct, and treated each under its own head.

Light.—This treatise not having chemistry for its primary object, but merely embracing chemistry as a collateral adjunct, it may be sufficient to comprehend under the general appellation *light* all non-calorific radiant influences. Strictly speaking, we ignore by this arrangement the existence of a peculiar radiant influence termed actinism; but so long as the exclusion be noted, and a reason assigned for the omission, no prejudice to scientific truth will result. A sufficient reason is, that the function of actinism concerns the meteorologist in a minor degree; that it has already been discussed in the treatise on Chemistry; and that all its meteorological relations may be with convenience included under the general treatment of light.

Theories of Light.—Except for the completeness of description, it is rarely worth while to quote the opinion of philosophers of Greece and Rome on any matter of natural science. The wonderful acumen, the quick perception, the subtle reasoning faculty of the Greeks—though the source of a noble literature, of a sculptured embodiment of all that is beautiful in living forms, of a terse logic and wonderful geometry—was perhaps disadvantageous to the development of experimental science. Minds that could venture so far in the region of speculation, were not the most likely to invoke the tedium of protracted experiment which the cultivation of physics demands; accordingly, all that has reached us relating to this branch of knowledge was crude and unreliable. The first theory of light which is on record is, I believe, that of Plato, who assumed that light consisted of certain emanations evolved from the eyes of animals. Subsequently the prevalent notion was that light consisted of emanations from luminous bodies,—a theory which was adopted by Newton, and has been designated the theory of corpuscles, for a reason which will speedily be evident. Even previous to the time of Newton, a theory of light, called the undulatory theory, had been advanced; but at that period its sway was short, though subsequently the theory has been revived, and is at the present time accepted almost universally. Of the corpuscular theory, the remark may be made that it affords a rough and gross explanation of the greater number of common luminous phenomena, for which reason it was long universally accepted; it is totally incompetent, however, to deal with some of the uncommon and very interesting phenomena of light, especially those of double refraction and polarization. The undulatory theory of light (so called from *undula*, a little wave) assumes that the property of function which affects the optic nerve, and which we agree to call light, is a result of the vibrations of certain waves occurring in an alternated medium far too subtle for chemical analysis, and which is conventionally termed ether. Now in strict truth it must be admitted that there is something opposed to the Baconian code of induction, in beginning with the assumption that a fluid ether of the kind indicated exists; and it must also be admitted that the direct evidence in favour of the existence of such ether is but slight. There does exist, however, a presumptive evidence favouring the existence of the agent, independently of the arguments analytically deduced from the *petitio principii* that light is really the result of waves. Astronomers have remarked that the motions of the heavenly bodies in space are subject to certain retardations, indicative of their travelling through some impeding medium; and this is, perhaps, the strongest argument which can be produced. If such medium be a reality, we have the *petitio principii* granted, which the undulatory theory of light demands.

The study of the agencies of light involves a consideration of less theoretical reasoning than is demanded by a corresponding study of the other imponderable agents. In studying the phenomena of electricity and of magnetism, we can hardly make one step without continually employing theory of some kind as a rallying-point for our ideas, and a stepping-stone by which we rise to our deductions. Not so in the matter of light. Whatever be the ultimate cause of this agency, whether corpuscular or undulatory, the function or impression of light is exercised in straight lines, except in a few special cases, which will be brought under notice hereafter.

Velocity of Light.—Astronomical observations of two distinct kinds furnish us with very precise observations, relative to the velocity of light. Its rate of travelling is, firstly, deduced from certain phenomena of Jupiter's satellites; secondly, from the aberration of light. As the result of both these kinds of investigation, light is found to travel at the rate of about 192,000 miles in a second of time. The rapidity, as will be seen, is enormous; yet it is far exceeded by the rapidity of the passage of electricity.

Determination of the Velocity of Light by the First Method.—Astronomical calculations inform us when each particular eclipse of Jupiter's satellites should take place, and the instant any such eclipse does occur may be seen by observation. Now, considering that the diameter of the earth's orbit is 190,000,000 miles, it is evident that our planet must at one time be 190,000,000 miles nearer the planet Jupiter than at another time. Hence, the visual indication of such an eclipse must come to us through a path at one time 190,000,000 miles nearer than at another time, inasmuch as 190,000,000 miles is the measure of the diameter of the earth's orbit. From comparative observations of this kind, it is determined that light occupies about sixteen minutes and twenty seconds in traversing the distance of 190,000,000 miles, which gives the velocity of light per second at about 192,000 miles.

Determination of the Velocity of Light by the Second Method—Aberration of Light.—It will be convenient now to adopt the common expression "ray," as indicative of a luminous agency exercised rectilinearly. Whatever theory of light be adopted, this definition will hold good.

Having premised this definition of the term luminous ray, we may now say that luminous bodies are rendered evident to us by reason of rays of light darted off in straight lines. Provided, then, that a luminous body darting off these rays, and the observing eye which receives these rays, be both at rest, and provided that all interfering causes were absent, the eye would refer the luminous body to its true point in space. If, however, the case be varied by assuming the observer to be in motion, or the luminous body to be in motion, or both, then the eye would not refer the luminous body to the correct point in space, because of what is termed the aberration of light. Inasmuch as our planet is in motion, and the heavenly bodies are in motion, we never see the latter in their true positions, but in the positions which they respectively occupied at some anterior period proportionate to the time occupied by light in travelling from them to the eye. From these considerations it will be evident that if we know the position in space of a heavenly body at any instant of time, and the space travelled over by the observer in a similar time, also the direction of motion in the two cases, the necessary elements are furnished for calculating the velocity of light.

The following diagram (Fig. 53) is intended to illustrate the foregoing proposition.

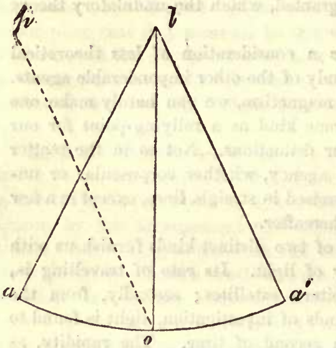


Fig. 53.

In the diagram l is a luminous body in space, $a\,o$, $o\,a'$ represent portions of the earth's orbit travelled over by the observer in given equal portions of time—seconds, for example. The direction of luminous rays is indicated by $l\,a$, $l\,o$, $l\,a'$. It is now demonstrable that if light do *not* occupy time in travelling, the luminous object l will appear in its true position for each time of observation, however much the observer may have progressed. If, on the contrary, time be really occupied by light in travelling, then the observer's eye, supposed to move in the direction $a\,a'$, will not see the luminous body l by reason of the rays which emanate from it at the period of observation, but by reason of the rays which started on their journey at some anterior period; and, seeing that the direction, or angular position, of luminous objects is determined by taking cognizance of their luminous rays, it follows that l will never be seen by the moving observer in its true position. Let us suppose the observer's eye to be at a, then l will not appear in its true position,—namely, the position indicated by the line $l\,a$, but in some antecedent position, which the diagram does not represent. Supposing the observer to have arrived at o, the apparent position of l would correspond to p (*i.e.*, parallel to $l\,a'$, as indicated by the dotted line $o\,p$). It follows, then, that the distance of a luminous body being known, also its true position and its apparent position, the rate of travelling of light can be determined by trigonometric calculation.

Consideration of Primary Optical Laws.—The meteoric relations of light being almost exclusively optical, it will be proper to enumerate a few primary optical laws.

Ray of Light.—Definition: *A ray of light is a rectilinear agency of the luminous essence for any given transparent medium.* This definition is equivalent with the ordinary expression that light travels in straight lines—so far as that expression is correct. Taken without limitation, however, the expression is not correct. The agency of light in

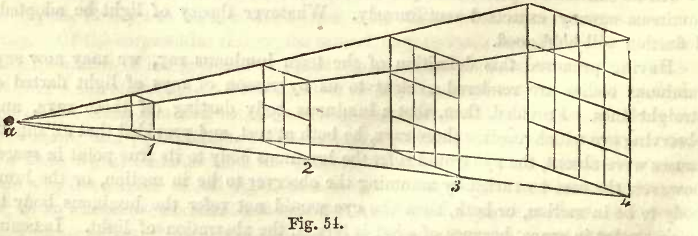


Fig. 54.

straight lines is only maintained for one homogeneous transparent body, and not those in some peculiar cases.

Law I.—The intensity of light varies inversely to the square of the distance. The operation of this law is illustrated by the preceding diagram, wherein the figures 1 2 3 4 represent four distances from a luminous object; the intensity of light at 2 will be one-fourth the intensity of the same at 1; at 3, one-ninth; and at 4, one-sixteenth. If *a* in the preceding body be conceived to stand for an opaque screen, having determinate square divisions—say one foot—and 2 3 4 other opaque screens, having the respective dimensions of four, nine, and sixteen feet, then at position 1 the one-foot screen will intercept all the light, at 2 the four-feet square screen, &c.

Law II.—When a ray of light falls on a reflective surface, the reflected and the incident ray are both in one plane. Thus, in the annexed diagram, *m i p* represents a reflective plane, *d* an incident ray, *n* a reflected ray, and *i* the point of impact; thus the rays *d* and *n* lie in one and the same plane.

Law III.—The angle of incidence and the angle of reflection are equal. Thus, referring to the subjoined diagram (Fig. 55), where *d i* represents the incident ray, impinging at *i* and reflected at *n*, the ray *d i* makes the angle with a line *b i* perpendicular to the reflecting plane *m i p*, which is equal to the angle made by the reflected ray *i n*.

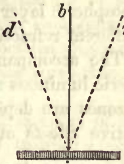


Fig. 55.

Law IV.—When a ray of light passes from one transparent medium into another of different density to the first, refraction ensues. If the density of the second body be more considerable than the density of the first, it is refracted in a direction towards a perpendicular to the plane of the refractive surface. If the order of relative density be reversed, the ray of light is refracted from the perpendicular plane of the refracting surface.

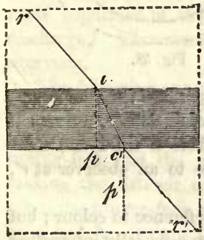


Fig. 56.

The annexed diagram (Fig. 56) is intended to illustrate the law just enunciated. The diagram represents two refractive media. The upper one is indicated by four dotted lines, including a rectangle; the lower one by four plain lines, also including a rectangular space. We may assume, for the conditions of our argument, the upper rectangular space to be filled with atmospheric air; the lower rectangular space corresponding with a block of glass. Assuming, now, *r* to stand for a ray of light passing in the direction *r i c' r'*, we remark that on entering the glass the ray bends towards the perpendicular *p*, because glass is the denser medium. On leaving the glass, the ray bends from *p'*, and assumes its original course. Hence, the law is satisfied. Hereafter we shall discover that a full appreciation of the action of lenses depends upon a previous cognizance of the law.

Many natural instances continually present themselves in exemplification of this law. The salmon-poacher well knows, that if he would succeed in spearing the fish which he sees lying on the bed of a river, he must not strike in the apparent direction of the object, but he must make allowance for the refraction of light caused by the water.

A very common experiment, illustrative of the refraction of light, is performed with a basin containing some small object, which latter, for a certain position of the observer, is only rendered evident when the basin is filled with water. Thus, in the annexed diagram (Fig. 57), the basin is supposed to contain a boy's marble. The latter would be invisible to the eye at E by a ray of light passing in the direction of E K, although visible by the same ray when bent in the direction of O, as would be the case provided the vessel were filled with water.

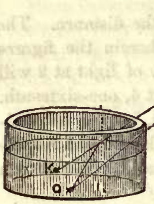


Fig. 57.

Far more important to the meteorologist is the following illustration of the law of luminous refraction by the atmosphere. We have already seen that the atmosphere is to be considered physically as made up of concentric shells of elastic matter of varying density. Practically, then, each successive atmospheric layer (to assume the existence of layers where the blending is complete) has a different refractive power for a ray of light.

The accompanying diagram (Fig. 58) is intended to represent the effect of atmospheric luminous refraction. For the purpose of illustration, three atmospheric shells or zones are depicted. Let us now trace the refractive effects of these zones on a ray of light.

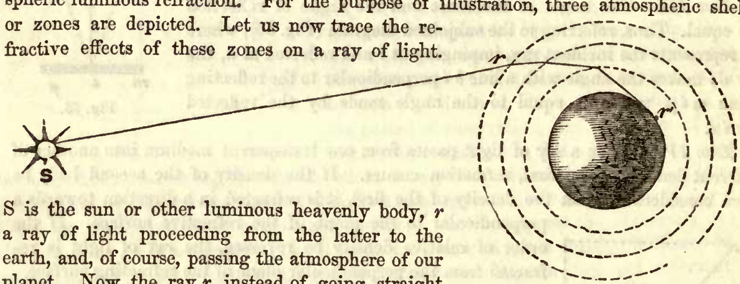


Fig. 58.

S is the sun or other luminous heavenly body, *r* a ray of light proceeding from the latter to the earth, and, of course, passing the atmosphere of our planet. Now the ray *r*, instead of going straight on as it would have done if the transparent medium—the atmosphere—were of one uniform unvarying density, takes the course *r r′*. The outermost zone of air refracts it a little; the second zone being denser, refracts it still more; and the third, or innermost zone, denser still, effects a third and final amount of refraction; so that the sun would be rendered visible to an observer at *r′*, although really below the horizon.

Chromatics.—Hitherto, light has been treated of without reference to colour; but certain phenomena of light, involving the production of colour, are especially interesting to the meteorologist. The rainbow—the tint of clouds, and aurora or morning dawn—the manifold hues of sky and sea, may be cited as familiar examples.

To the immortal Newton we are indebted for the first consistent theory of colours; a theory which, slightly modified, is generally accepted at the present time. The fact is almost too familiarly known for comment, that Newton effected the decomposition of light by means of a triangular prism, causing a white ray to split into coloured rays, and demonstrating that white light consisted of the prismatic colours blended together.

According to Newton, the primary or prismatic colours were seven, as follow:—1. Red; 2. Orange; 3. Yellow; 4. Green; 5. Blue; 6. Indigo; 7. Violet;—violet rays being most, and red rays least refrangible. Subsequent experimenters, however, have reduced the number of primary rays to three,—namely, *red*, *blue*, and *green*. This demonstration cannot be satisfactorily arrived at by prismatic decomposition; but by employing glasses of different colours, and absorbing certain tints of light, the demonstration is easy.

The subject of meteorology scarcely demands that I should enter upon the discussion of spherical or chromatic aberration, still less on the consideration of double refraction and polarized light. I shall, therefore, conclude this short theoretical exposition of the functions of light by presenting a summary of the arguments for and against the corpuscular or emissary, as well as the undulatory theory.

It has already been remarked that the wave theory of light—*i.e.*, the undulatory theory—originated at a period anterior to the corpuscular theory introduced by Sir Isaac Newton. The great objection to the wave theory was this:—if light be the result of waves, it was argued, how is it that light will not travel round a corner after the manner of sound? which latter was known to be the result of vibrations in the air or other medium. This question was deemed to present an impossibility to the comprehension of the advocates of the wave theory of light. Curiously enough, the modern philosopher may accept the corner-test as one of the strongest proofs in favour of the wave theory of light.

As the most striking similarity prevails between light and sound in many of their relations, let us establish a comparison between the two, in respect of turning a corner. Every one knows that sound *can* turn a corner; but the fact is scarcely less patent that, in the act of turning a corner, a portion of the soniferous impulse is deadened or lost. The proof of this assertion is so common, that we scarcely require the performance of an artificial experiment. Who is there who has not noticed the sudden deadening of the rumbling noise of carriage-wheels, immediately the carriage has turned to the right or left down a side-street? Who that has been present during artillery practice—sometimes standing near the muzzle of a cannon, sometimes behind it—has not been made cognizant of the difference between the violence of the report of the cannon's discharge? Thousands of instances of this kind must have presented themselves to everyone.

The following experiment simply, yet satisfactorily, illustrates the same propositions. If a tuning-fork be struck and held at arms-distance from the ear, its prevailing note will be heard with a certain distinctness. If, now, a card be interposed between the tuning-fork and the ear, the former may be brought very near the latter without making the listener cognizant of a sound equal in intensity to that which he heard when the tuning-fork was more distant, but when no card intervened. Indeed, whatever test be devised for demonstrating the deadening of sound by necessitating its travelling round a corner, the result is invariably of one kind—it is affirmative of the proposition.

In endeavouring to establish the existence of a similar property in respect of light, due allowance must be made, of course, for the difference of degree between sonorous and luminous vibrations. I shall very soon demonstrate that, whatever may be the cause of light, each particular colour corresponds to a certain size of *something*, either of wave or of particles. Assuming these measures to be the measures of waves, then we are in the condition to prove that the difference between the size of sound-waves and of light-waves is enormous; and being enormous, we cannot expect that light should be able to turn a corner to a similar extent and with the same facility we find sound to do. But that it can turn a corner within certain limits is unquestionable; therefore, we establish an analogy in an important particular between light and sound, and furnish an answer to the argument which Newton thought to be unanswerable.

The simplest demonstration of the fact that light turns the corner is furnished by the phenomena of shadow. What artist is there who does not perfectly well know that the edge of a shadow is somewhat more illuminated, or less dark, than the centre of the shadow? and granted that the fact be so, does it not prove that light and sound, in the matter of turning a corner, present a complete analogy?

Another illustration, not so familiar as the last, but equally expressive, is this:—If a minute perforation be made in a card, of course a certain amount of light can be caused to pass through the perforation. If, now, an object be viewed through the aperture, the object will be represented magnified, just as it would if a magnifying lens were fixed in the aperture. Now, on the assumption of the passage of light through the aperture, merely subjected to the law of diminished intensity, inversely as the square of the distance, we cannot account for this magnifying power; but if we grant that the light, by friction (to use a comprehensible but not unexceptionable term) against the edge of the aperture, is bent outwards, then the result is accounted for.

Interference of Light.—Some of the most beautiful arguments in favour of the undulatory theory have reference to what is called the interference of light. What is meant by this term may be thus summarised. It is possible, by certain optical arrangements, to produce darkness by causing one ray of light to impinge against another ray in a certain distance; whereas, varying the distance, it is also possible to make the luminosity of the first ray more powerful by the extent of the luminosity of the second. How beautifully, how completely does this accord with the phenomena of musical sounds! Let the following experiment be performed by a person whose ear is moderately sensible to harmony, and the effect noted:—Let two musical instruments—wind-instruments are the best (and perhaps two organ pitch-pipes are preferable to any other)—be caused to produce simultaneously discordant notes. That there is discord the ear can hardly fail to recognize; but to recognize the cause of discord will require a little attention. The two series of pulsations will be heard clashing mutually against each other; all idea of musical tone will have departed; and even the sound, regarded as a mere noise, will have become less than the sum of the two sounds.

If, however, the two organ pitch-pipes be now set in harmony, as the musicians term it; and, more especially, if one be set to produce a tone one octave above the other, and both simultaneously sounded; not only will the result be harmonious, satisfying the musician's ear, but the power of the sound will be equal to the sum of the power of the two notes.

Now the scale-value of musical notes can be demonstrated to correspond with, and be dependent upon, waves of definite size for any particular medium; and it admits of demonstration that musical harmony depends on an accordance between sonorous vibrations; moreover, that discord results when soniferous waves clash in different phases of their vibrations. All this, however, will be more evident if we seek an illustration in a case involving the production of visible waves; as, for example, the illustration furnished by the waves which can be made to arise on the surface of water. If a stone be thrown upon the surface of water in a pond previously unruffled, a series of concentric waves will be developed, originating in the centre, or point of impact of the stone, and extending outwards concentrically. If, now, a second stone be thrown on the surface of the pond, evidently a second series of concentrically expanding rays will be produced, which, meeting the first series, will give rise to one of two opposite effects, according to the manner in which the waves strike each other. If the crest or swell of one wave happens to correspond with the crest or swell of a second, then the two will blend, and the result will be a wave larger than either. If, however, the crest of one wave happens to strike the depressed curve of another, the result will be a diminution of the size of both waves—nay, the absolute destruction of both, provided they were originally of precisely the same dimensions.

The meaning of the expression, "*correspondence of phase of vibration,*" will now be evident. If the crests of two waves strike and coalesce, both curves pursuing the same direction, they are described as meeting in the same phase of their vibration; if they meet, the curves of each wave pursuing poposite directions,—that is to say, one rising while the other is falling,—then the waves are said to meet in opposite phases of their vibration.

I have selected the surface of water as furnishing a visible illustration of wave interference, in every way comparable to the interference of sonorous waves as demonstrated; and to the interference of luminous waves as assumed on the strongest grounds of probability.

Let us proceed now to develop the principles from the consideration of which the size of an unseen wave may be demonstrated. Sonorous waves are of this kind.

Firstly, supposing atmospheric air to be the medium of soniferous waves, we require to know the velocity of sound through this medium. This has been determined to be about 1,120 feet per second at a mean temperature and pressure. Considering then that the velocity with which sound travels has been determined, and that each particular tone of the musical scale corresponds with a determinate number of undulations or vibrations in a given tone, we may ascertain the dimensions of sonorous waves corresponding with any particular tone, provided we know the number of vibrations for any given tone. M. Savart accomplished this by a very ingenious instrument, the construction of which will be best introduced by the following reference to a circumstance frequently occurring. Perhaps it may have happened to the reader that on some occasion when briskly passing along near a long range of iron or wooden railings, he has unconsciously touched them with the end of his cane, which necessarily will have struck each bar of the railing with lesser or greater amount of velocity, according to the rate at which the pedestrian may have been walking along. Now it will scarcely fail to have been noticed that for every degree of rapidity of impact, there will have been produced a different sound, the tone becoming more and more shrill in proportion as the velocity of impact is greater.

On this principle is founded the instrument of M. Savart—a spiked wheel, capable of being set in motion with a determinate velocity. Inasmuch as this machine furnishes a known velocity for a known sound, we have two of the data for ascertaining the size of a sonorous wave; the remaining datum is the velocity of sound, already mentioned. The size of a sonorous wave, corresponding with any particular musical note, may now be determined by application of the subjoined formula:—

Let $S =$ velocity of sound per second,
$N =$ number of vibrations per second necessary to produce any given note,
$W =$ length of wave corresponding to that note;

then $\frac{S}{N} = W$.

From the application of this formula are determined the lengths of organ-pipes, corresponding to different notes, as given in the following table:—

NUMBER OF VIBRATIONS PER SECOND PERFORMED BY WAVES OF AIR CORRESPONDING TO CERTAIN MUSICAL NOTES, AND LENGTH OF THE RESPECTIVE WAVES.

Notes of the Organ.	Length of Pipe.	No. of vibrations per second.	Length of Wave.	
Lowest C	32	16	70	or $\frac{1120}{16}$
C^1	16	32	35	or $\frac{1120}{32}$
C^2	8	64	17·5	or $\frac{1120}{64}$
C^3	4	128	8·75	or $\frac{1120}{128}$
C^4	2	256	4·375	or $\frac{1120}{256}$
C^5	1	512	2·1875	or $\frac{1120}{512}$

Determination of the Size of Sonorous Waves.—Having illustrated some of the phenomena of waves by reference to a surface of water, and shown in what manner the size of sonorous waves may be determined let us now proceed to apply a parallel course, of reasoning to a determination of the size of luminous waves, corresponding with any particular colours,—assuming, of course, as we are obliged to assume, that the sensation of light be referable to the existence of waves. The accompanying diagram (Fig. 59) will illustrate the manner by which this can be effected: it represents a plano-convex lens, laid with its convexity downwards upon a flat glass surface. If this be done, and if the two be pressed together with a certain degree of force, the space of air lying between the flat glass and the convexity of the lens at every point, with the exception of the centre, will be tinted with the primary colours. The outermost band of colour, represented in the diagram by the letters *a a'*, will correspond with red light; and the innermost or central band, circumscribed around *b'*, will correspond with violet light; and between the two all the prismatic tints will appear in their ordinary scale of gradation. Let us contemplate the beautiful deductions which flow from this simple experiment. Firstly, it is evident, that for each coloured band there is a corresponding definite thickness of air; so that whatever the cause of light may be—whether particles, or waves, or anything else—the space corresponding with each particular colour is the measure of that on which the colour depends, to the same extent that the cleft between two rocks, into which a fish has become fixed, is a measure of the size of the fish: so if we can ascertain the size of this aerial space for any given point, we can ascertain the size of the cause of light; and granted that waves of different dimensions are the cause of different colours of light, we can speak confidently of the size of each particular wave. These measurements do not admit of being determined by rough direct measurement of rule and line; but they can easily be measured by obvious trigonometrical calculations, inasmuch as the curve of the lens is the solid formed by the rotation of an arc, of a circle of known diameter.

Fig. 59.

Knowing the velocity of light, and knowing that it travels at the rate of 190,000 miles per second, we are now in a position to determine that a wave of the extreme red of the solar spectrum has a length of ·0000266th part of an inch, and that it vibrates 458 million times per second; that a wave of extreme violet light has a length of

·00000467th part of an inch, and accomplishes 727 millions of vibrations in a second. The steps of the calculation, as will be observed, are the exact parallels of the steps already given above for the calculation of the size of sonorous waves, and are based on a knowledge of the velocity of light per second, and the actual space corresponding to each particular tint. Inasmuch, however, as the subject of light is somewhat abstruse, perhaps the following parallel cases will render the train of reasoning, by which the size of the waves of light are determined, more obvious :—

PARALLEL CASES.

Light travels at the rate of 190,000 miles per second.	A man travels at the rate of 60 yards per minute.
Length of waves of red light, ·00000266th part of an inch.	(Assumed) length of the man's strides, 1½ yard each.
Query.—How many vibrations does a ray of red light make per second?	*Query.*—How many strides does the man make in a minute.
Formula for solving the query.	*Formula for solving the query.*
$\frac{\text{Velocity of light per sec.}}{\text{Length of wave of every colour}} = \text{No. of vibrations per sec.}$	$\frac{\text{Velocity of man per min.}}{\text{Length of stride}} = \text{No. of strides per min.}$
Or,	Or,
Answer.	Answer.
·00000266)190,000(458 millions of vibrations per second.	1½)60(40 strides per minute.

Atmospheric Decomposition of White Light.—Coloured light has been demonstrated to be a component of white light; and, indeed, there is very little white light in nature. Owing to the various decomposing agencies to which light is subject, the result is generally coloured. The tints of natural objects are generally determined by their quality of luminous absorption: If a surface absorb red and blue light, merely reflecting yellow rays, then the tint of the body in question will be yellow. If it absorb yellow and red, merely reflecting blue rays, then the tint of the body will be said to be blue; and so on for the remaining case. An absolutely white body should of course reflect the rays of every colour, but absolute whiteness is rare. An absolutely transparent body, again, should transmit rays of all colours; but this absolute transparency can be scarcely said to exist. Even the atmosphere, transparent though it seem to be, obstructs much light, though the blue colour of the atmosphere is not owing to the blue colour of its particles, but to the reflection of blue rays.

Water, again, is said conventionally to be transparent; but we have only to look through a mass of water, or to look upon the surface of a mass of water, to be convinced that this liquid has the property of absorbing some colours more than others. The consequences which flow from the imperfect transparency of the atmosphere are very curious and important. If it were perfectly transparent, the heavens would appear black to us, and the heavenly bodies would be seen brilliantly shining as if in a framework of jet. By its absorptive power the atmosphere becomes to a certain extent visible; the light of the heavenly bodies is mellowed and softened down; and the beautiful phenomena of twilight and morning dawn are determined. Were the atmosphere perfectly transparent, the surface of the earth would be illuminated in a way totally unadapted to our necessities. Wherever the direct rays of the sun might fall, the surface would be illumined with a blaze of light; but all other spots, provided light did not chance to be reflected upon them, would be quite dark. Aeronauts, and travellers who ascend elevated mountains, confirm the indications of theory relative to the agency of the atmosphere in diffusing or scattering luminous rays. In proportion as the elevation above the earth's surface is greater, so does the sky appear more dark.

Magnetism.—The magnetic-needle, when freely poised on a pivot or freely suspended, is known to assume a directive tendency; and that tendency is popularly described as being north and south. Actually, however, the direction of north and south is only correct for certain parts of the earth's surface. In by far the greater number of places, the line of true north and south is more or less departed from. In certain localities the departure is very great; thus, for example, in Greenland the magnetic-needle actually points east and west; and Parry even found that in one part in the west of Greenland the north pole of the magnetic-needle actually turns to the south. In France the magnetic meridian, or line in which the freely-suspended needle comes to rest, is nearly coincident with the astronomical meridian, only differing from it by 22° towards the west; thus giving rise to what is called magnetic declination, or variation. A few centuries ago there was an absolute coincidence between the magnetic and the astronomical meridians—there was, in point of fact, no magnetic deflection or variation.

Independently of its northern and southern directive tendency, the magnetic-needle is subject to the influence of what is called the magnetic-dip. The dipping-needle consists of a magnetic-needle poised in such manner that it can move in a vertical plane, when the influence of dip will be rendered manifest in a way best illustrated perhaps by the following case:—Premising that a new magnetic steel-needle may be readily magnetized by contact with a magnet, it is evident that such a non-magnetized needle may be so poised on a pivot, or suspended by a string, that it shall lie in a perfectly horizontal direction. If, whilst lying thus, it be suddenly magnetized by contact, and if the operation be performed anywhere in the northern hemisphere, the horizontality of the magnetic-needle will be immediately departed from, and the northern extremity or pole will be depressed. If the experiment be performed anywhere in the southern hemisphere, then the horizontality of direction will also be departed from; but it is the southern extremity now of the magnetic-needle that will be depressed. The amount of the depression or dip is various for different parts of the world. At a certain line, not quite correspondent with the terrestrial equator, the needle lies horizontally—there is no dip; this line corresponds with what is called the magnetic equator. The average amount of dip for this part of Europe is about 70° north. Proceeding towards the north, the dip continually increases; and it attains its maximum at the north magnetic pole, which, however, is not coincident with the terrestrial north pole, but some distance removed from it.

As the northern magnetic-dip goes on increasing as we pass towards the north, so does the southern magnetic-dip go on increasing when we travel in the opposite direction; but the magnetic phenomena of the southern hemisphere have not been so accurately studied as the phenomena of the northern. Here it should be remarked that some confusion has arisen for want of accurately defining the meaning of the term magnetic pole. Sometimes it has been held to signify the two points of greatest magnetic energy of the whole earth, independently of the collateral energy due to the operation of local causes; at other times it has been held to be synonymous with the point exhibiting the greatest influence of these local causes. Adopting the latter idea, some writers describe two northern magnetic poles—one in Siberia, the other in North America; but this seems an unphilosophical application of the term, polarity. Accepting the term magnetic pole in its first sense, it will be easy to see that one of the northern magnetic poles, at least, corresponds with the point of greatest cold.

Variations of Terrestrial Magnetism.—These may be divided into regular and irregular. The former are dependent on determinate causes; and though the causes of the latter be not determinate, analogy furnishes us with a plausible explanation of them. Referring to magnetic variations of the determinate kind, they will be found to present a correlation with variations of temperature. Some time during the morning the north polar extremity will have attained its greatest variation towards the east, and shortly past noon it will have deviated towards the west of its normal meridian; it then returns eastward again, and about midnight it will have assumed a deviative position almost similar to that which it had in the morning. These oscillations have not the same amplitude at all times of the year; they are greater in summer than in winter—greater on a warm and cloudless, than on a cold and clouded day: circumstances which point to the thermal origin of the variations.

The amount of dip also manifests horary variations; a circumstance which leads to the inference that the magnetic poles are not fixed spots like the geographic poles of the earth, but are subject to deflections. This is exactly what should result, if the thermal theory of terrestrial magnetism be adopted.

The regular variations of the magnetic-needle are so clearly referable to the normal effects of solar heat operating upon the surface of our globe, that philosophers have universally agreed to refer them to that cause. But the influences of solar heat are occasionally abnormal; besides which, specialities of locality, the effect of casual flows of tepid oceanic water, the influence of volcanoes, &c., furnish a sufficient basis for an *a priori* assumption that other magnetic variations besides those which admit of being predicted will come into operation. Hence, other phenomena of magnetic aberration will be determined—they have been studied more especially by M. Gauss; and their dependance upon what may be termed an abnormal-thermal condition of our globe is rendered the more probable that they are coincident with irregular variations of the barometer.

Three systems of lines are employed to represent on charts the three different values of magnetic declination, inclination, and intensity. These lines were denominated by Humboldt *isogonic*, *isoclinic*, and *isodynamic* lines.

Isogonic lines are such as connect those parts of the earth possessing equal magnetic declinations; and charts are formed in accordance with these lines, called declination charts. Inasmuch, however, as the amount of magnetic declination for any one place is never permanent, but continually changing, these charts are only reliable for short successive periods, and require to be frequently altered. There are, nevertheless, a few points on the earth's surface where the amount of declination is permanent, or very nearly so; the most remarkable of these are Spitzbergen and the wertern parts of the West Indies. The most important and most remarkable of all the isogonic lines is that coinciding with places where the magnetic and astronomical meridians exactly coincide; and where, consequently, the needle points due north. In the year 1657, this line passed through London, and two years later through Paris.

Isoclinic lines are such as connect parts of the earth which are characterized by the same amount of magnetic inclinations. Charts of these lines exist under the name of inclination charts. The most important of these lines is the one corresponding with the magnetic equator; and at which, as before explained, the dipping-needle has no inclination. The magnetic and the terrestrial equators cut, as was before explained, and the points of intersection continually vary. In 1825 one point of intersection of the two equators occupied a position near the Island of St. Thomas, on the western coast of Africa, being distant about 188½° from the South Sea node; between 1825 to 1837 the former node shifted 4° westward. On the Brazilian coast the magnetic is situated 15° south of the terrestrial equator. About one-fifth of the magnetic equator cuts the surface of the ocean.

Places at which the intensity of magnetic force is equal are said to be isodynamic, and on charts are represented as being cut by isodynamic lines. Generally the intensity of magnetism may be said to increase from the equator to either pole; nevertheless, isodynamic magnetic lines neither run parallel to the magnetic nor to the terrestrial equator. The minimum of intensity occurs near the coast of Brazil. The maximum of magnetic intensity is about twice the minimum.

Cause of Terrestrial Magnetism.—Reference has already been made to the influence of heat in causing perturbations of the magnetic-needle. We shall presently find that the very existence of terrestrial magnetism is ultimately referable to heat.

When treating of the thermoscope of Nobili, some mention was made of the function of thermo-electricity, and the conditions necessary for bringing it into operation. It will now be desirable to discuss the properties and conditions of this function more closely.

Nothing can be more certain than the correlation which subsists between heat, electricity, and magnetism. It is impossible to produce an elevation or a depression of temperature without producing at the same time a manifestation of electrical excitement. This will be demonstrated hereafter under the head of Electricity. For present purposes it will be sufficient to establish the law of electro-magnetic excitation, and to show in what manner it is in some cases ultimately referable to the operation of heat. Long before the precise dependance of magnetism upon electricity was known or suspected, the connection subsisting between them was assumed. Pieces of steel were frequently rendered magnetic during thunderstorms; the polar tendency of magnets already existing was reversed by the same cause; and at a later period in the progress of electrical experiment the discovery was made that a small steel-needle might be converted at pleasure into a magnet by subjecting it to the influence of a wire helix, acting the part of an electrical conductor.

The experiment in question is very easy, and as follows:—Within the coils of a wire helix (see Fig. 60) a needle, enveloped in paper or some equivalent imperfectly-conducting material, is laid. An electric discharge then being transmitted through the conductor, and the needle removed, it will be found to have acquired magnetic properties, indicated by its quality of attracting iron-filings at either end; by its north pole or end repelling the north pole or end of a known magnet, attracting the opposite, and *vice versa*.

Looking at the conditions of this experiment, it will be perceived that, whatever connection between the producing electric current and the produced magnet there may be, the electricity has been acting tangentically to the long axis of the needle. This is an important point, for we shall hereafter see that the same tangential relation continues to subsist in all subsequent experiments resulting in the formation of electro-magnets.

Common or frictional electricity does not furnish the operator with a means of proceeding far in his examination of the relations subsisting between electricity and magnetism. The aid of voltaic electricity is required, as in the following experiments:—If a metallic wire be twisted into a helix, as represented in the following diagram (Fig. 60), and a bar of iron, previously enveloped in paper, inserted within the helix; if now a current of voltaic electricity be transmitted through the wire, the iron bar will for the time-being be converted into a magnet. This experiment is, indeed, similar to that already indicated, with the exception that an iron bar instead of a steel needle is employed; the fact being that, though steel, when once rendered magnetic, retains the magnetic influence with much permanence, iron is more readily amenable to the same influence, and is therefore commonly employed in these and similar experiments. Instead of using a plain wire, it is better in practice to employ a wire covered with flax, or cotton, or silk fibre, or with a layer of gutta-percha, when the necessity which previously existed of enveloping the bar in paper ceases. Coated wire of this description is extensively prepared by manufacturers of gutta-percha.


Fig. 60.

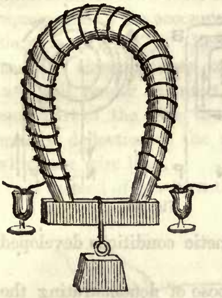


Fig. 61.

The influence of voltaic electricity in determining magnetism is still more evidently manifested when the iron bar, instead of being straight, is bent into the horse-shoe form as represented in the accompanying diagram (Fig. 61); and the power of the developed magnet is greater if the number of helical turns be increased. Usually, therefore, in practice, several wires are soldered together at either extremity, as represented in the following woodcut (Fig. 62). In all these instances, the circumstance will not fail to have been noticed that the magnetic power is developed at right angles, or tangentically to the direction of the passing electric current.

Voltaic Conducting Wires are themselves Magnetic.—If a wire conducting voltaic electricity be brought in proximity to iron-filings, it attracts the latter just as a magnet would do; thus begetting a strong *a priori* assumption that such conducting wire, for the time being, is itself magnetic. Now, if the assumption be well founded, of course it should exercise the usual influences of attraction and repulsion when a freely-poised or freely-suspended magnetic-needle is brought into its vicinity. Such influence is found to be manifested; and thus we shall presently see that all the hitherto anomalous tangential influences are lucidly explained. Firstly, let us not discard the illustration presented by the attraction of iron-filings with the conducting wire, without deducing from these phenomena an important corollary.

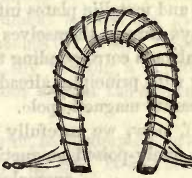


Fig. 62.

Assuming A B (Fig. 63) to represent such a wire, and assuming, as is really the fact, that the iron-filings are attracted all round the surface of the wire, it is evident that the magnetic polarity is developed in lines at right angles to A B—that is to say, in the direction of *c d;* whence it follows that such conducting wire is a magnet at right angles to its length.

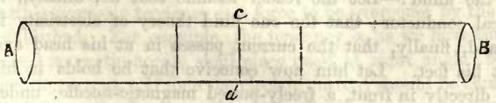


Fig. 63.

This point is very strikingly illustrated by the following contrivance:—Z C (Fig. 64) are respectively plates of zinc and copper, communicating with a wire in such manner that a current of electricity passing from one plate to the other must necessarily pass along the wire. Now, the instrument here represented may be caused to swim, by means of a cork-float, in a basin of dilute acid, when it becomes an active voltaic combination; and, inasmuch as the liquid support admits of the free motion of the instrument, allowing it to turn in any direction, the vertical plane cut by the wire ring should, provided magnetism be developed, assume the direction of the magnetic meridian, *i.e.* north and south. This it is found to do—again illustrating the proposition, and more plainly than before, that a wire conducting voltaic electricity is magnetic at right angles to its long axis. Not only does this remark hold good, but the two magnetic polarities have a definite relation to the transverse section of the wire; one definite side of the plane always pointing north, whilst the other necessarily points south. If the conducting wire, instead of being bent into a mere ring, be twisted helically, as represented in Fig. 65, the magnetic conditions developed will be still more evident.

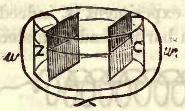


Fig. 64.

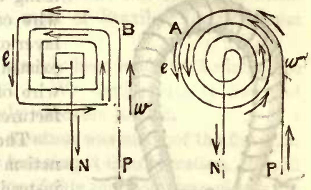


Fig. 65.

This was a form of wire devised by Amperè, for the purpose of demonstrating the magnetic character of wire in the act of transmitting electric currents. The forms of apparatus in question may be delicately suspended or converted by means of pieces of cork and metallic plates into floating arrangements. Thus arranged, the flat spirals will always arrange themselves in the direction of north and south; one definite side of the coil always corresponding to one invariable direction of the electric current. In conformity with principles already enunciated, each coil of the flat helices may be regarded as a separate magnetic pole.

If, now, we carefully investigate the law of this developed magnetism by means of a freely-poised magnetic-needle, it will at a first glance appear to be altogether anomalous. Thus, if a voltaic conducting-wire be held in successively different relations to a magnetic-needle, the needle will seem to be deflected according to no recognizable rule; but further examination demonstrates not only the existence of a law, but demonstrates the seemingly irregular motions to be still due to the operation of the tangential force already described.

Fig. 66.

The following simple rule will, under all circumstances, serve to fix the direction of the polarity of a magnet developed by electrical agency in the mind:—Let the reader assume that he, himself, is the electrical conductor; that the one fluid theory of electricity is adopted; and, finally, that the current passes in at his head and emerges at his feet. Let him now conceive that he holds in his hand, and directly in front, a freely-poised magnetic-needle, under which circumstances the north pole of the magnet would always be deflected towards his right hand. In accordance with these facts, and in illustration of them, the following diagram (Fig. 66) has been devised. It is a soldier, who holds a musket in his hand; the bayonet of which musket is assumed to stand for the north magnetic pole. Supposing, then, a current of electricity to pass in at his head, and emerge at his feet, the bayonet would invariably be directed towards his right hand.

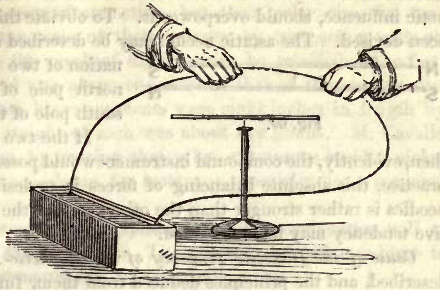


Fig. 67.

We have next to consider the effect of causing an electric current to encircle a freely-suspended magnetic-needle in a plane coincident with its axis, as represented in the accompanying diagram (Fig. 67). Reflection on the circumstances of this case will render manifest, that each part of the wire thus arranged will tend to produce the same general result—namely, deflection of the needle to a position at right angles to the vertical plane in which the wire lies.

If instead of one turn the wire be caused to encircle the magnetic-needle twice (Fig. 68), then the needle will be deflected with an energy double that effected by the previous combination; and *generally* in proportion as the number of coils is greater, so will the deflecting power be more considerable.

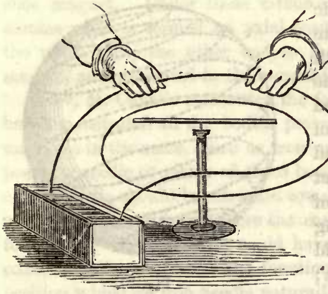


Fig. 68.

On an appreciation of these principles depends the instrument termed the galvanometer, which teaches the force of a voltaic current in motion, by causing a deflection of a greater or lesser axis of the suspended magnetic-needle.

The galvanometer, in its simplest form, is given at page 277, Fig. 30. It will be seen to be nothing more than a close mechanical adaptation of the principles developed in the two preceding operations. By increasing the number of coils in a galvanometer, it necessarily follows that its power of deflecting a suspended magnetic-needle will be increased also. Accordingly, delicate galvanometers are always formed with a compound coil, and are, moreover, covered by a glass shade, as represented at page 277, Fig. 31.

In all these experiments I have assumed, for the sake of not complicating the matter needlessly, that an ordinary single magnetic-needle has been employed. The use of such a needle, however, is attended with this important disadvantage,—namely, the earth's magnetic tendency is a force to be overcome by the magnetic energy artificially established. For example, the tendency is, as we have constantly seen, that a freely-poised magnetic-needle shall place itself at right angles to the direction of a passing electric current. If then the electric current should be caused to pass in the direction of north to south, the magnetic-needle should, in accordance with the principles developed, arrange itself east and west. Such is the tendency, and such is the direction the magnetic-needle would assume, provided the voltaic current be sufficiently powerful; but it is not difficult to conceive a case where, the electric current being weak, the natural directive tendency of the needle—*i.e.* north and south—in obedience to the earth's magnetic influence, should overpower it. To obviate this interference, the astatic needle has been devised. The astatic needle may be described as being a double magnetic combination of two needles mounted on one pivot, the north pole of one needle being opposed to the south pole of the other, as in Fig. 69.

Fig. 69.

If the two magnets be of exactly equal power, then, evidently, the compound instrument would possess no natural directive tendency. In practice, this absolute balancing of forces is undesirable; therefore, usually one of the needles is rather stronger than the other, so that the slightest possible amount of directive tendency may be maintained.

Cause of the Directive Tendency of the Magnetic-Needle.—The experiments already described, and the principles deduced from them, furnish a rational explanation of the directive tendency of the magnetic-needle. Firstly, it is granted that any variation of temperature always develops a current of electricity. This proposition the reader will accept as authority for the present; but, hereafter, under the head of electricity, the demonstration will be made plain. Secondly, it is granted that wherever there is an electric current set up, there will always be a magnetic energy developed at right angles to the electric current. If we now assume, as the proximate cause of the magnetic-needle's north and south directive tendency, that it does so because the earth itself is a magnet in the direction of north and south, we have only to discover the cause of an electric current at right angles to this direction, and the mystery is explained. Now it is evident that our globe is diurnally heated in the direction of east to west by the sun's rays; whence, according to the result of artificial experiments, there should also exist an electric current in the same direction; and, this being so, the earth itself becomes a vast magnet, the one pole of which is northern, and the other southern.

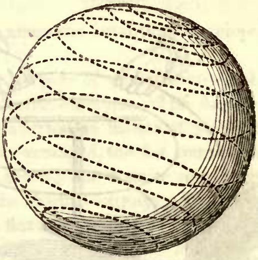


Fig. 70.

In illustration of this, the following experiment has been devised:—A hollow paper globe (Fig. 70) has been lined internally with a revolving copper wire, so arranged that it should serve as an electrical conductor. If electricity be passed through this copper wire, and a freely-poised magnetic-needle be placed in various successive positions on its surface, all the variations of deflection and dip which naturally occur may be indicated in the clearest manner imaginable.

Dia-magnetism.—For a long time it was imagined, and even in this day the idea is popularly entertained that iron alone, of all bodies, is susceptible of magnetism. Experimenters eventually admitted that the metal nickel participated with iron in the property in question, and the notion began to be entertained that yet other bodies might be included in the same category. It was by no means easy, however, to subject the opinion to the test of experiment, considering the known difficulty experienced in banishing every trace of iron from the materials operated upon. Magneticians even argued that the magnetism of nickel might be only apparent, the quality being attributable to the presence of iron. At length M. Biot set these doubts at rest definitively. He caused some nickel to be freed from all traces of iron by that distinguished chemist

M. Thenard; he then caused magnetic-needles to be made of this nickel; he not only determined the existence of their power of attraction, but their polar directive tendency; and he finally discovered the ratio of their polarity by comparison with an ordinary steel magnetic-needle. On the result of his inquiries he established the fact, that the directive force of the nickel was about one-third of that of the steel needle. The needles with which he conducted his experiments were eight inches in length by two-tenths of an inch wide, and the weight of each was about five grains. M. Cavallo followed in this line of demonstration, by proving that other substances besides nickel were susceptible of ordinary magnetism—brass, for instance; especially brass rendered hard by hammering.

The term *ordinary* magnetism requires to be explained, and the explanation will at once introduce the phenomena of *dia-magnetism.* The property of being subject to magnetic influence long known to be manifested by iron, and subsequently proved to be participated in by nickel and brass, is perhaps universal; but the kind of influence differs. Assuming iron to represent the normal kind of influence, let us consider what takes place if we suspend a needle of that metal in what is called the magnetic field—namely, the space between the two extremities or poles of a horse-shoe magnet. Under these circumstances, the iron needle would assume what is termed an axial position, one end being attracted to the north pole, the other end to the south pole of the horse-shoe magnet, as represented in the annexed diagram (Fig. 71).

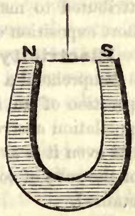


Fig. 71.

Now, M. Cavallo committed the following important mistake:—He fancied that he had demonstrated all the bodies proved by him as being magnetically endowed, to be magnetic in the same sense as iron and nickel are magnetic; that is to say, that supposing a needle of either of these bodies to be suspended in the magnetic field, one end of the needle should be attracted towards the north pole, the other end to the south pole of the magnet. If such were the case, the function now to come under notice as the function of dia-magnetism could have no existence. Before entering more into detail concerning the properties and functions of dia-magnetism, it must be premised that the position which an iron needle naturally assumes when hung in the magnetic field is said to be an *axial* position, or it is said to arrange itself *axially.* If it were to assume a position at right-angles to the same, its position would then be described as being *equitorial.* Now, M. Cavallo believed that all bodies endowed with a magnetic tendency, in any degree, would manifest that tendency by assuming the axial position when freely suspended between the poles of a horse-shoe magnet. This, as I have already remarked, is an error: some bodies arrange themselves axially under these circumstances, and are therefore said to be magnetic; whilst others arrange themselves equatorially, and are said to be dia-magnetic.

The knowledge of *dia-magnetism* may be said to have originated with Becquerel, though Coulombe and the Abbé Haüy had both laboured in the same direction. The investigation has been followed up with great ardour by Professors Faraday and Tindall in England, and Professor Plücker of Bonn, to whose published papers on this subject I must refer the student who desires further information relative to dia-magnetism than accords with the nature of this treatise. It must be remarked, however, that when bars are made of different substances, and submitted to the influence of the magnetic field, those of iron, nickel, and cobalt, point axially: most probably those of titanium, palladium, and platinum, are in the same category; but needles of all other metals assume the equatorial direction in the magnetic field, and are therefore *dia-magnetic.* The following table presents a list of magnetic and dia-magnetic bodies:—

Magnetic Bodies.		Dia-Magnetic Bodies.			
Iron	Cerium	Bismuth	Cadmium	Silver	Uranium
Nickel	Titanium	Antimony	Sodium	Copper	Rhodium
Cobalt	Palladium	Zinc	Mercury	Gold	Iridium.
Manganese	Platinum	Tin	Lead	Arsenic	Tungsten
Chromium	Osmium				

From a consideration of the preceding remarks, it will be observed that the functions of heat, magnetism, and electricity are intimately allied, more especially the two latter. Instead, therefore, of entering upon the discussion of meteorologic phenomena, due or attributed to magnetism, in this place, it will be desirable to present the reader with a short exposition of electrical science and phenomena.

Electricity.—*Definition and Derivation of Term.*—The term electricity is applied to comprehend a large class of phenomena, which are related in various ways with the operation of an invisible force, to which, founded on speculative considerations, the appellation *electric fluid* has been given; not that such fluid can be proved to exist, or that even it is at this time, by the majority of philosophers, supposed to exist, although, for the sake of convenience in illustration, the expression, electric fluid, is still popularly retained.

The science of electricity is one of the most recent; nevertheless, the primary phenomena on which the science is based are of very ancient date. Theophrastus and Pliny were aware that the substance amber, if rubbed with silk, flannel, &c., became endowed with the property of influencing the motions of certain light bodies, such as feathers, attracting them under certain circumstances, and repelling them under other circumstances; but there the investigation of this class of phenomena ended. About the middle of the last century, however, the subject was returned to, recommencing from the starting-point of Theophrastus and Pliny; and from the simple fact of the peculiar excitation of amber under certain circumstances of treatment, to build up the interesting and important science now known as that of electricity.

Development of Electricity.—The first development of electricity was accomplished by the friction of one particular substance—amber, as we have seen; but when the attention of modern philosophers was directed to the science, they soon found that amber only furnished one particular cause of a result far more general. Many other bodies, in addition to amber, were discovered which, on being submitted to friction, became electrically excited, or electrical; and to these the general term *electrics* was given. Furthermore, it was discovered that the bodies thus capable of electrical excitation were not capable of conveying away electricity; whence they were also called non-conductors of electricity. Great as was the advance thus made on the crude notions of Theophrastus and Pliny, it fell far short of the truth, modern electricians having proved that no real or functional difference subsists between conductors and non-conductors, only a difference of degree; consequently, bodies do not admit of division into the classes of non-conductors and conductors, except in a conventional sense, and as a matter of practical convenience. Experiments fully illustrative of the propriety of this view will be furnished hereafter.

Though friction be the earliest observed cause of developed electricity, and though it constitute the principle on which the ordinary electrical machine is founded, nevertheless it is only one cause, and perhaps the least important, of those which the meteorologist has to take cognizance of as coming within the scope of his science. It is difficult to say what alteration of matter, chemical and mechanical, is *unattended* by the development of electricity. In all probability there is none of this kind, though it happens that in most cases special, and sometimes very refined, contrivances are necessary for rendering electrical excitation evident. A notable illustration of this is furnished by the hydro-electric machine, familiar now to many people by its exhibition at the Polytechnic. This machine constitutes the most powerful instrument for developing electricity by artificial means known; yet if the glass legs on which it stands were removed, the instrument would become inoperative, and the existence of all the vast force of electricity which it generates would remain unknown.

Having premised these general remarks concerning electricity, it will be desirable now, before taking cognizance of the operation of this force in nature, to present the student with the fundamental causes or propositions on which the science of electricity depends. In doing this, I shall avoid, as much as possible, having recourse to the electrical machine, or any complex electrical arrangements, which, though indispensable to the full illustration of secondary electrical facts, are rather perplexing than otherwise so long as fundamental principles alone are concerned.

Definition of the term Electric.—Any body which after having been rubbed acquires the property of attracting light substances, after the manner of amber, is an electric.

What bodies or class of bodies are Electrics?—Inasmuch as the act of friction will be involved in our experiments having reference to this demonstration, it necessarily follows that only one physical division of bodies—namely, solids—admit of being readily submitted to our notice; for though liquids and gases can be subjected to friction, yet the contrivances for effecting this, consistent with the requisite electrical demonstrations, are so complex that they cannot be taken cognizance of at present.

I shall assume that our present observations are limited to three bodies—glass, sealing-wax, and a metal; each, for convenience of manipulation, fashioned into the form of a stick. I shall assume, moreover, that the rubbers, or body wherewith friction is effected, are of flannel and of silk. By the employment of these simple materials some important results will be arrived at.

Experiment I.—If the stick of sealing-wax be briskly rubbed, and held at some distance (not too far) from a suspended feather, represented in Fig. 72, the latter will be attracted towards the sealing-wax—will attach itself to the latter: but the attachment will not be permanent. After a time it will leave the sealing-wax, and be repelled.

Experiment II.—If the previous operation be repeated with a stick of glass, the feather will be first attracted, and afterwards repelled, in a precisely similar manner as before. Hence, for aught we at present see, the kind of influence developed by friction on glass is similar to that developed by friction on sealing-wax.


Fig. 72.

Experiment III.—Let the glass rod be excited by friction, and held near the feather as before. The feather will necessarily be first attracted, then repelled. If the rod or sealing-wax be similarly excited, and held near the feather, which has refused to be further attracted towards glass, it will, nevertheless, be attracted toward the sealing-wax, and *vice versa.* This experiment demonstrates that, whatever be the nature of electricity, this force is susceptible of two manifestations: it is, in point of fact, a *dual* or polar force, similar in this respect to magnetism. It admits of being demonstrated that, in either of the preceding experiments, the rubber or body wherewith friction is excited always assumes an electrical polarity different to that of the body rubbed.

Designation of the two Electric States.—As the two polarities of magnetic energy are designated respectively *north* and *south,* without which, or some equivalent designation, it would be impossible to describe the peculiarities of magnetic phenomena; so, in like manner, it will be necessary to designate the two electrical functions already proved to exist. Accordingly, the terms, positive and negative, or vitreous and resinous electricities, have been long employed. The words, positive and negative, have reference to the theory of Franklin, that all the phenomena of electricity depended upon the operation of one electric fluid. A certain class of electrical phenomena he assumed to depend upon an excess of this fluid—another, or opposite class of phenomena, to depend on a diminution of the same. The first class of phenomena he termed positive, the second negative.

The origin of the terms, vitreous and resinous, will perhaps have been anticipated from a consideration of the teachings of Experiments I. and II. Glass, it has been seen, when rubbed, gives rise to the development of one function of electricity, and sealing-wax of another. Now, glass and sealing-wax are, in this respect, only the types of all other bodies.

Conductors and Non-Conductors.—Referring to Experiments I., II., and III., three distinct stages of electrical condition may be observed. Firstly, the feather, before it has been subjected at all to the influence of the excited glass or sealing-wax, presented the condition of electric neutrality. Secondly, it presents two conditions of excitement, namely, attractive excitement and repulsive excitement. If, whilst the feather is under either of the latter conditions, it be touched with various substances successively, certain important results will be observed. If it be touched with the finger, all electrical excitation will be at an end. This effect is best demonstrated by touching the feather when in the repulsive phase of excitation. A similar result will ensue if, instead of the finger, the excited feather be touched with any metal or wood, or one of numerous other bodies to which the term electrical conductor is *conventionally* applied—I say *conventionally,* because the circumstance has been already indicated that the distinction between conductors and non-conductors is purely one of degree, not of kind. Nevertheless, in practice it is useful to divide bodies into electrical conductors, and electrical non-conductors. A table, representing this division, is appended. The terms non-conductor and insulator are, it is necessary to observe, synonymous.

CONDUCTING BODIES, PLACED IN THE ORDER OF THEIR CONDUCTING POWER.

All the metals.
Well-burnt carbon.
Plumbago.
Concentrated acids.
Dilute acids.
Saline solutions.
Metallic ores.
Animal fluids.
Sea water.
Spring water.
Rain water.
Ice above 13° Fah.
Snow.
Living vegetables.
Living animals.
Flame.
Smoke.
Vapour.
Salts soluble in water.
Rarefied air.
Vapour of alcohol.
,, of ether.
Earths and moist rocks.
Powdered glass.
Flowers of sulphur.

INSULATING BODIES, PLACED IN THE ORDER OF THEIR INSULATING FACULTY.

Dry metallic oxides.
Oils (the heaviest are the best).
Ashes of vegetable bodies.
Ashes of animal bodies.
Many dry transparent crystals.
Ice below 13° Fah.
Phosphorus.
Lime.
Dry chalk.
Native carbonate of baryta.
Lycopodium.
Caoutchouc.
Camphor.
Some silicious and argillaceous stones.
Dry marble.
Porcelain.
Dry vegetable bodies.
Wood that has been strongly heated.
Dry gases, and air.
Leather.
Parchment.
Dry paper.
Feathers.
Hair, wool.
Dyed silk.
White silk.
Raw silk.
Transparent precious stones.
The diamond.
Mica.
All vitrifactions.
Glass.
Jet.
Wax.
Sulphur.
The resins.
Amber.
Gum lac.

Gutta-percha is one of the most perfect insulators, but its exact place in the above table is yet undetermined.

The terms *conduction*, *non-conduction*, *insulation*, and, indeed, most other terms of electrical science, have reference to the idea of an electrical fluid or fluids; and, indeed, however much we are constrained to refuse our sanction to the probability of the existence of such fluids, nevertheless we cannot proceed far in electrical investigations without recognizing the convenience of many terms suggested by the assumption.

Division of Bodies into Electrics and Non-electrics untenable.—If the experimenter try to render a bar of metal electrical, as he succeeded in rendering a bar of sealing-wax and of glass respectively electrical, he would not succeed. The earlier electricians, having noted this result, termed the metals, and indeed *all* conducting bodies, non-electrics; but if the conducting property of the hand and of metals be considered, this division, so arbitrarily made, cannot fail to seem premature. No legitimate conclusion, as regards the electric or non-electric property of bodies, can evidently be arrived at until the body rubbed has been held by a non-conducting handle; for otherwise, even though electricity should be excited, it would readily pass away. If the experiment of rubbing a metallic bar be tried after such bar has been provided with a non-conducting handle, it is rendered electrical, its electrical excitation being made evident by the usual tests of attraction and repulsion. In conducting experiments of this kind, very satisfactory insulating handles may be made by enveloping one end of the bar to be operated on with a piece of gutta-percha, previously warmed by the fire, or softened by dipping into boiling water. The gutta-percha should be wrapped round and about the extremity of the bar, and trimmed whilst yet warm by a pair of *wet* scissors.

Induction.—In strict propriety of language, no one electrical function or set of functions can be referred exclusively to induction. Electricians of the last century were in the habit of thinking differently; they spoke of induction as if it were a function that might be exercised at will, whereas, in point of fact, no such exclusive electrical function exists.

If an insulated conductor, charged with either condition of electricity, be brought near to another conductor; the second conductor, if examined, will be found to be in the opposite electrical condition, which condition was sure to be induced. The term induced, though still employed, conveys a very different meaning to that formerly accepted; but a discussion of this point is hardly consonant with the requirements of this treatise; wherefore I must direct the reader who would know more concerning it to the volume of this series on Chemistry.

Electrical Generalizations.—In the few remarks on the imponderable agents already made, it is not proposed to present the reader with more than a faint outline of their general nature and correlations. All-important though they be to a meteorologist, that importance is paradoxical, though the statement may serve as a sufficient justification for treating very casually on them in a treatise like the present. The objects of meteorology are so numerous, and its topics so varied, that to devote more space to a consideration of the imponderable agents would be injudicious. Let us summarize, then, what has already been remarked concerning them, so far as relates to the subject of meteorology. Probably light, heat, electricity, and magnetism are all effects of one cause, differently modified. Between heat, electricity, and magnetism the alliance is marked; so is the alliance between light and heat.

Electricity is, perhaps, the most stupendous imponderable agent with which the meteorologist has to concern himself, and it is the one most amenable to human control. Not less wonderful than the energy of electricity is its universality: not a drop of water can be evaporated by the sun, not a current of water can flow, not a leaf can move or reed bend, not a breeze can skim the surface of the earth, without developing this wonderful force. Very short, indeed, is the task of specifying the material causes of electrical energy. We have only to include every known case of mechanical motion, and every known cause of chemical action, and the task is complete: it is one of universal inclusion.

In discussing the meteoric relations of the imponderables, it matters little with which we begin. Already certain meteoric functions of heat have been brought collaterally under the reader's notice; I purpose now considering the imponderable agents, not secondarily, but primarily.

Phenomena of Atmospheric Refraction.—A sketch of the laws of refraction has already been given, and what may be called the normal function of atmospheric refraction has been announced. Referring to that announcement, it will be seen that the amount of refraction is due to inequality of the density of the air, determined by pressure alone. But inequality of density, and therefore inequality of refractive power, may be the result of varying amounts of expansion, referable to the operation of varying degrees of heat; and thus arise what may be termed the abnormal effects of atmospheric refraction.

Every one must have noticed the peculiar, tremulous condition of the air in summer-time over an ignited brick-kiln or near a red-hot bar of metal, or even on the surface of the ground, provided the weather be sufficiently hot. This tremulous appearance is referable primarily to the expansion of air near a hot surface, and immediately to the diminished refrangibility attendant on such expansion. These local sources of heat set up local currents, each being composed of air of a different density from that of neighbouring currents, whence each has a different refractive power. That which an ignited brick-kiln, or a glowing metal bar, can accomplish on the small scale, is accomplished on a larger scale by many natural causes, giving rise to phenomena both striking and delusive. Pictures of ships and towns inverted, the vain semblance of lakes of water in the midst of burning sands where no water really exists, aerial cities, spectral forms of men and animals,—all these, and many more, are the phenomena of atmospheric refraction and reflection.

One of the most common effects of irregular atmospheric refraction is the twinkling of the stars. This appearance is strictly conformable with all the teachings of theory in reference to the laws of refraction, and is due to the fluctuations of variously-heated currents of air. When these small aerial currents, having different temperatures, are numerous, bad weather is likely to supervene; hence an explanation of the increased twinkling of stars before bad weather sets in,—a phenomenon which has been very commonly noticed.

Extreme examples of atmospheric phenomena are, for the most part, only seen in hot climates; but there they are frequent. The mirage is an atmospheric phenomenon, in part attributable to refraction and in part to reflection; it occurs in Egypt, and gives rise to the impression in a stranger's mind, of a lake or tranquil expanse of water, though the region is only a waste of sand. The explanation of the phenomenon is this:—The villages throughout Lower Egypt are usually built on elevated mounds; hence the houses are to some extent elevated above the general level of the earth, which level becoming intensely hot, imparts heat to the atmosphere placed in contact with it, and alters the refractive power of that portion of atmosphere. An optical illusion now ensues—the lower or heated atmospheric layer assumes a tremulous appearance, like the surface of a lake, on which the images of the buildings of the village are seen reflected, whilst the direct image of the village is still evident in its true position. The Egyptian mirage is so deceptive, that a stranger seeing it for the first time can hardly be convinced that the semblance of water is only an optical delusion. The term *mirage* is peculiar to India; yet the phenomenon to which it refers is common in many other hot regions, especially in Central India and the Sahara.

The visual inversion of objects, a phenomena not at all uncommon in hot places, is partly due to refraction and partly to reflection,—for, in point of fact, the function of reflection may be demonstrated to be only an extreme case of refraction.

The *locale* is supposed to be a hot, sandy region, and a date palm is the object seen inverted, the explanation of which phenomenon is as follows:—The eyes of the observer being at *p*, will first see a direct image of the palm-tree by rays which come straight in the direction of the line *h p;* simultaneously he will see an inverted image of the palm-tree. Let us examine how this happens. Referring to the illustration, several parallel lines will be seen, c c' c'' c'''. These are intended to denominate atmospheric layers of different amounts of density. Tracing the ray of light *h i*, let us now examine what becomes of it. Firstly, it impinges on the upper atmospheric layer, which is more hot, and consequently more expanded, than the next layer above; the ray *h i* is, therefore, refracted *from* the perpendicular, according to the law mentioned at page 511. Passing on to the next layer, it is refracted still more *from* the perpendicular; and this refractive gradation is repeated on the ray *h i* until it arrives at *m*, at which point, the tendency to fly from the perpendicular still remaining, this tendency is manifested not under the con-

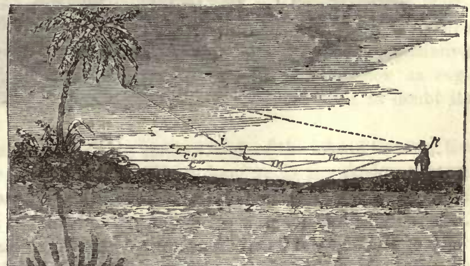


Fig. 73.

dition of refraction but reflection; consequently, the ray *hm* is directed towards the eye of the observer, and, along with the other rays upon which a similar operation has been effected, gives rise to the appearance of an inverted object. In order that the phenomenon should occur, however, there must be the following conditions besides those already mentioned:—Not only must the solar heat be considerable, but the air must be calm, so that the lower atmospheric layers may retain a density less considerable than the density of those above them.

As, under the peculiar circumstances just mentioned, refraction may pass into reflection, and the reflection may be excited upwards from below, so may the operation be reversed; in which case the inverted images of terrestrial objects will be seen in the air.

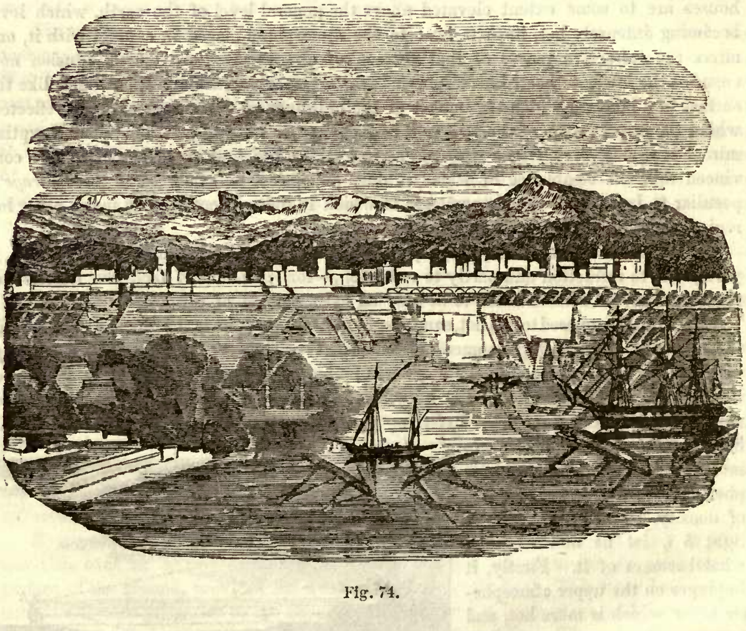


Fig. 74.

The celebrated *fata morgana*, sometimes observed on the Calabrian coast, and more especially at Reggio, is a celebrated example of this kind. At certain times the whole city of Messina and its environs are reflected downwards from an upper stratum of the air; thus presenting an appearance sufficiently curious, but by no means the striking and well-defined character which the records of early travellers would lead us to suppose.

The correlation between atmospheric refraction and atmospheric reflection, and, at the same time, a *rationale* of the peculiar aerial visions which may occur in certain atmospheric states, is furnished by the diagram (Fig. 75) suggested by M. Biot. The line *b t c* is supposed to be a ray of light proceeding from *b*, passing thence downwards to the point *t*, whence it is reflected to the observer's eye at *c*. Now the optical conditions of this arrangement are such that any rays proceeding from *b* below the ray *b t c* represented, would he invisible to the observer at *c*, whilst two images will be seen of all objects above this line. Supposing the object in question to be a man,—suppose, further, the man to be walking *from* the observer, he would be presented to the latter under the successive forms seen in Fig. 75.

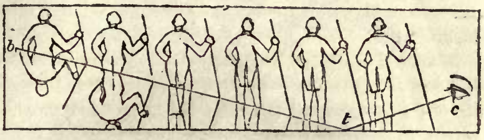


Fig. 75.

In these atmospheric optical delusions, involving the appearance of two images, one of them inverted, both natural and inverted images have occupied a horizontal plane. Occasionally, however, the reduplication of image has been projected on vertical planes, of which phenomenon the following is an example. On June 17, 1820, whilst MM. Soret and Turine were in the second story of a house on the lake of Geneva, they looked towards a ship two miles off, and making for the harbour. Immediately the vessel in question arrived at *q* she appeared reduplicated on a vertical plane; when she came to *r* the reduplication still continued, but the second image was further removed than before, and both were distorted; lastly, when the vessel arrived at the point *s*, the reduplicated image had receded to a distance still farther away, and both images, though distorted, presented an appearance of distortion very different from before; they were apparently drawn out, elongated both as to the hull and rigging, as represented in the accompanying diagram (Fig. 76). The following is the explanation of the phenomenon as suggested by the two observers above-mentioned, and there seems no reason to doubt its correctness.

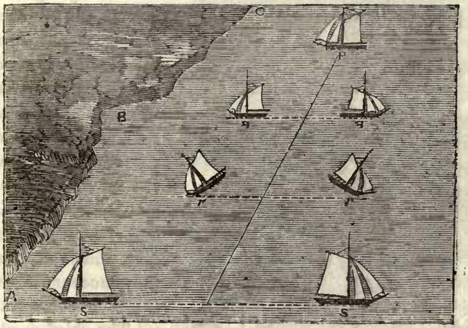


Fig. 76.

The letters, A B C, represent an outline of the eastern bank of the lake of Geneva; the air over that bank had, at the time of observation, been long under the shadow thrown upon it by the mountains of Savoy, whilst, contemporaneously the western bank had been strongly heated by the sun; hence, from the conjoint operation of these two causes, there were two vertical layers of atmosphere of different temperatures, and consequently of different densities; hence, they were of two different refractive and reflective powers.

All that is necessary to determine aerial reflections is a sufficient difference between the temperatures of any two adjacent atmospheric layers. In the instance already mentioned, this difference has been occasioned by portions of the ground being hotter than the strata of air with which they are in contiguity. The reverse of these conditions may, however, obtain, and phantastic atmospheric delusions may be the result. This latter case generally presents itself at sea, and by no means exclusively in warm localities. Thus, for instance, it is prevalent enough in the Northern Ocean. Sometimes the atmospheric delusion has merely the effect of prolonging the appearance of an object really below the horizon; sometimes not only is the appearance prolonged, but the body is seen double. Whatever the appearance, the class of atmospheric delusions now under consideration are usually seen near the horizon—a position where the optical powers of the atmosphere attain their greatest intensity.

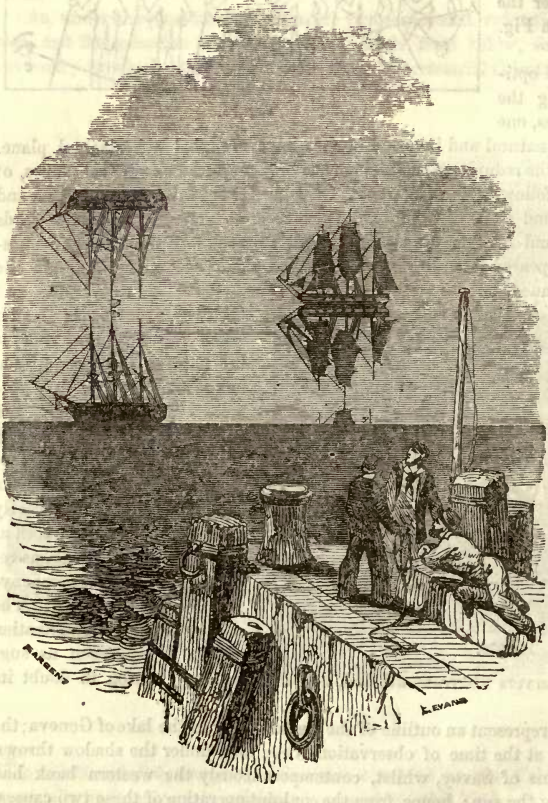


Fig. 77.

The Rainbow.—The most beautiful of all luminous meteorologic phenomena is the rainbow, which results from the decomposition of light by refraction through drops of rain, and subsequent reflection. Rainbows are of two classes, solar and lunar; the latter, however, are rare, and even when they do occur the bow is seldom coloured.

The chief conditions under which a solar rainbow may occur are the following:—The sun must not have less than 42° of angular elevation; the back of the spectator must be towards the sun, and rain must be falling from a highly illuminated cloud. The rainbow is usually double, and the theory of its formation may be thus explained. Let it be assumed that a straight line passes from the eye of the observer through the sun; then this line will constitute the axis of a cone, the base of which will be the rainbow, and its vertex the eye of the observer. If the bow be at the horizon, and the place of observation be a level plain, then the rainbow will appear as a perfect circle constituting the base of the cone. This complete circular appearance is, however, rare, the rainbow being far more generally, as its name implies, a mere arc of coloured light. The explanation is now evident of the fact that the rainbow cannot appear when the sun has attained an elevation greater than 45°. The rainbow, though still depicted, is depicted below the horizon, and is, therefore, invisible. It follows, then, that the size of the visible rainbow is inversely to the elevation of the sun above the horizon.

The annexed diagram (Fig. 78) illustrates the formation of the rainbow. The straight line A P is supposed to be drawn between the sun and the eye of the observer, passing through the latter. Through this line a vertical plane is supposed to be drawn. If the line A *x* be drawn through A so that the angle P A *x* shall amount to 42°, the rain-drops will reflect coloured drops to the eye. Assuming the line A *x* to rotate, a cone will evidently be generated, part of which, lying below the horizon, will be invisible. It is the surface of the cone thus generated which is the reflecting surface, and to which, therefore, the rainbow is due. Inasmuch as every colour has a refractive quality peculiar to itself, each drop only represents one tint to the eye. An arc having the breadth of about 2° is sufficient to include all the prismatic colours; 2° therefore is about the breadth of the rainbow.

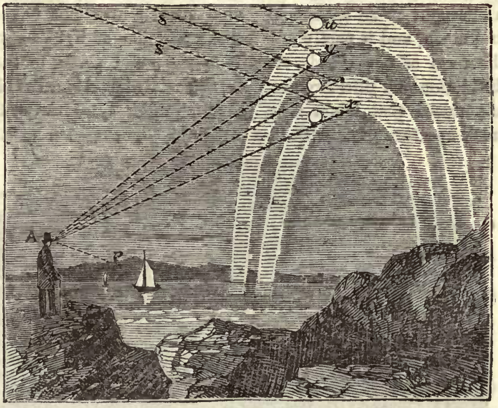


Fig. 78.

The colours of the rainbow are partly due to refraction and partly to reflection, as has been observed. The first effect of light on the drops of rain is refraction, by the operation of which white light arrives at the posterior side of each drop of rain, decomposed or dissected into the primitive colours of which it is composed. At the posterior aspect of each drop of rain the dissected colours are reflected unto the eye, and a coloured image is presented.

Such is an explanation of the theory of the primary rainbow—besides which, the surrounding rainbow requires to be noticed. The secondary rainbow is outside the primary, and is larger than it, but also much fainter. Its angular position is defined by the limits 50° 59′ and 54° 9′, measured with reference to the axis A*x*. The secondary rainbow has all the colours of the primary, but less completely defined, and in a reverse order. Its existence may be explained by the statement that it is the result of light twice decomposed, whereas the true rainbow is the result of light only once decomposed. The secondary rainbow, then, is produced by drops of water very far off.

Inasmuch as any angular elevation of the sun above 45° is incompatible with the existence of a rainbow, it is evident that this beautiful meteor can never occur in the south. It may occur, however, either in the east, west, or north.

As concerns lunar rainbows, they are, as I have before remarked, exceedingly rare, and are very seldom coloured. Nevertheless, in northern latitudes, where the moon shines with a brilliancy unknown to us, coloured lunar rainbows are occasionally seen.

Halos and Parhelia.—These meteoric phenomena are far more rare with us than in more northern latitudes, where they are continuously visible for long periods of time, and give rise to phenomena of extraordinary beauty. The term *halo* is applied to a luminous circle occasionally seen around luminous bodies, more particularly the sun and moon, and is partly due to the refraction of light by vaporous water, sometimes in the form of true clouds, sometimes not; and partly to the properties of light termed diffraction and interference. As respects diffraction, the circumstance has been already announced that when light passes through a minute orifice—such, for example, as a small aperture punctured in a card—the edges of such light bend: this is termed diffraction. The term, interference of light, is used to explain the phenomena of colour, or alterations of luminous condition generally, which result from the assumed jarring impact of luminous waves meeting in different phases of their vibration.

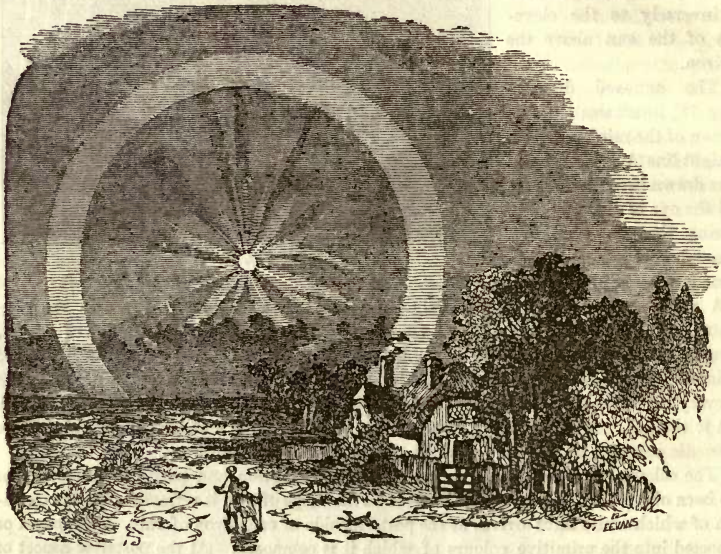


Fig. 79.

Solar halos frequently exist, though unnoticed, the sun's light being so powerful that the eye of the observer cannot withstand its impressions. By the aid of a sheet of glass rendered dull by smoke, these halos are frequently rendered visible.

Although halos, and also the phenomena next to be described, are referable to the action of atmospheric moisture on luminous rays, yet it is evident that the condition of that moisture will vary according to temperature; in other words, the aerial moisture which would be mere cloud-vesicles at temperatures above the freezing-point, would, if depressed below 32° F., be converted into snow, or spiculæ of ice. The alteration which these are capable of effecting on luminous rays being far greater than mere uncongealed vesicular water can effect, the resulting optical phenomena are far more brilliant and remarkable. Hence in northern latitudes the phenomena of halos and parhelia,—as arcs of light appearing near the sun, and sometimes intersecting each other, are called,—are brilliant and impressive beyond anything which corresponding phenomena occurring in this region would lead us to conceive. These luminous arcs, sometimes intersecting each other, are as often occasioned by the moon as by the sun. As the phenomena in question, when referable to the latter cause, are demonstrated *parhelia*, so when dependent on the former cause they are termed *paraselenæ*.

Frequently parhelia and paraselenæ consist, not only of the intersecting arcs just mentioned, but of circular luminous meteors to which the term *mock suns* are especially applicable. Associated with parhelia, and sometimes included under the same name, is a luminous band, passing horizontally through the sun, and not unfrequently making a circuit of the whole heavens. Where this luminous band and the inner parhelion cross, a mock sun usually appears, as represented in the accompanying diagram (Fig. 80).

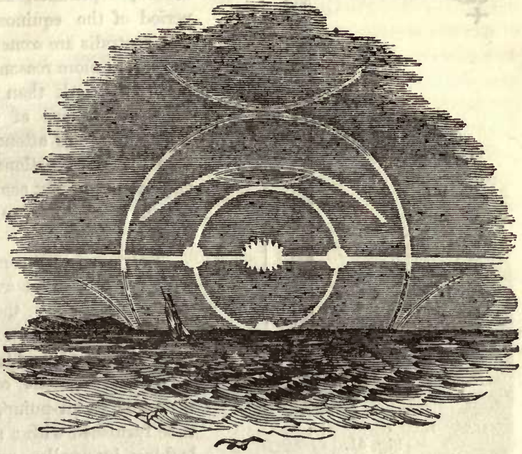


Fig. 80.

Aurora Borealis.—It has already been indicated, under the head of electricity, that various circumstances materially operate to produce the condition termed electrical. By far the best-studied of atmospherical electrical phenomena are thunderstorms; but it is an error to suppose that the atmosphere contains at the time of a thunderstorm its maximum of electricity; the experiments of Faraday have sufficiently made out this point.

Reserving the consideration of thunderstorms for the present, I shall introduce here the subject of electrical phenomena by a description of the aurora borealis—a phenomenon sometimes said to be magnetic, inasmuch as the magnetic-needle is strongly affected during its prevalence, but which, nevertheless, seems more naturally to belong to electricity.

The term *aurora borealis*, or northern light, is applied when the phenomenon to be presently described occurs in the north; and the term *aurora australis* is applied when it occurs in the south. But the former has been seen as far south as 45° of southern latitude; and the latter has more than once been visible in Britain. Nevertheless, the beautiful phenomena of northern and southern lights are most prevalent towards the north and south poles respectively.

Northern and southern lights, when in their greatest perfection, consist of a well-defined arc of white light, and luminous streams of coloured light flowing therefrom. The arc is not permanent as in the rainbow, but bends and twists in all directions like a ribbon agitated by the wind. The intensity of the aurora varies within extensive limits: when faint, the light is only recognizable at night by careful examination; but when highly developed, the aurora borealis, or australis, can be seen during broad sunshine.

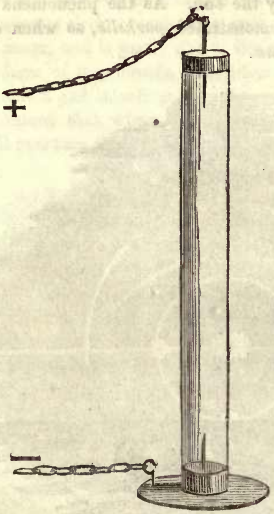


Fig. 81.

These phenomena may occur at any season, but they are most prevalent in the months of March, September, and October, or about the period of the equinoxes. The aurora borealis and australis are sometimes said to be magnetic storms; a more reasonable foundation is required for the remark than is supplied by the turbulent agitations of the magnetic-needle with which they are attended; but we have already seen that the functions of magnetism and electricity are so nearly connected, that it is impossible in some cases to distinguish between the two.

There is a very common electrical experiment which furnishes an artificial phenomenon very nearly resembling the northern and southern light, in all respects except in the shape of the illuminated body, which is a luminous arc.

The experiment consists in exhausting, by means of an air-pump, all the air out of a glass tube furnished with a metallic point at each end, looking internally, and placed in the electric current, as represented in Fig. 81. When a stream of electricity, of adequate intensity, is passed through the apparatus from + to —, the whole interior of the tube becomes illuminated with flashes of light, very similar in appearance to the flashes of the aurora.

The phenomenon of the aurora borealis was noticed by Aristotle and Pliny, although neither philosopher could have seen it to advantage. Gassendi first originated the term aurora borealis, to indicate the phenomenon of this kind observed by him on September 12, 1621. These phenomena appear to be subject to some laws of secular variation not yet understood. That they have appeared in certain years, and certain groups of years more than others, is certain. According to Mairan, twenty-six occurred between A.D. 583 and 1354; thirty-four between 1446 and 1560; sixty-nine between 1561 and 1592; seventy between 1593 and 1633; thirty-four between 1634 and 1684; two hundred and nineteen between 1685 and 1721; nine hundred and sixty-one between 1722 and 1745; and twenty-eight between 1746 and 1751.

After 1790, auroras became unfrequent, but since 1825 they have been on the increase. A very remarkable aurora borealis occurred in the autumn of 1847: it was conspicuous not only in England, but even so far south as Italy and Spain.

Height of the Aurora.—As a proof of the doubt which exists concerning the height of the aurora, they have been variously estimated from 3000 or 4000 feet to several miles. The probability is, that the conditions on which the aurora depends vary in the altitude of their operation; but the truth is, that, notwithstanding the electrician by his artificial experiments can imitate the light of the aurora borealis and australis, notwithstanding the prevalence of the phenomena in question near the magnetic poles seems to point to magnetic agency as the cause, our real knowledge concerning the aurora borealis and australis is very slight.

It may be as well here to present the reader with a summary of the various opinions which have prevailed at different times relative to the phenomenon in question. Many early writers referred the appearances presented to mere optical causes, considering them to be due to the reflection of the sun's light thrown upwards by a mirror of snow and ice, and a subsequent reflection downwards by atmospheric agencies. De Mairan, the observer who, perhaps more than anyone else, is entitled to be considered the chronicler *par excellence* of the phenomena of the aurora, attributed them to the penetration of our planet at certain periods into the solar atmosphere. On this supposition it will be remarked, that the solar atmosphere must be assumed to extend to the orbit of our planet, an hypothesis totally irreconcilable with the teachings of optics and astronomy. The celebrated Euler, the philosopher who could deal so satisfactorily with the abstrations of number and quantity, seems to have offered a most crude and improbable theory explanatory of the aurora. Adopting the molecular theory of light, he assumed that the solar rays, striking against the particles of our atmosphere, actually carried particles of the latter up into the heavens to a height of more than four thousand miles, the height at which Euler believed auroras to exist. Some philosophers, of whom Volta may be regarded the Coryphæus, adopted a chemical theory of auroras, referring them to the ignition of hydrogen gas spontaneously generated on the earth, and rising by its light specific gravity to the higher atmospheric regions. It was assumed by these philosophers that the evolution in question took place in the tropical regions chiefly, and that

Fig. 82.

it was wafted by the upper current of air—treated of in connection with the trade-wind—to the north and south poles respectively.

Halley was the first, I believe, who suggested that the phenomena of aurora borealis and australis might be due to the passage of magnetism from one magnetic pole to the other; and the theory of Halley is so far retained, that the aurora is assumed to be in some way connected with electricity and magnetism, but in what manner is beyond the competence of observers to decide.

On the Phenomena of Thunder and Lightning.—Perhaps no meteorologic phenomena are now so well understood as these; though, before electrical science had been studied by the phlosophers of the last century, and the crowning experiment of Franklin performed, the phenomena of thunder and lightning were so mysterious, that even philosophers were content to refer them to the operation of an occult cause.

The intimate study of electrical science opens a field of somewhat abstruse matters for consideration; the field is far too wide and too abstruse to be dealt with satisfactorily here. In the treatise on Chemistry of the Imponderable Agents, belonging to this series, it has been treated somewhat in detail; and to this I must refer the reader who desires to know more on this subject than strictly belongs to the necessities of what I may term *practical meteorology*.

With this explanation I shall not hesitate to adopt the term *electric fluid*, although the reader has already been made aware that no such fluid is at all likely to exist. Let us now contemplate the phenomenon of that electrical excitation, the solution of which is lightning, under the simplest conditions that the phenomenon can assume. Let A and B (Fig. 83) represent two clouds, which, being made up of watery vesicles, are necessarily electrical conductors; and being surrounded by the atmosphere on all sides, are necessarily insulated. For the sake of our illustration, it will now suffice to assume that neither of the clouds here represented is electrically excited at this period of the description, and hence that the marks + and — are for the present misplaced. Let it now be assumed that the cloud A becomes positively electrified,—that is to say, charged with positive electricity, owing to some natural cause unnecessary here to explain; and let the results of this condition be traced out. Firstly, there is not in all nature, and there *cannot be*, such a condition as that of independent electric excitation; in other words, there cannot be one body *positively* excited without the co-existence of another body *negatively* excited. Hence, if cloud B were away and cloud A positively

Fig. 83.

excited, the air circumjacent to A would assume the second or negative function; but if the cloud B is present, it therefore becomes negative, and the two clouds A and B are mutually attracted, because opposite electricities attract each other. Hence they approach until the space of air between the two is insufficient to restrain their mutual electric tension: this condition having arrived, a discharge takes place, precisely analogous to the discharge of a Leyden jar. Under the postulates of our experiment, the discharge, or lightning flash, takes place between the two clouds A and B.

It follows, however, from the consideration of known electrical laws, that just as the two oppositely electrified bodies may be two clouds as assumed, so also may they be one cloud, and the surface of earth or water, or conductors placed upon either one or the other, under which conditions a downward discharge will take place; and generally electricity will always take the nearest path between any two bodies oppositely charged, the conducting facilites being equal.

Lightning-Conductors.—It is almost unnecessary in these days to announce that Franklin, in the year 1752, first demonstrated the nature of lightning by drawing electric sparks from the string of a kite, previously caused to ascend into the region of a thunder-cloud. This experiment performed, the connection between lightning and electricity could no longer be doubted, and a means of drawing off a surcharge of the electric fluid by lightning-conductors was immediately suggested. The most important instruments were not adopted, however, until after numerous and varied conflicts. Firstly, the argument was adduced by some that lightning-conductors could not be adopted without impiety, being intended to contravene the will of Providence. An argument so fallacious was no sooner abandoned than lightning-conductors were exposed to another ordeal, founded on an erroneous practical estimation of a truth in theoretical electricity. I allude, as the electrician will perceive, to the contest between the advocates of spherical, and of pointed, terminations for electrical conductors.

Now, regarding the question of points or spheres abstractedly, it is easy to see that preference should be given to the former, inasmuch as points draw off and give issue to the electric fluid in silence, whereas spheres draw off and give issue to electricity in sparks; but, inasmuch as the largest spherical termination ever used, or ever likely to be used, for the upper extremity of a lightning-conductor, is virtually a point in comparison with the enormous surface of the smallest thunder-cloud, the dispute, though violent and prolonged, never had the practical significance which was at one time taken for granted.

The history of lightning-conductors furnishes a remarkable illustration of the difference between the mere knowledge of a fact, and the confidence or conviction resulting from that knowledge and justifying its practical application. The whole theory of lightning-conductors was almost as well known half a century ago as now; yet it is only within the last few years, and owing to the unflagging perseverance of Sir W. Snow Harris, that due effect has been given to the theory, and lightning-rods have been fearlessly applied.

Electrical Principles connected with Lightning-conductors.—The electrical principles on which the efficiency of lightning-conductors depend are few and simple; they all admit of being readily demonstrated by electrical experiments artificially performed, and they have been universally justified by the result of three practical applications:—

(1.) *Electricity cæteris paribus follows its course through the best conductors which happen to be in its path.*—Thus, for example, if a Leyden jar be charged, and the electric connection between its external and its internal coating be completed by three linear substances of equal length—say, for example, silk, wire, and linen thread—thin wire being the best electrical conductor of the three, will transmit the whole of the electricity to the exclusion of the silk and the linen thread. It is assumed, however, in the performance of this experiment, that the wire is sufficiently large to convey the whole electric energy.

(2.) *Provided the conductor be good, and its sectional area adequate, the electric fluid or energy is conveyed harmlessly away.*—No point in the whole of electrical science can be more satisfactorily established than this. It admits of being illustrated by numerous experiments, amongst which the following may suffice :—

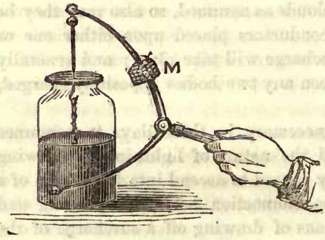


Fig. 84.

The diagram (Fig. 84) represents a common Leyden jar, represented in the act of being discharged by the ordinary discharging instrument. That instrument is, as usual, of brass, all save the handle, which is of glass, and therefore a non-conductor of electricity. Those who are conversant with the form and construction of the discharging instrument, are aware that its two terminal balls admit of being unscrewed. Assuming one of the balls, viz. the upper one in the diagram, to have been unscrewed, the liberated brass stem to be passed through a marroon, or box holding gunpowder, and the ball to have been again replaced, the conditions will have been fulfilled which the diagram represents. It is evident that the Leyden jar, as represented, will be discharged. It is, moreover, evident that the whole of the charge will be transmitted through the gunpowder contained in the marroon, yet that gunpowder will not inflame. If, however, instead of the conditions of the last experiment, a very fine metal wire (a steel wire by preference) be passed through the marroon, or rather through some combinations of explosive materials less potent than a marroon, which would now be dangerous, and electricity transmitted as before, the wire, not presenting a sufficient amount of transverse area of surface to convey the electricity, melts, and the explosive compound is inflamed.

(3.) *Lateral discharge must be provided against.*—The meaning of lateral discharge will be illustrated by the following experiment :—The diagram (Fig. 85) represents, as before, a Leyden jar readily arranged for being discharged through a metallic wire, one end of which has already been brought into contact with the outside of the jar, while the other end can be brought into contact with the knob communicating directly with the inside of the jar. The hand is represented in the act of holding a glass rod, around which one end of the wire is coiled, and the extremity of the wire is finished off with a ball. All these arrangements, the electrician will perceive, are necessary for giving effect to the efficient discharge of the Leyden jar through the conducting wire. The chief poin for observation, however, is the band of the wire, by means of which one part is caused very closely to approach another part, as represented at *a b*. Now it is possible by choosing a wire sufficiently small, and causing the two bands to pass sufficiently near, to determine the passage of an electrical spark from *a* to *b*, instead of proceeding through the entire length of the wire, from the internal to the external coating of the jar. This is what electricians call the lateral discharge, and it requires to be studiously guarded against in the construction and arrangement of lightning-conductors.

Application of the Foregoing Deductions.—Perhaps the deductions already arrived at will suffice for practical guidance in the matter of lightning-rods, though these deductions by no means exhaust the science of the subject. Firstly, the fact may be considered as proved, that all bodies, even the most dangerous and inflammable, all edifices, all living beings, may be shielded from the evil consequences of lightning, by the safeguard of lightning-conductors. The conductors, however, must present a sufficient external area; and the point has been made out by numerous trials, that a copper rod a square inch in sectional diameter will convey away the utmost fury of the most highly-charged thunder-cloud ever proved to exist. Copper is one of the best electrical conductors amongst metals; but, by providing a sufficiently increasing sectional area to compensate for inferior conducting power, any metal may be made to perform the function of copper. Whatever be the conductor, its upper extremity should project considerably above the edifice to be protected; and if pointed *theoretically*, all the better, though practically the bluntest termination could be only as a point by comparison with the enormous mass of a thunder-cloud. Far from preventing contact between the building to be protected and the conductor, as is sometimes done by the interposition of glass or earthenware guards, a lightning-conductor cannot be brought into too intimate metallic connection with every part of the edifice to be protected. The conductor should branch and ramify over the surface of the building, and should be brought into contact with every important system of metal line work, such as the iron pipe which frequently runs down the side of a wall; finally, the conductor should at its lower extremity be brought into contact as efficiently as possible with some good electric conductor, such as the system of gas or water-pipes which run underneath most houses, especially under the streets of most civilized towns. As regards the number of conductors necessary to be supplied to one building, that will depend, firstly, on the shape of the building, whether it be composed of many elevations, or whether, like a column, it has only one. Perhaps the best practical testimony on this point is gleaned from the fact, that a ship having three masts, one of which only was protected by a lightning-conductor, the unprotected masts have been shattered by the effects of a thunder-storm, while the other remained untouched. If a column be surmounted by a metallic statue, it is worse than useless to disfigure the head of the statue by a projecting metallic spike as the beginning of a lightning-conductor; nothing more is requisite in this case than to provide sufficient metallic conduction for the electricity downwards into the ground. Lightning-conductors, it should be remembered, *do not*, as they are commonly said to do, *attract* electricity. They no more attract electricity, than a gutter attracts water. They merely open a channel for electricity to pass through. Before the demonstrations of Sir William Snow Harris had taken effect, marine lightning-conductors were something more dangerous than lightning itself: consisting merely of chains, which were only elevated aloft after the thunderstorm had come on. Marine

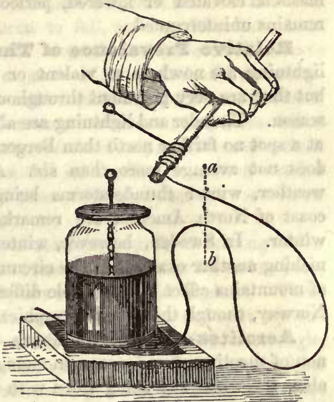


Fig. 85.

lightning-conductors are now fixtures on the masts; they are made of copper, running band-like down the mast, and embedded in the latter in such manner that, whether the masts be elevated or lowered, perfect metallic contact between any two pair of masts remains uninterrupted.

Relative Prevalence of Thunderstorms.—The phenomena of thunder and lightning are nowhere so violent or so frequent as in the so-called region of calms; but they are very prevalent throughout the torrid zone, more especially during the rainy season. Thunder and lightning are almost always absent in the polar regions; and even at a spot no farther north than Bergen, in Norway, the annual number of thunderstorms does not average more than six. As the rule, thunderstorms chiefly occur in hot weather, winter thunderstorms being comparatively rare. Iceland and the western coast of North America are remarkable for the predominance of thunderstorms in winter. In Sweden, however, winter thunderstorms are almost unknown; thus furnishing another example of the circumstance already noted, that the Scandinavian range of mountains effect a remarkable difference between the general climate of Sweden and Norway, though the two, geographically considered, are so close together.

Aerolites — Shooting Stars — Meteoric Stones.—The beautiful phenomenon of shooting stars is common enough; but at certain periods it is peculiarly remarkable, the whole sky being filled with these fleeting meteors. The beginning of August and the beginning of November are noticeable for their connection with shooting stars; more especially have they been recorded between the 9th and the 14th of August. The bouquet of shooting stars observed at this period in North America has been sometimes called the Shower of St. Lawrence.

For our knowledge respecting the periodicity of the phenomenon of falling stars, we are indebted to Quetelet Besenberg and others; but Muschenbroek, so long back as 1762, first directed attention to the so-called *shower of St. Lawrence.* In addition to the August and November phenomena of the kind under consideration, other periods have been noticed—for instance, in April, and from the 6th to the 12th of December; but these bouquets of shooting stars which thus occur are less considerable and less regular than the former. Besides these showers of shooting stars, the periodicity of which is well attested, single meteors of this kind are frequently noticed, and they occur at all seasons; therefore, whatever may be the cause of shooting stars, this cause must be regarded as continuously operating.

Sometimes the luminous meteor termed a shooting star attains a large magnitude; observers then speak of it as a fire-ball. The identity of shooting stars and fire-balls is now well established, though formerly they were treated of as distinct. Fire-balls are sometimes seen alone, but more frequently in connection with shooting stars. Their light and their bulk are frequently so considerable, that they can be seen in broad daylight. Their velocity through the heavens, or rather through the upper layers of our atmosphere, is various; but it generally exceeds that of the earth.

As regards the nature of shooting stars, we have only theory and analogy for our guidance; but our knowledge of fire-balls is far more accurate, and there seems no reason to doubt that their teachings illustrate the nature of falling stars. Numerous fire-balls dart through our atmosphere, become luminous, and disappear, no one knows whither. Others, though passing near to our atmosphere, fail to enter it, and therefore are not rendered visible. A third division not only come within our atmosphere, shine, and burst with a loud report, but they fall; yet, falling either into the sea or upon an unfrequented spot of land, the locality of their fall remains unknown. Whilst a fourth division of fire-balls may be seen to fall, dug out, and examined; thus supplying data for an investigation of fire-balls in general.

Masses of this kind are termed aerolites, and their connection with fire-balls has been placed beyond all doubt. Fire-balls have been seen to fall, and aerolites have been extracted from the place whereon they have fallen. Nevertheless, some aerolites have fallen upon the earth without the assumption of a previous appearance of luminosity. Cases, though rare, are well attested of an aerolite suddenly falling from a small cloud, attended with a noise resembling the discharge of cannon; others, again, have fallen silently, and out of the clear air, not the slightest trace of cloud being visible at the time.

Testimony concerning showers of stars and the fall of aerolites has been handed down to us from all periods, but it is only since the time of Chladni that the occurrence of these phenomena has been placed beyond doubt.

Amongst the best-attested examples of the fall of aerolites are the following:—On the 16th of June, 1794, a shower of stars fell at Sienna; and in the following year, December 13, an aerolite, weighing no less than fifty-six pounds, fell in England. Three years afterwards, and remarkably enough also on December 13, a fire-fall split up and discharged round stones. A very large shower of stones fell April 26, 1803, near Aigle, in France; the occurrence is particularly interesting on account of its having been noticed and verified by M. Biot. Ten such meteoric showers were observed in France in twenty-six years—*i. e.*, between 1790 and 1815. The meteoric shower at Aigle in 1803, which poured its contents over a surface of two and a half French miles long, by one in breadth, consisted of 2,000 fragments of different sizes, some weighing not more than two drachms, others near twenty pounds. Aerolites are sometimes much larger than this; one fell at Agram on the 26th of May, 1751, having a diameter not less than eighteen feet, and weighing seventy-one pounds; but the largest known aerolite fell in Mexico, and weighed between 30,000 and 40,000 pounds.

As to shape, aerolites are generally prismatic, or angular, rarely smooth; and almost always sheathed in a crust of pitchy blackness. Their specific gravity is various, some being sufficiently porous to absorb water with rapidity, others being dense and metallic. Looking at the specific gravity of aerolites in the aggregate, it may be said to vary between 1·94 to 4·28, thus presenting a mean of about 3·5. All the heavier varieties of aerolites are made up of iron, holding a little nickel; traces also of cobalt, manganese, chromium, copper, arsenic, tin, and other well-known elementary bodies, are found.

Origin of Fire-balls and Shooting-stars.—Various opinions have been advanced to account for these bodies. One of the earliest, if not the very earliest, of these hypotheses, originated in 1660, and assumed fallen aerolites to be mineral masses originally projected from lunar volcanoes; and calculations were made, having for their object to demonstrate what volcanic force might be sufficient to project aerolites of a given mass into the sphere of attraction of the earth's atmosphere. Unfortunately for the probability of this theory, the moon's surface appears to be altogether devoid of active volcanoes. Then followed the chemical hypothesis, according to which it was assumed that aerolites were nothing more than aggregations of metallic vapours, which had risen to the upper region of the atmosphere, aggregated there, and fallen. The opinion of Chladni is now, however, generally received; he regards aerolites to be of cosmical origin—to be so many planets, or planetary fragments, which revolve in orbits of their own, variously inclined to the orbit of the earth; that our planet encounters periodic shoals of these little worlds, some of which, becoming entangled in the earth's gravitating system, pass into our atmosphere, become heated by friction against its particles, and ultimately fall to the ground. Although the discovery of aerolites is comparatively rare, the meteors, of which they are the final result, are by no means so. It has been calculated that the average annual fall of aerolites is not less than 700, or about two daily.

Meteorologic Result of Occult Emanations.—When the utmost powers of a refined chemistry have been applied to the analysis of atmospheric constituents and conditions, much still remains to be unveiled. There are atmospheric causes, whatever they may be, of epidemic and endemic diseases, and perhaps other agencies which our philosophy little suspects or dreams of. I have ventured to include these undetermined agencies under the general expression *occult emanations*. It is not difficult to point out objections to this designation in some of its applications. Perhaps it is not strictly philosophical to speak of emanations thus hypothetically; perhaps this may be only a repetition of the error of assuming the existence of an electric fluid; perhaps the number of influences due to allotropism and to polarity is greater than we imagine; but, at any rate, the term "occult emanations" may be accepted as a rallying-point for a certain class of facts, until the time arrives when their true significance shall be correctly made out.

Without invoking the hypotheses of allotropism and polarity, there are undoubtedly some atmospheric agencies to which the expression occult emanations is applicable, and concerning which the only thing occult about them is the insufficiency of ordinary chemical examinations to demonstrate their existence, though that existence admits of being demonstrated by extraordinary chemical means. Thus, for example, it is a well-authenticated fact, that the atmosphere of localities in which fever is endemic, usually contains minute traces of hydrosulphuric acid, and an odorous animal matter—substances which ordinary chemical processes fail to detect, but which, nevertheless, by the adoption of refined methods of investigation can be proved to exist. The late Professor Daniell was of opinion that the much-dreaded fever of Western Africa was augmented by the diffusion, through the atmosphere of that coast, of minute traces of sulphuretted hydrogen. And the circumstances under which African fever originates, are perfectly consonant with the above theory. The disease only prevails now on the coast, its ravages being limited to a small belt, partly of land and partly of sea, Central Africa being comparatively exempt from its inflictions. Now Professor Daniell assumes the hydrosulphuric acid to be the result of decomposition, under a powerful sun, of matter borne seawards by the Niger and other great rivers, in connection with certain sulphates of sea-water. Be this theory true or the contrary, there can be no doubt as to the truth of the assumption which refers fever, when endemic in certain localities, to a vitiated condition of atmosphere; which vitiation may be generally summed up as consisting of minute traces of hydrosulphuric acid, and of undetermined animalized matter.

Amongst other occult emanations, we can hardly refuse to admit the cause, whatever that cause may be, of intermittent fevers. The ultimate, if not the proximate, cause of this class of disease is so well known, that we may almost produce or banish intermittent fevers at pleasure. Given heat and moisture continuously, ague almost invariably sets in, and continues its ravages as long as the conditions of heat and moisture coexist.

What is the occult emanation here? What is the proximate cause of intermittent fever? Are we to attribute the disease to the conjoined evaporation of moisture and heat *directly*, or to some further emanation to which these conditions give rise? Some pathologists have assumed that light carbonetted hydrogen, or marsh-gas as it is called, determines the disease; but the notion hardly coincides with known facts in relation to this disease. The horizontal demarcation of altitude above which the influence of ague cannot extend, is one of the most remarkable circumstances in connection with the disease; a difference of no more than ten feet in perpendicular height frequently corresponding with the region of fever and the region of salubrity respectively.

The mention of light marsh-gas naturally suggests the curious meteorologic phenomenon called Will-o'-the-wisp, or Jack-o'-lantern; of which gas ignited, or, according to some, phosphuretted hydrogen gas, it is believed to consist. The Will-o'-the-wisp is not a very frequent phenomenon anywhere; but it is chiefly seen in marshes and churchyards,—the latter locality apparently adding to the hypothesis that it is nothing more than ignited phosphuretted hydrogen gas.

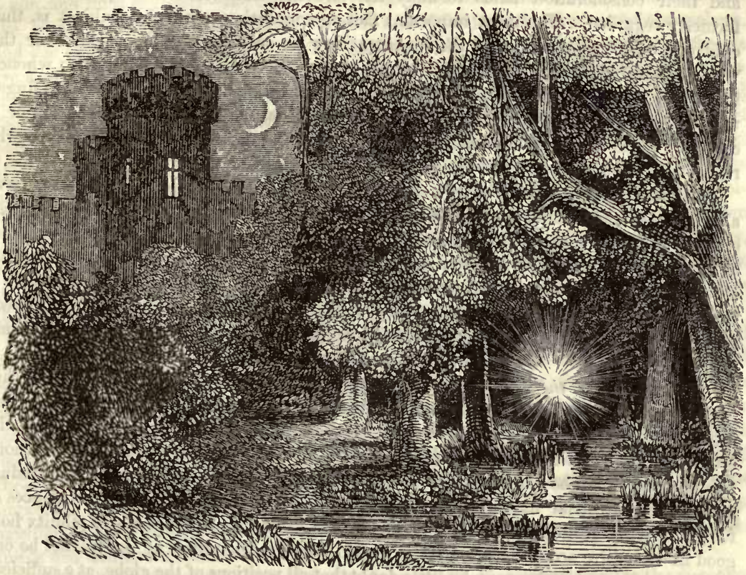


Fig. 86.

Scarcely less accurately demonstrated than the locality of ague, is the locality of yellow-fever, the focus of which may be considered to be Vera Cruz. Strange to say, the yellow-fever is totally unknown on the Pacific coast of Mexico; it extends north as far as New Orleans, but rarely further. This condensation, so to speak, of febrile energy, points to some local cause — most probably of atmospheric origin; but chemistry has been unable to determine its nature.

Reflections similar to the above are suggested by the contemplation of several contagious diseases; of which the plague is a notable example. This scourge, although capable of spreading from its normal focus into regions wide apart, is in certain spots determined conditionally by the existence of some unknown conditions; and these are most probably atmospheric. The plague never originates in very hot or very cold regions. Its focus of development is Egypt, Turkey, and the Levant, from which spots it can never be said to be absent altogether; but it only appears with violence at intervals of eight or ten years. Still more extraordinary than any of the preceding, are the varied conditions which give rise to Asiatic cholera. Unlike the plague and the yellow-fever, and intermittents, this fell destroyer seems independent of region, recognizable limits, or other conditions of demarcation. From east to west it has extended its ravages, under every vicissitude of season and of clime. Much as there is mysterious in this—absolutely ignorant though we be of the proximate influences by the operation of which cholera and other epidemics are generated, important facts have, nevertheless, been made out; and their consideration tends to allay the extreme fear wherewith epidemics were formerly regarded. The most important fact in connection with this subject is, that epidemic influences, whatever their nature may be, only as a rule prevail over the weak, exhausted, ill-fed, or mentally broken-down individuals of a community; whence it happens, that here in our metropolis the medical statician is enabled to lay his finger upon the regions of epidemic virulence, as he would on the locality of a mountain or a coal-field; and with equal satisfaction can he point to localities where epidemics formerly raged, but whence they have been banished by the art of man.

Climatology.—Many of the effects of heat, in its meteorological relations, have already been incidentally considered; but reference has not yet been made to the sources of heat, and to the means of its distribution over the surface of our planet. The term heat, as applied to the matter now under investigation, may be regarded as synonymous with elevation of temperature; and inasmuch as such elevation necessarily presupposes a condition of antecedent depression, we may, without impropriety, comprehend the meteorological effects of high and low temperatures (heat and cold) under one and the same generalization.

Central Heat of the Earth.—The hypothesis was first propounded by Leibnitz, that the whole of our planet was once a molten mass, which by the operation of cooling, uninterruptedly going on in successive ages, has become superficially encrusted over, the crust having become adapted to the necessities of animal and vegetable life. Various circumstances may be adduced in favour of this notion, more particularly the gradual increase of terrestrial heat downwards, the heat of deep springs, and the evidences of fusion in what geologists term the igneous rocks. Whether the idea of Leibnitz hold good in its entire acceptation,—that is to say, whether the centre of our planet be one molten mass or not,—there can be little doubt that all positions of the globe, at a sufficient distance below the surface, have at some period been submitted to fusion. Nevertheless, at this time, the earth's central heat may be altogether ignored as tending to influence, in any manner, the climatic temperature of our globe. Primarily, the sun's direct rays determine the climatic temperature; those portions of the world's surface being most strongly heated on which the sun shines at the greatest angle—a remark which of course applies to the tropics; while those are least heated on which the direction of solar rays is most oblique—a remark which of course applies to the arctic and antarctic regions. But the latitude of a region has less connection with its climatology than might at first seem probable. The varying conditions of insular and continental sea level, or elevated table-land, valley or mountain, and still more the influence of thermal oceanic currents, have much to do with the climatic result. The high table-land of Mexico is strongly illustrative of the effect of mere elevation. The traveller who disembarks first on the Atlantic coast, and wanders inland, soon finds himself amidst all the luxuriance of a tropical forest, and surrounded by all the dangers of tropical existence. Still wending his way inland, he ascends a mountain elevation, and finds himself suddenly transported to a region, where, on account of its elevation, the climate has totally changed, and with it the vegetation. So marked is the change, that the high table-land of Mexico is well adapted to the growth of wheat, which refuses to grow anywhere in tropical lowlands.

Of all the causes which influence the climate of a region, that attributable to oceanic currents has been hitherto least studied; yet there is none which deserves to be scrutinized more narrowly. Looking at the enormous amount of oceanic surface in comparison with that of the land—taking into consideration the mobility of water, its susceptibility of thermal impressions, and the effect of the configuration of capes, headlands, and lines of coasts—the contemplative observer soon arrives at the deduction, that the ocean presents to him, at least, as wide a field for investigation as the atmosphere, and one scarcely less interesting. "The fauna and the flora," says Maury, "of the sea are as much the creatures of climate, and are as dependent for their well-being upon temperature, as are the fauna and the flora of dry-land. Were it not so, we should find the fish and algæ, the marine insect and the coral, distributed equally and alike in all parts of the ocean. The polar-whale would delight in the torrid zone, and the habitat of the pearl-oyster would be also under the iceberg, or in frigid waters colder than the melting ice." The particles of water being mobile, the ocean, and indeed aqueous collections generally, are amenable to the same law of conviction as was described when treating of the cause of winds. Hot water, being specifically lighter than cold water, must necessarily come to the surface, and for every current in one direction there must be a counter-current in the reverse direction, precisely in the same manner as occurs in the development of a wind.

Contemplating the ocean in its relation to the effects of heat and motion, our original ideas concerning that vast collection of waters are modified and expanded. Instead of regarding the ocean as one shapeless aggregation of briny water, it presents itself to us as an assemblage of many streams,—a network of mighty rivers, each following its own course, each having its own temperature, its own flora, its own animals; and though devoid of palpable banks, scarcely less accurately defined on that account. Amongst all these oceanic currents, that denominated the gulf-stream is the largest in size, the most important in the functions it subserves. The gulf-stream is so far from being an imagining of mere theory, that the dark blue alone of its waters suffices to point out its limits and define its course.

All hypotheses as to the cause of the gulf-stream are as unsatisfactory as the direction of the stream itself, and its benign influences are evident. The first idea relative to the gulf-stream was, that it originated in the impetus given to the ocean by the disemboguement of the Mississippi; but placing out of consideration the inadequacy of this assumed cause, on account of the comparatively small amount of water which even a river so vast as the Mississippi can pour forth, it follows that, if really the cause of the gulf-stream, the whole Gulf of Mexico should, in process of time, be found to contain only fresh, or at the most brackish water. This, it is scarcely necessary to remark, is not the case. Franklin advanced the theory, that the gulf-stream is referable to the pressure of an inordinate amount of water against the coast of the Gulf of Mexico by the trade-winds,—an idea which is scarcely more tenable than the last.

Whatever the cause of the gulf-stream may be, the direction of its current is obvious. Setting out from the hot regions of the Mexican Gulf and the Caribbean Sea, it proceeds northward to the great fishing-bank of Newfoundland, and thence to the shores of Europe, yielding up its heat to the genial west winds, and thus transferring a portion of the superfluous heat of the tropics to our colder shores. The greatest heat of the oceanic water of the Mexican Gulf is about 86°, or about 9° above the ocean temperature due to latitude alone. After it has ascended to 10° of north latitude, the gulf-stream has still only lost 2° of the original heat with which it set out. Ascending northwards a distance of three thousand miles from its first origin, this mighty oceanic river still preserves the heat of summer even in winter time. It now crosses in a westerly direction, in a line coincident with about the fortieth degree of north latitude, spreads itself out, and imparts to Europe a genial temperature; which mere latitude could never give. The gulf-stream now pauses in its course; it is split into two divisions by the British Isles, and two gulf-streams are formed. Of these, one tends northward in the direction of Spitzbergen, whilst the second enters the Bay of Biscay—imparting temperature to each, and causing a soft mantle of vapour to arise, which, wafted landward, in its turn disperses the heat of the gulf-stream far inland. Very little is known concerning the depth to which the gulf-stream extends.

Lieut. Maury, of the United States naval service, assumes that depth to be two hundred fathoms; and arguing on this assumption, he calculates that the amount of heat led away from the Gulf of Mexico by this oceanic torrent raises, on a winter's day, the whole atmosphere which hovers over France and the British Isles from the temperature of 32° F. to about 79°; in other words, from winter-cold to summer-heat. But the genial influence of the gulf-stream on the British Isles is more than this. Every western breeze that blows towards us crosses the mighty gulf-stream, robs it of a portion of its heat, and comes towards our shores charged with warmth and laden with balmy moisture, clothing Ireland in a suit of green, and imparting a mildness to both England and Ireland which can be best appreciated when we consider that the coasts of Labrador, on the American side, and under the same parallel of latitude as England, are rigid with ice. In 1831, the harbour of St. John's, Newfoundland, was closed with ice as late as the month of June; yet the harbour of Liverpool, though 2° further north, is never ice-locked even in the severest winters. By referring to any chart of isothermal lines, the current of the gulf-stream, as just described, may be readily traced.

Although the climatic effect of the gulf-stream is so advantageous to Western Europe, more especially to these Isles, it is scarcely less advantageous to the regions whence it originates. If the gulf-stream be the channel along which an amount of heat so considerable passes westward, we may speculate on the consequences that would have arisen had the amount of temperature now conveyed away remained in the gulf itself. Even now the coast-line of this region is extremely hot and unhealthy; how much more hot and unhealthy would it have been had the gulf-stream not existed!

Under-Current of the Gulf-Stream.—As the trade-winds are only an under atmospheric current, passing in an opposite direction to a current above; so the gulf-stream is only the counterpart of an inferior current of cold water flowing back to compensate for that which has departed. Not only does theory proclaim this, but it is borne out by experiment. At a mean depth of two hundred and forty fathoms, an under-current of water flows into the Caribbean Sea; and the temperature of this current has been found as low as 48°, whilst the surface-water had a temperature of 85°. At the depth of three hundred and eighty-six fathoms the temperature had fallen to 43°; and at the very bottom of the gulf-stream the temperature was only 38°; hence the existence of the returning cold current is fully borne out. It comes, there is little reason to doubt, from the arctic circle; presenting the closest analogy to the lower aerial current which constitutes the trade-wind.

The course and extent of the gulf-stream were not generally known until the celebrated Dr. Franklin drew attention to the subject. The history of this event is worthy of narration, illustrating as it does the discriminating and logical mind of that extraordinary individual.

Happening to be in London in 1770, his opinion was demanded respecting a memorial presented by the Board of Customs at Boston to the Lords of the Treasury, stating that the Falmouth packets were generally a fortnight longer on their voyage to Boston than common traders were from London to Providence, Rhode Island: whence their request that the Falmouth packets might be sent to Providence instead of to Boston. "Franklin could not understand the reasonableness of this request, inasmuch as London was much further than Falmouth, and from Falmouth the routes were the same, so that the difference should have been the other way. Desiring a solution of his difficulty, he consulted Captain Folger, a Nantucket whaler, who chanced to be in London at the time. The whaler explained that the difference arose from the circumstance that Rhode-Island captains were acquainted with the gulf-stream, while those of the English packets were not. The latter kept in it, and were driven back sixty or seventy miles a-day; while the former avoided it altogether."—*Maury.*

The manner in which the old whaling captain had been made acquainted with the existence, the extent, and the direction of this gulf-stream, is curious enough in its way. His instructors were the objects of his search, *the arctic whales*—animals which, having a dislike to warm water, never enter the gulf-stream, though they swim close up to it on both sides.

Franklin having extracted this intelligence from the whaling captain, got him to draw a chart of the gulf-stream to the best of his ability. The chart was drawn, Franklin had it printed, and copies were sent to the Falmouth captains. They, however, were foolish enough to pay no heed to its teachings; nor did they profit for many years after by the knowledge of the gulf-stream. Though the date of Franklin's discovery was 1775, yet a knowledge of the gulf-stream was not generally diffused and acted upon until fifteen years later. Not the least extraordinary fact in connection with the gulf-stream is the sharpness of its line of demarcation. No river imprisoned between two scarped rocky banks could flow in channel more defined. "If," remarked the American author Jonathan Williams, "these strips of water had been distinguished by colours of red, white, and blue, they could not be more distinctly discovered than they are by the thermometer." "And, he might have added," remarks Maury, "nor could they have marked the position of the ship more clearly."

The notion prevails amongst sailors that the gulf-stream is the great storm-breeder of the Atlantic—the father of storms; and, indeed, the tempests which follow in its course or on its borders warrant that designation. What are the indications of theory in this respect? Had the Atlantic been still an untravelled waste, and the existence of a gulf-stream, such as we now know it, been propounded as the basis of discussion, would not the theorist have predicted that storms must originate in the meeting of the hot, moist atmosphere which hovers over the ocean tract of seething waters from the fiery shores of Mexico and the Caribbean Sea, mixed with the chilling blasts of the north? What torrents of water must result from the condensation of the tepid mists—what stupendous electrical force must be brought into operation!

If the gulf-stream, by its impulsive flow, sometimes impedes the mariner and drives his ship from the desired course, it nevertheless affords a compensation, not only in assisting to propel ships sailing in the direction of its course, but in affording a genial climate to the weather-beaten mariner, frozen and benumbed by the shivering blasts of the regions outside its channel. "No part of the world," says the writer to whom I am largely indebted for much that in these pages concerns ocean currents and ocean climatology,—"no part of the world," remarks Maury, "affords a more difficult or dangerous navigation than the approaches of our (the American) coast in winter." Before the warmth of the gulf-stream was known, a voyage for this reason from Europe to New England, New York, and even to the capes of the Delaware or Chesapeake, was many times more trying, difficult, and dangerous than it now is. In making this part of the coast, vessels are frequently met by shore-storms and gales which mock the seaman's strength, and set at naught his skill. In a little while his bark becomes a mass of ice, and his crew frosted and helpless. She remains obedient only to her helm, and is kept away for the gulf-stream. After a few hours' run she reaches its edge, and almost at the next bound, passes from the midst of winter into a sea at summer-heat. Now the ice disappears from his apparel; the sailor bathes his stiffened limbs in tepid water; feeling himself invigorated and refreshed with the genial warmth about him, he realizes out there at sea the fable of Antæus and his mother Earth. He rises up and attempts to make his port again; and is again as rudely met, and beaten back from the north-west; but each time that he is driven off from the contest, he arises forth from this stream, like the ancient son of Neptune, stronger and stronger; until after many days his freshened strength prevails, and he at last triumphs, and enters his haven in safety, though in the contest he sometimes falls to rise no more, for it is often terrible. Many ships annually founder in these gales; and I might name instances, for they are not uncommon, in which vessels bound to Norfolk or Baltimore, with their crews enervated in tropical climates, have encountered, as far down as the Cape of Virginia, snow-storms that have driven them back into the gulf-stream, times and again; and have kept them thus out for forty, fifty, and even for sixty days, trying to make an anchorage.

Nevertheless, the presence of the warm waters in the gulf-stream, with their summer-heat in mid-winter off the shores of New England, is a great boon to navigation. At this season of the year especially, the number of wrecks and loss of life along the Atlantic sea-board are frightful. The month's average of wrecks has been as high as three a-day. How many escape by seeking refuge from the cold in the warm waters of the gulf-stream, is a matter of conjecture. Suffice it to say, that before this temperature was known, vessels thus distressed knew of no place of refuge short of the West Indies; and the newspapers of that day—Franklin's *Pennsylvania Gazette* among them—inform us, that it was no uncommon occurrence for vessels bound to the capes of Delaware in winter to be blown off, and to go to the West Indies, and there wait for the return of spring before they would attempt another approach to this part of the coast.

The gulf-stream is the largest known oceanic current; it has been perhaps more fully studied than any other, and its teachings may therefore be appropriately regarded as the type of the rest. We have seen how powerful and extensive are its effects; we have seen a few of the purposes to which it ministers. The ocean is full of streams similar to this, each taking its well-defined course, carrying its own temperature, clad with its own fauna and flora, peopled with its own denizens. Thoughts like these prove how false and unfounded is the expression, *ocean waste*, so commonly applied. The ocean has its regions, its valleys, and its mountains—climates and varied inhabitants—no less than the earth.

Other Oceanic Currents.—*The Mediterranean.*—It has long been known that an upper or sailing current constantly sets into the Mediterranean through the Straits of Gibraltar. What, then, becomes of the water of the currents? That water must either be dissipated by evaporation, or there must be a second or back-current.

The existence of this under-current was first demonstrated very curiously in 1712. At that time, France being at war with Holland, M. L'Aigle commanded a French privateer, called the Phœnix of Marseilles. Near Ceuta this privateer gave chase to a Dutch ship bound to Holland, come up with her, delivered one broadside, when the Dutch ship immediately went down. A few days later, the sunken ship, with all her cargo of brandy and oil, came to light again; but this took place on the coast of Tangier, at least four leagues westward of the place where the ship went down, and in a direction quite opposite to that of the upper or navigable current. This well-authenticated case was communicated to the Royal Society in 1724.

Currents of the Red Sea.—Precisely similar to the Mediterranean currents, just described, are those of the Red Sea. The necessity of a free change of waters here is even more necessary than in the Mediterranean; the sea is not only shallower, and subjected to a more powerful evaporation, but its waters are not freshened by the afflux of any rivers. It has been calculated by Dr. Buist, that, taking into consideration the mean evaporation on every part of the surface of the Red Sea, a sheet of water, eight feet thick, and equal in superficial area to the whole extent of the surface of the Red Sea, will be raised in vapour annually. When this enormous rate of evaporation is considered, the necessity for a continuous interchange of water between the Red Sea and the external ocean will be evident. If the Red Sea outlet were choked up, so that ingress and egress were no longer possible, the evaporation of about a thousand years would, it is calculated, completely dry it up.

Currents of the Indian Ocean.—Many thermal currents originate in the Indian Ocean. Amongst the foremost of these is the Mozambique current; another of these currents, first escaping from the Straits of Malacca, and being swollen by warm streams from the Java and Chinese Seas, flows out into the Pacific between the Philippines and the Asiatic shores. Passing thence towards the Aleutian Isles it ultimately loses itself on the north-west coast of America. Meteoric conditions like those which mark the course of the gulf-stream also mark the course of this. Fogs and mists follow in its track, and storms are also generated on the bank of this oceanic river.

For a fuller account of oceanic currents than is consistent with the limits and objects of these pages, I must refer the reader to treatises which deal with the special matter, and above all to the work of Lieutenant Maury, of the United States service, to whom meteorologists are under deep obligations for his contributions to their knowledge of ocean phenomena.

In contemplating these oceanic currents, of which the gulf-stream may appropriately be considered the type, we cannot fail to be impressed with an evidence of design, where at first no design would seem to exist. These oceanic currents originate in, and are determined by, a peculiar conformation of the land. Now what can be more seemingly irregular or capricious than the shape of land? If dropped down into the ocean at random, or elevated by a subterranean power equally capricious, the crust line of islands and continents, the solid blocks of our planetary crust, could not well be more irregular than they are; and yet how practically harmonious is the relation between land and water: how well adjusted the powers of each, how well adapted to the mutual benefit of mankind. It appears an unimportant matter when in the map of the world we skim our eye over the southern hemisphere of the terrestrial globe; there we behold the limits of the African and American continents in their furthest extent; but how terribly would the locomotive faculty of mankind have been impeded had either continent expanded itself to the south pole, or even traversed much further south than is actually the case!

In connection with the subject of ocean currents, the effects of aqueous temperature on the ocean's denizens deserves a passing word of remark further than has already been devoted to it. In the Caribbean Sea, and other ocean caldrons, where stores of heat are accumulated for distribution in regions far away,—in the hot currents which originate in these tepid sources of oceanic rivers, there are a fauna and a flora: the fauna no less marked than we see on tropical lands. There grows the coral, there swims the shark; and thousands of shelled mollusca, of gorgeous colour and enormous size, revelling in oceanic forests of rank and bulky growth, represent the land forests and their denizens of corresponding climes. But though grandeur and beauty be the characteristics of these warm ocean spots—the thermal ocean-tropic (if the propriety of that expression be allowed)—it is the colder oceanic currents which support the form of animal life most useful to man. Strange though the circumstance may appear, it is no less true, that the fish of the hot parts of the world are always indifferent as food. This fact is strikingly illustrated in the Mediterranean. The temperature of the Mediterranean water is usually four or five degrees above the temperature of the external ocean, and what a difference in the fish! Whoever has compared the edible fish of the Atlantic with those of the Mediterranean, will be at no loss to admit the vast superiority of the former. The naturalist does not require to be informed, that not only are Mediterranean fish inferior to those of the Atlantic, but they are for the most part of different species.

Let us now take a glance at the locality of the principal fishing regions. Limiting ourselves to two of these, they would unquestionably be the fishing grounds of Newfoundland and Japan. The former is the better known of the two, though, perhaps, the latter is the more considerable, seeing that the natives of Japan are debarred from the use of animal food by their religion, although the eating of fish permitted, they are all ichthyophagi; and, notwithstanding the dense population of the Japanese islands, their inhabitants, though fish-eaters, are abundantly fed.

Between the gulf-stream and the coast is a narrow band of cold water: here are the fisheries of Newfoundland. Between the China current, as it is denominated, and flowing in an opposite direction, is the cold current, in which the Japanese fisheries are prosecuted. These are the two most prominent examples, and they will be found to present the type of many others.

Cold, and its Effects.—Under the heads of snow, hail, and hoar-frost, some of the meteorologic effects of cold have been already described. The phenomena due to this powerful agency are, however, so numerous and so important, that it may be well to make the subject of cold a matter of special contemplation. If, casting our eye over the field of nature, we endeavour to select the most prominent results of cold, they will be found to relate to the departure from an ordinary law, which Nature has made in the expansion of water during the act of freezing.

The term *freezing* is but a general expression for the act of solidification by cold. Popularly, the term is only applied to solidified water; but this is altogether a conventional acceptation of the word. We are justified, then, in comparing the act of solidification of water, with the act of solidification of any other fluid, and seeing to what extent the conditions which regulate one also regulate the other.

When the temperature falls to 32° F. water ceases to be liquid, and becomes ice; the weather is said to be frosty, and water is said to be frozen. Whatever water be contained in the atmosphere at the freezing temperature, is deposited in the solid form of hoar-frost, the particles not being irregular, but bounded by definite mathematical outlines—frequently giving rise to forms of great beauty, especially on window-panes, blades of grass, and leaves (Fig. 87). These forms are similar, in general contour, to those of well-formed snow-flakes (Fig. 88), but far more beautiful, and, like snow-flakes, prove that frozen water is a crystalline body, and that it crystallizes in forms belonging to the rhombohedral system.

Fig. 87.

But the most important point connected with the freezing of water, and without which our globe would cease to be habitable, is this:—Water, during the act of freezing, expands, and thus becomes specifically lighter. Ice, therefore, swims on water; it cannot sink. How stupendous are the consequences of this departure from the law of freezing! Had it so happened that frozen water, like frozen mercury, was more heavy than the corresponding liquid material, each frozen sheet of water would sink as soon as formed; and thus, being far removed from the melting influence of solar rays, the production of ice would have been accumulative, and the ocean, long ere this, would have been completely ice-locked.

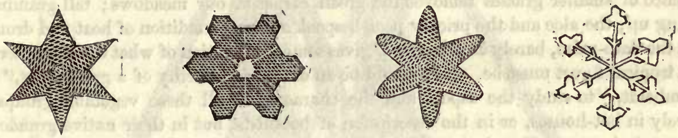


Fig. 88.

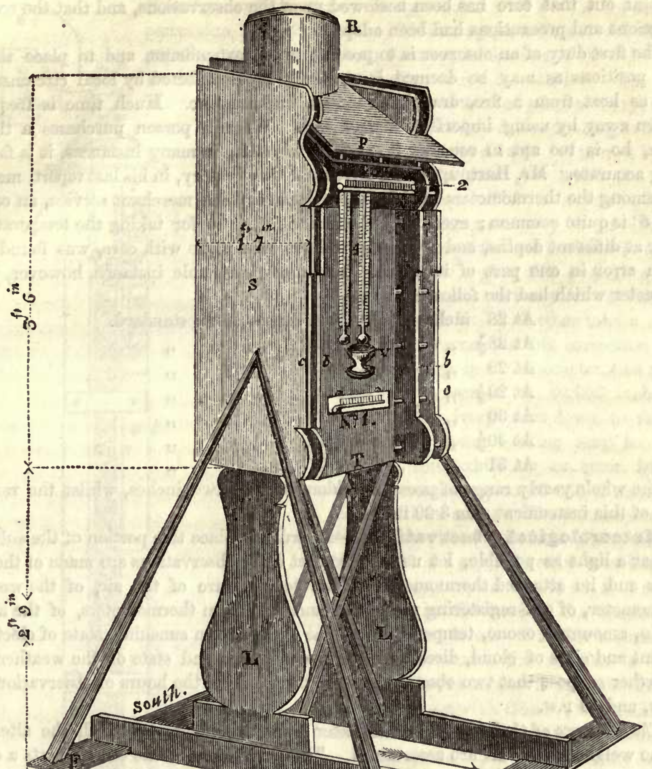
In tracing, hypothetically, an assumed aberration of Nature to its consequences, the mind is speedily entangled and lost in the chaos of jarring effects. The speculative meteorologist finds himself unable to thread the labyrinth of causation here involved. Having shown that the ocean would have been full of ice, had the ordinary law of solidification not been departed from in the case of water, it is perhaps unnecessary to follow the development of our hypothetical case further. That ocean life must have been destroyed is evident; that the sea's liquid highway would have ceased to be, is only a figurative expression for a frozen ocean. But would what is now the solid land have then served the purposes of animal life? Where could the rivers have flown, had the ocean been a block of ice? or would not the rivers have remained frozen too, seeing the vast cooling power of a frozen ocean? It is easy to see that, under such circumstances, our planet would have been totally unfit to be a resting-place for its present denizens had the freezing of water not assumed a departure from a law, though it be impossible to imagine all the consequences that would have resulted.

The same expansive force of water during the act of freezing, by the operation of which it is rendered specifically lighter than water, subserves many important purposes in the world's economy, besides floating the ice. Water percolating into the fissures of rocks, and being subsequently frozen there, displays its irresistible force by splitting large rocks into fragments, and disintegrating their fragments. In this way hard and sterile districts become covered with useful soil, in which low forms of vegetable life can take root; and by their subsequent decay, contribute the elements necessary to the support of higher forms of vegetation.

Relation of Climate to Organic Development.—The naturalist who, in his desire to see as in a dioramic picture the wonderful characteristics of animal and vegetable types, sighs to think that a vision so glorious will never pass in reality before his gaze, may at least console himself with the assurance of that great master of philosophic travel, Humboldt, that it is in the power of man's creative faculty, aided by philosophy, to imagine those striking types in the vividness of their truth, gladdening the closet with ideal images of the living features of Nature.

Even in the narrow region of European travel, the intelligent observer will not fail to see distinctive physiognomies. Passing from the cold green-sward and modest vegetation of our own Isles to the Mediterranean shore, a striking change in the aspect of nature meets the view. The sturdy oaks and elms of our own forests disappear; the absence of smaller grasses removes the green carpet of our meadows; tall graminaceæ spring up; the aloe and the prickly pear bespeak a mixed condition of heat and drought; and the date-palm, barely acclimatized, gives some faint notion of what the characteristics of a tropical forest must be. "It would be an enterprise worthy of a great artist," says Humboldt, "to study the aspect and the character of all these vegetable groups, not merely in hot-houses, or in the description of botanists, but in their native grandeur in the tropical zone. How interesting and instructive to the landscape painter would be a work which should present to the eye, first separately, and then in combination and contrast, their leading forms! How picturesque is the aspect of tree ferns, spreading their delicate fronds above the laurel-oaks of Mexico; or the groups of plantains overshadowed by arborescent grasses. It is the artist's privilege, having studied these groups, to analyze them: and thus in his hands the grand and beautiful form of nature which he would portray resolves itself, like the written works of men, into a few simple elements."

When the meteorologist has exhausted his knowledge in the laying out of climatic groups—when he has placed in correlation conditions identical, as he thinks, in every respect—the growth of vegetable forms demonstrates his inability to comprehend many hidden secrets of nature, which their delicate organization makes known. European olive-trees grow luxuriantly at Quito, but they bear neither fruit nor flowers; and a similar remark applies to walnut-trees and hazel-nuts in the Isle of France. In India, the bamboo flowers luxuriantly; but in South America, where it flourishes equally well, so far as general aspect of growth is concerned, so rare an event is the infloration of the bamboo, that during a four years' residence in South America, Humboldt was only enabled to obtain blossoms once. But perhaps a still more remarkable example of luxuriant growth without inflorescence is furnished by the sugar-cane. The West Indies have come to be considered as the region *par excellence* of the sugar-cane; yet it seldom bears flowers there—nor indeed does it in any part of the American continent; thus furnishing a strong presumptive argument in favour of the theory which asserts that no variety of the sugar-cane is indigenous to the New World.



LAWSON'S THERMOMETER STAND.

PRACTICAL METEOROLOGY.

So many amateur meteorologists are now springing up in every direction, that it may be desirable to point out the precautions and reductions necessary in order to render the raw observations useful to science. The present paper is, therefore, written in continuation of Dr. Scoffern's Meteorology, to enable the amateur, with as little trouble as possible, to reduce his observations to useful results.

To the non-meteorologist such terms as adopted mean temperature, elastic force of vapour, reduced barometer, &c., unexplained, serve rather to perplex than to enlighten or point out that care has been bestowed upon the observations, and that the requisite reductions and precautions had been adopted.

The first duty of an observer is to procure good instruments, and to place them in such positions as may be deemed least likely to be affected by local circumstances, such as heat from a fire, draughts round a building, &c. Much time is frequently thrown away by using imperfect instruments. When a person purchases a thermometer, he is too apt to consider it correct; whereas, in many instances, it is far from being accurate. Mr. Hartnup, of the Liverpool Observatory, in his last report, mentions that among the thermometers used by the captains of the merchant service, an error of 4° or 5° is quite common; even a thermometer fitted up for taking the temperature of water at different depths, and professing to have been made with care, was found to be 8½° in error in one part of its scale. The most laughable instance, however, was a barometer which had the following errors:—

At 28 inches was — 2·22 inches of the standard.
At 28½ „ „ — 1·88 „ „
At 29 „ „ — 0·73 „ „
At 29½ „ „ — 0·30 „ „
At 30 „ „ — 0·02 „ „
At 30½ „ „ + 0·33 „ „
At 31 „ „ + 1·07 „ „

The whole yearly range of pressure seldom reaches two inches, whilst the range in error of this instrument was 3·29 inches.

Meteorological Observations.—In order to place this portion of the subject in as clear a light as possible, let us suppose that daily observations are made of the barometer and its attached thermometer, of the temperature of the air, of the wet bulb thermometer, of self-registering maximum and minimum thermometers, of the amount of rain, amount of ozone, temperature on the grass and in sunshine, state of electricity, amount and class of cloud, direction and force of wind, and state of the weather. Let us further suppose that two observations are taken daily, the hours of observation being 9 A.M. and 10 P.M.

The Pressure of the Air.—The barometer is the instrument by which the alterations in the weight of the air are ascertained. The gravitation of the earth exerts a certain pressure which would always be alike, were it not that lateral disturbances had the power of removing a portion of that pressure and adding it elsewhere. Thus, suppose the average pressure to be 29½ inches, if the barometer is seen to rise to 30 inches, it is certain that in another portion of the earth a corresponding fall has taken place to account for this change; however, as it is not our object to enter into the physical and local changes of the weather here, we shall at once proceed to describe the reductions that are requisite.

It is essential to correct observation that the barometer used be a standard instrument. The ordinary instruments are useless, owing to the friction of the mercury against the sides of the glass in small tubes, the impossibility of applying the reduction necessary to *correct* for the alteration of the height of mercury in the cistern with the common wheel barometer, owing to a rise and fall in the tube; and, further, because if errors occur in this barometer, they are increased by the circumstance of the index of the wheel barometer being a long-arm worked by a small wheel, thus multiplying all the errors.

The Standard Barometer should have a tube of not less than $\frac{4}{10}$ths of an inch in diameter, and the nearer it approaches to $\frac{6}{10}$ths the better, as the correction requisite for the friction against the sides of the glass rapidly diminishes with an increase in the size of the tube. This is the correction for capillarity, which is additive. The base of the tube should be plunged into a cistern of pure mercury, and the scale of inches should have a rod attached, terminating in an ivory point, so contrived as to be moved by rack-work until the point *just* touch the surface of the mercury. This is requisite, in order that the measurement may be made from the surface of the quicksilver in the cistern. Suppose we either neglect this operation, or the barometer is one not capable of having it applied; and let us further take a reading without reference to this correction after a sudden change in the barometer, this reading may be represented as 30·036 inches; on bringing the ivory point down to the mercury, this second reading may be 30·074 inches: thus exhibiting an error, from the want of this precaution, of ·038, or nearly four-hundredths of an inch. The thermometer fitted for use should have its bulb plunged into the cistern of mercury, otherwise it will not give the temperature of the mercury itself, but merely show the heat of the apartment in which it is placed. Such an instrument is made by Newman, the optician in Regent Street; it is the same as is made for the Royal Society, Greenwich Observatory, Admiralty, and the British Colonial Observatories.

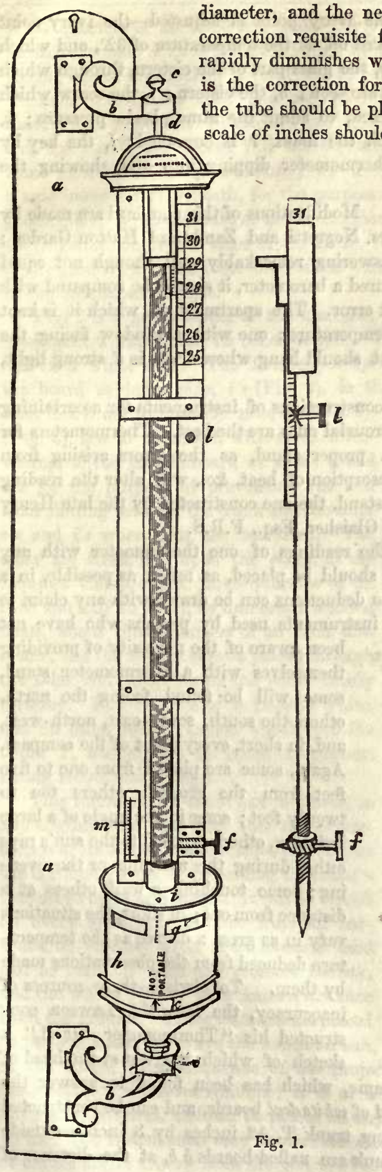


Fig. 1.

Description.—*a* is the mahogany board to affix against the wall; *b*, brackets which support the barometer, between which it is capable of being revolved so as to observe the light on the surface of the mercury; *c*, a vase, which unscrews to allow of the socket *d* being removed to receive the upper end of the barometer; *e*, the adjusting screws for shifting the lower centre, by which the barometer is to be made exactly perpendicular: to accomplish this, the ivory point is to be adjusted to the surface of the mercury, the barometer gently turned between the two brackets; and if in any position the point should be elevated from the surface, or depressed into the mercury, the screws must be altered accordingly, until the point coincides in every position; *f*, the key by which the ivory point is adjusted—the ivory point being a termination of the brass scale marked off at the temperature of 32°, and which is adjusted by means of a tangent screw; *g*, the glass part of the cistern, through which the surface of the mercury and ivory point are seen; *h*, the cistern; *i*, the screw which is to be loosened when the barometer is fixed, to admit the atmospheric pressure; *k*, the moveable part of the cistern, on which the index ↑ is engraved; *l*, the key by which the vernier is adjusted; *m*, the thermometer dipping into and showing the temperature of the mercury.

This barometer is necessarily expensive. Modifications of this standard are made by Mr. Barrow of Oxendon Street, and Messrs. Negretti and Zambra of Hatton Garden; and these are more reasonable in price, answering remarkably well, though not equal to Mr. Newman's Standard. Having procured a barometer, it should be compared with the Standard, in order to ascertain its index error. The apartment in which it is kept must not be subject to great changes of temperature; one with a window facing the north is to be preferred; and the instrument should hang where there is a strong light, but an outer wall should be avoided.

Thermometers.—There are various constructions of instruments for ascertaining the temperature of the air; of these the mercurial ones are the best. Thermometers for comparison require to be placed upon a proper stand, as the errors arising from peculiarity of situation, from radiation, absorption of heat, &c., will alter the reading very materially. There are two forms of stand, the one constructed by the late Henry Lawson, Esq., F.R.S., the other by James Glaisher, Esq., F.R.S.

Thermometer Stands.—In comparing the readings of one thermometer with any other, it is requisite that each instrument should be placed, as much as possible, in a similar manner; without this uniformity no deductions can be drawn with any claim to accuracy. In looking to the situation of instruments used by persons who have not been aware of the necessity of providing themselves with a thermometer stand, some will be found facing the north, others the south, south-east, north-west, and, in short, every point of the compass. Again, some are placed from one to five feet from the ground, others ten to twenty feet; some in the angle of a large building, others exposed to the sun's rays either during the morning or the evening; some touching a wall, others at a distance from one; in short, the situations vary in as great a degree as the temperature deduced from the observations made by them. To obviate these sources of inaccuracy, the late Mr. Lawson constructed his "Thermometer Stand," a sketch of which is given at the head of this chapter. This stand consists of a frame, which has been found to answer the intended purpose very well. It is composed of *white deal* boards, and can be constructed by any carpenter. It consists of an oblong trunk T, 12 inches by 8 inches outside measure; to the opposite side of which trunk are nailed boards *b b*, at the distance of

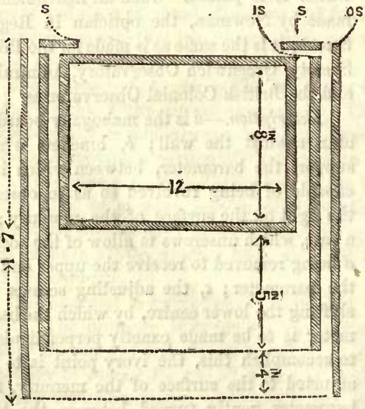


Fig. 2.

three quarters of an inch, and projecting about six inches from the trunk towards the north. Outside of these are nailed other thin boards *c c*, full half an inch distant, and projecting about four inches beyond the last-mentioned boards, also towards the north. These sides or shades being multiple, prevent the sun from heating the interior of the stand where the thermometers are placed. The top, or pent board, P, is made double, and the boards are placed full three-quarters of an inch distant from each other, and come forward so as to overhang, by a full inch, the Night Index Thermometer, placed immediately beneath, for the purpose of preventing rain or dew from falling perpendicularly upon the bulb of the thermometer. The legs, L L, of the stand are merely the continuation of the sides of the trunk. The board or feet, F F, are loaded or fixed to the ground, to sustain the force of the wind. The interior, T, is blackened to prevent strong reflections of light.

Fig. 2 is a ground-plan of the machine, which will prove sufficiently clear to any intelligent workman for its construction. The sides (and wood-work generally) are of half-inch white deal. The distance or space between the sides of the trunk T and the board or inner side, *i s* (Fig. 2), is three-quarters of an inch; and the distance from that board to the outer side, *o s* (Fig. 2), is full half an inch. The narrow boards, *s s* (Fig. 2), are to be nailed, with studs intervening, to the middle board or side *i s*, and are for the purpose of preventing the sun from shining between the trunk and the sides *o s* and *i s* when near the meridian. The sides are fixed, one upon the other, at the required distance (viz. three-quarters of an inch and half an inch), by numerous wooden studs, about three-quarters of an inch diameter; and the nails or screws passed through the sides and studs, fixing the whole firmly together. The whole is to be painted white, and no other colour, except the face of the trunk T, which may be black, to prevent strong reflections of light.

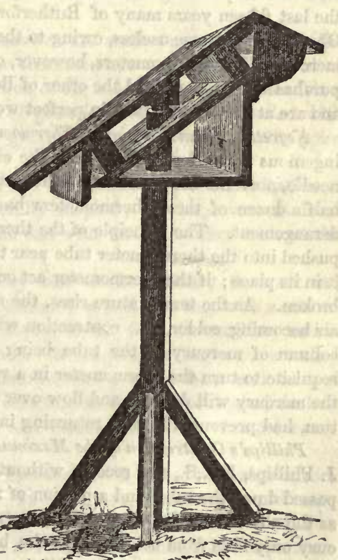


Fig. 3. Glaisher's Stand.

This thermometer-stand can be placed in *any* eligible spot that may suit the convenience of its owner; its four sides should face the cardinal points, commanding therefore a true north and south aspect. It can be visited on every side, and be free from all surrounding objects. The thermometers used can be read off with the greatest facility, and the whole will be at a known distance from the ground. Those instruments placed on the south face will have the meridian sun, and those on the north face will be always in the shade, in consequence of the projecting wings. It can be employed by any meteorologist, wherever residing; it is of a determinate form, height, and size; it is not costly, but firm, and can be placed on any open spot that may be thought eligible for its use. The instruments may be read off with the greatest promptitude, so as to prevent or reduce errors arising from the person of the observer being too long in the vicinity of the thermometers. By the general adoption of this stand, instruments placed upon it will all be used or observed under similar circumstances, and deductions from them be more correctly drawn than where there is no stand. It follows that observations made by individuals wherever residing, either in Europe, Asia, Africa, or America, if drawn from instruments thus similarly placed, can be compared one with the other with far less chance of error than has hitherto been the case.

Mr. Glaisher, F.R.S., has likewise constructed a stand differing from the one just described, but which is also an excellent contrivance.

Rutherford's Thermometer.—The mercurial thermometer of Rutherford's construction pushes a registering-pin before it as the mercury expands by heat; on the air becoming cooler, the mercury contracts, leaving the registering-pin at the point of maximum heat. One objection to this instrument will always be felt, *i.e.* the pin is not unlikely to become entangled with the mercury, especially if the mercury should oxidize.

It is very desirable to incline Rutherford's maximum thermometer from the horizontal position, so that the bulb shall be slightly the highest, in order that the thermometer may have the assistance of gravitation in pushing the pin forwards. Within the last fifteen years many of Rutherford's construction have at the Highfield House Observatory become useless, owing to the registering-needle becoming entangled with the mercury. Two thermometers, however, of this construction deserve to be noticed, the one purchased of Dollond and the other of Bennett: they have done their duty satisfactorily, and are at the present time in perfect working order.

Negretti's Patent Maximum Thermometer.—Too much praise cannot be given to this ingenious invention, which, from the circumstance of doing away with the registering-needle, prevents the possibility of the instrument getting out of order. Since the invention, half a dozen of these thermometers have been constantly employed here without any derangement. The principle of the thermometer is this:—A small piece of enamel is pushed into the thermometer tube near the bulb, and the tube is then bent so as to secure it in its place; if the thermometer act once, it will continue to act until the instrument is broken. As the temperature rises, the mercury will flow over this enamel; yet, on the air becoming colder, the contraction will only take place below this point, the whole column of mercury in the tube being left to mark the maximum heat. It is only requisite to turn the thermometer in a vertical position, and give it a gentle shake, when the mercury will descend and flow over the obstruction, which, in the horizontal position, had prevented it from returning into the bulb of the thermometer.

Phillips's Construction of the Maximum Thermometer.—This, the invention of Professor J. Phillips, F.R.S., also records without a registering-needle. A small bubble of air is passed down the tube, and a portion of mercury is made to remain above this bubble; as the air increases in temperature the whole column rises, yet, when it cools, the mercury only falls from below where the bubble of air is situated. It is an instrument liable to get out of order in travelling; yet, when once properly fixed, does its work well. In consequence of the bubble of air expanding with an increase of temperature, a slight error will be occasioned, and the thermometer will read a little too high in warm weather, and the reverse when cold.

The Minimum Thermometer, until lately, has been filled with *spirit* instead of *mercury*, with a slender glass pin floating in the liquid. This pin is carried down with it to the lowest point; on the temperature rising, this pin is left behind, and thus marks the coldest point. Like the maximum thermometer, gravitation should be allowed to assist the descent of the pin, which is accomplished by slightly lowering the bulb from the horizontal position. The best that I have received have been from Messrs. Negretti and Zambra; in these the pin is much longer and more slender, and they very rarely get out of order. A disadvantage will always be felt with spirit thermometers; their action differs from those filled with mercury.

The Mercurial Minimum Thermometer.—Meteorologists have for some time urged the opticians to invent a mercurial minimum thermometer, an invention which long seemed almost to be an impossibility. However, such an instrument now exists, thanks to Messrs. Negretti and Zambra. A thermometer with a large tube is placed in a vertical position, in which is a slender, pointed needle, which is brought down to the surface of the mercury; quicksilver being heavier than the needle, it is held above it; yet, the needle being pointed, plunges a small, but sensible, distance in the mercury, which it invariably does by the side of the glass of the thermometer tube. This being the case, the needle will descend to the lowest degree of cold; on the thermometer rising, the mercury presses the needle to the glass, and rises up by the side of it, instead of raising the needle. Four months' working of this thermometer has proved it to be a valuable invention. The instrument must come into general use amongst meteorologists.

The Solar and Terrestrial Radiation Thermometers are made entirely of glass, the scale being engraven upon the bulb itself. For thermometers continually exposed to damp, the swelling of the wood and the obliteration of the index thereon has been felt a great annoyance; consequently, the substitution of glass for wood has been hailed with pleasure by meteorologists, independently of its great improvement in a scientific point of view.

The white enamel placed along the back of the thermometer tube, an invention of Negretti and Zambra's, is now becoming generally adopted; the improvement is at once manifest on inspecting two instruments, the one with and the other without the enamel.

The Wet and Dry Bulb Thermometer.—The dry bulb is the ordinary thermometer, and the wet bulb differs only in having the bulb enclosed in a muslin bag, with a cotton-wick conductor to a cup of water, so that it shall always be wet from the capillary action of the cotton conveying the water constantly to it. If the muslin bag were attached to self-registering, instead of ordinary thermometers, the greatest heat and cold of the wet bulb would be obtained—an important addition to the meteorological instruments, yet one almost unknown. The muslin and cotton should be changed every month.

Bennett's Photographic Wet and Dry Bulb Thermometer is an additional evidence of the close relationship between heat and light. In this most ingenious contrivance *light* is incessantly writing down the *heat* of the air. It is simply requisite to place a sheet of paper upon the roller once a day in order to record every change in temperature of the wet and dry bulb for the twenty-four hours. This is, indeed, a triumph of science.

Evaporators.—Having had constructed gauges of various sizes, I am enabled to speak with confidence as to their working. The water in gauges under eight inches in diameter becomes too warm, owing to the small quantity that can be contained in them; consequently, an excess of evaporation results. There are two gauges to be recommended; the one Newman's, and the other Negretti's. These gauges work well. Newman's is a very convenient and ornamental instrument, having a graduated glass tube

It consists of a short cylinder twelve inches in diameter, having connected with it, by means of a stopcock, a glass tube graduated to hundredths, and terminating in a lower vessel, which will contain a sufficient quantity of water to be raised by artificial pressure into the upper one for exposure to the atmosphere.

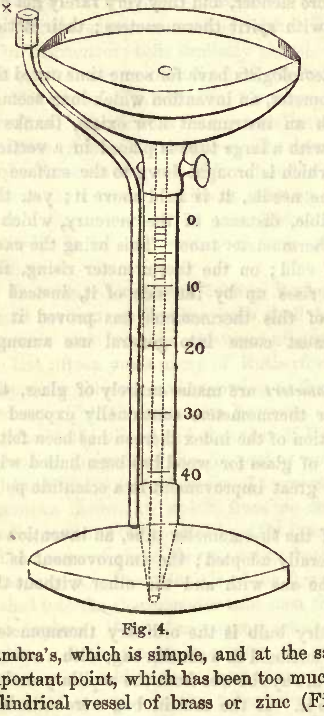


Fig. 4.

To use the apparatus, pour water into it until it rises to the zero in the glass tube, then by means of a syringe force the air through the tube × (Fig. 4) into the lower vessel, so as to raise the water into the upper one to any height you please. Now shut off the stopcock beneath to retain the water in the upper vessel; then, having exposed the apparatus for any length of time required, open the cock, the water will run into the lower vessel, filling it and part of the glass tube, the divisions of which will now indicate the quantity of water evaporated. Negretti's is the cheaper, being simply a cylinder of the diameter of eight inches, which fits into a wooden box filled with wet sand; this keeps the outside of the metal cool, and prevents that excessive evaporation which would result from the heating of the metal by the sun. Where the diameter of the gauge is large, and the water several inches deep, the effect of the sunshine on the metal sides is not felt.

Rain Gauges.—There are several constructions, yet none so good as Negretti and Zambra's, which is simple, and at the same time prevents any loss by evaporation,—an important point, which has been too much overlooked. Another contrivance is that of a cylindrical vessel of brass or zinc (Fig. 5); the latter would be the cheapest, and answer all purposes equally well. Into this cylinder, a funnel, with its tube bent, fits tightly; the diameter should be eight inches, and the tube about an inch in length. The object of this bended tube is to prevent evaporation taking place from the surface of rain collected in the rain gauge, for a few drops of water will hermetically seal the opening from the escape of vapour, and most frequently the evening dews will deposit sufficient moisture for this purpose, which the heat of the day will scarcely have time to dissipate before night brings a fresh supply.

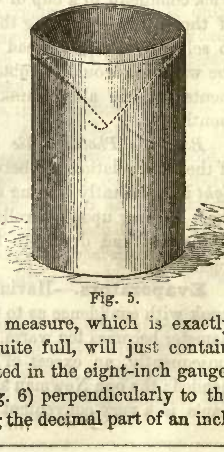


Fig. 5.

The readiest mode of measuring the amount deposited in the gauge, is by procuring another cylindrical vessel, or measure, which is exactly four inches in diameter, and four inches deep; this, when quite full, will just contain an amount equal to the deposit of an inch of rain as collected in the eight-inch gauge. Parts of an inch can be measured by plunging a rule (Fig. 6) perpendicularly to the bottom of the measure, the portion wetted by the water being the decimal part of an inch required. Thus, having made a rule exactly four inches in length, and divided it into ten equal parts, and each division being subdivided into ten others, a measure is obtained which will read off the hundredth of an inch; and as the divisions are tolerably wide, it is not difficult to estimate even to thousandths of an inch. Thus, for example, as used in the measure, the rule four inches long, divided into 100 parts, represents one inch of rain fallen; the score at twenty-five, or one inch, represents a fall of a quarter of an inch, and so on.

Electrometers.—Atmospheric electricity has been much neglected by meteorologists; it is an important item of meteorological investigation. There are several methods of studying the subject: the most simple is Glaisher's electrometer, which being portable, should become generally adopted. Where there are the conveniences for having exploring wires, properly insulated, the results are more satisfactory; and when this plan is adopted, the following electrometers should be used:—

1. De Saussure's Electrometer, which consists of two fine wires, each terminated by a small pith-ball, their expansion being measured by a graduated scale.

2. Volta's Electrometer, consisting of two thin stems of about two inches in length, and fitted to a metal rod by small rings.

3. Singer's Electrometer, consisting of two slips of gold-leaf. For stronger electricity, a pair of Dutch-gold leaves become a useful addition.

4. Zamboni's Dry-pile Electrometer. It is a single gold-leaf suspended from the conducting-rod between two dry piles, the negative pole of the one and the positive of the other being uppermost. This shows whether the electricity is positive or negative.

For powerful electric storms, the self-registering apparatus belonging to the atmospheric recorder is very useful; whilst a nicely-arranged electrical bell will be a means of warning the observer that his presence is required in the electric-room.

The effect of a thunder-storm, when three or four miles distant, as shown on these electrometers, is exceedingly interesting. It is not only possible to witness the instantaneous convulsion caused by a flash of lightning at least twenty seconds before the peal of thunder occasioned by it is heard; but it is also possible to know, several seconds before a flash takes place, that one is about to occur.

The beneficial effects of electricity on the vegetable kingdom are of a character so apparent, that any extended researches upon the branch of Meteorology calculated to throw additional light upon the subject, is very desirable.

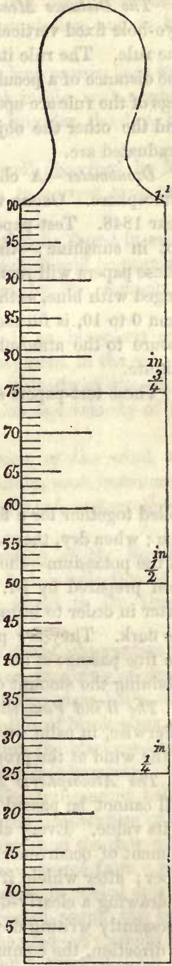


Fig. 6.

The Gimbal Vane.—This is a wind-vane exactly balanced and hung on gimbals, having vertical fans to carry it in the direction of the wind, and horizontal fans to enable it to tip *up* or *down*, to show the angle at which the air is blowing.

The Rain Angle is a simple contrivance for showing the angle at which the rain descends. It consists of a rod, which moves along a graduated arc.

The Distance Measurer.—A modification of the carpenter's rule, having an elevated eye-hole fixed vertically in the joint, and a slender pin screwed vertically on each leg of the rule. The rule itself slides on a graduated arc. In order to measure approximately the distance of a peculiar cloud, or other celestial phenomenon, from any fixed object, the legs of the rule are opened until one of the vertical pins covers the object to be measured, and the other the object to which it is referred. The distance will be seen on the graduated arc.

Ozonometer—A chemical contrivance for ascertaining the amount of ozone in the atmosphere. Ozone was discovered by Dr. Schönbein of the University of Bâle, in the year 1848. Test-papers are hung in a situation where there is a free current of air, but not in sunshine;—the north face of a thermometer-stand is a convenient situation. These papers will remain colourless if there be no ozone present, and will be more or less tinged with blue, as the ozone is more or less powerful. A scale of different tints, marked from 0 to 10, is furnished with the test-papers, to which the slips are referred after exposure to the atmosphere, immediately after immersion in water for the space of one minute.

These test-papers are made in the following manner:—

200 parts of distilled water,
10 „ of starch,
1 „ of iodide of potassium,

boiled together for a few seconds, and then slips of bibulous paper dipped into the solution; when dry, they are ready for use. If there be any ozone present in the air, it seizes on the potassium—the blue colour left being iodide of farina. Other test-papers have been prepared by Dr. Moffat of Hawarden, which do not require to be plunged into water in order to bring out the proper colour. Dr. Moffat's test-papers must be kept in the dark. They are placed in a box, the bottom of which is perforated with holes for the free passage of air. These test-papers, if kept in the dark, will last for several years, retaining the amount of discoloration.

The Wind Vane should be so contrived as to move with the least amount of friction; otherwise, in calm weather the changes will not be seen to take place in the direction of the wind at the proper time.

The Atmospheric Recorder, although too expensive for the ordinary meteorologist, still cannot be passed over in silence. Having had one in work for a year, I can speak of its value. Every change in the atmosphere is written down by pencils at the precise moment of occurrence. It is merely requisite to supply the cylinders with sufficient paper; after which, if the clock is occasionally wound up, and the pencils kept capable of drawing a clearly-defined line, no further care or trouble is needed. This machine is incessantly writing down the force of every gust of wind, the extent of every change in its direction, the commencement and termination of every shower, the quantity of rain which has fallen, and the amount of evaporation and electricity. The temperature of the air, the pressure and hygrometrical condition, are recorded every quarter of an hour. The discussion of these records cannot fail in being productive of much good to meteorologists. Mr. Dollond makes this machine.

The Actinometer.—An instrument for ascertaining the force of solar radiation. It consists of a large hollow cylinder of glass, soldered at one end to a thermometer tube, terminated at the other end by a ball drawn out to a point, and broken off so as to leave the end open. The cylinder is closed at the other end. It is filled with a deep blue liquid (ammonio-sulphate of copper). The cylinder is enclosed in a chamber which is blackened on three sides. This instrument requires careful manipulation, and is but little used.

Intensity of Light.—The gauge for ascertaining this consists of a long narrow box, with a window at one end facing the north. The box is painted black inside, with a white belt of a couple of inches in width, graduated up to 100. The brighter the day, the further can the figures be seen up this box.

The Transit Instrument is a useful addition. It has been well described by Mr. Breen in his treatise on astronomy. A very close approximation to correct time may be obtained by the use of Dollond's Portable Transit.

A good astronomical clock, with a mercurial pendulum, ought to be found in every observatory, and a good watch in the pocket of every observer; each should be provided with the seconds-hand. The watch in use here was supplied by Mr. Bennett of Cheapside; it has performed its work to my entire satisfaction.

Whewell's Anemometer, invented by the Rev. Dr. Whewell, is an ingenious self-registering anenometer, which gives the amount of horizontal movement in the air. A system of wheels is worked by windmill-sails, according to the velocity of the wind; and these carry a pencil, which is constantly recording the direction and velocity of the wind.

Osler's Anemometer constantly records the force and direction of the wind, and also the amount of rain. An admirable invention. Unfortunately, such instruments as this and Dr. Whewell's are too expensive for the majority of meteorological observers.

The Electrical Observatory at Kew, under the able management of Mr. Ronalds, has become a most important meteorological station, being, in fact, a collection of all requisite electrometers; a brief description of which will be found in Dr. Drew's "Practical Meteorology."

Daniel's Hygrometer.—An instrument for ascertaining from direct observation the temperature of the dew-point. This is an interesting contrivance, as a ring of dew is precipitated at the temperature of the dew-point. It consists of two glass balls, communicating with each other by means of a bent tube. The one ball is of black glass, and the other transparent. A thermometer is fixed with its bulb within the blackened ball; and as soon as three-fourths of this ball is filled with sulphuric ether, it is immersed. The air having been exhausted, the tube is hermetically sealed. The transparent ball is covered with muslin. A duplicate thermometer for ascertaining the temperature of the air is attached to the stem of the instrument. To find the temperature of the dew-point, all the ether must be made to run into the black ball; ether is then poured from a phial on the muslin; this produces rapid evaporation, and the temperature is cooled down to that of the dew-point; at this temperature, a ring of dew is formed round the black bulb, and at this instant the immersed thermometer must be read off: rapidity of observation being necessary, as the temperature will continue to fall below this point, and the ring of dew also to increase in width. In a few seconds the ring will gradually disappear, and at this moment the thermometer should be read a second time. The mean of the two readings will give the temperature of the dew-point. It is necessary that the ether should be very good.

The results obtained by actual observation and by calculation (from the wet and dry-bulb thermometers) are very nearly identical, as the following illustration, taken to-day at noon (May 17), will show :—

By Observation.

Daniel's hygrometer, temperature of air	56°·0
Daniel's hygrometer, temperature of dew-point when ring was formed	48°·1
Daniel's hygrometer, temperature of dew-point when ring disappeared	48°·2
Daniel's hygrometer, mean temperature of dew-point	48°·1
Daniel's hygrometer, temperature of dew-point below temperature of air	7°·9

By Calculation.

Temperature of dry bulb	56°·0
Temperature of wet bulb	52°·0
Calculated dew-point	48°·2
Temperature of dew-point below temperature of air	7°·8

Regnault's Hygrometer.—Another instrument for ascertaining the dew-point from direct observation. It differs considerably in its construction. Some meteorologists prefer it to Daniel's hygrometer. Messrs. Negretti and Zambra have constructed a modification of Regnault's hygrometer, and from them it can be procured at the same price as that usually charged for Daniel's hygrometer.

Connell's Hygrometer is a third instrument for ascertaining the dew-point from observation. In this the temperature is lowered to the dew-point by means of an exhausting syringe. The wet and dry bulb thermometer, however, answers every purpose, and to the ordinary observer is not so liable to be incorrectly read off.

The Cyanometer consists of a flat ring, divided into 53 equal parts, and numbered from 0 to 52, the 0 being white, and 52 very dark blue; the other numbers are painted every intermediate tinge from nearly white to deep blue. By its use the colour of the sky can be ascertained by observation.

General Directions.—The following occasional phenomena require a few words. The most uninstructed observer may give useful information on these subjects with comparatively little trouble to himself, by making known the particular features desirable to observe. It is desirable to note in

Thunder-storms, the direction in which they move, the point of the horizon in which they were first noticed, and that in which they disappeared; the time when thunder was first and last heard; the colour of the lightning; the number of seconds elapsing after a flash before thunder became audible (noted at different periods during the storm's continuance); the commencement and termination of rain; the direction of the wind before, after, and during its continuance; the time when the electrical breeze springs up (this is a peculiar violent breeze noticed in most thunder-storms); whether hail falls; and any other feature that may appear remarkable or be deemed desirable to be recorded.

Aurora Borealis.—Its position amongst the stars, whether merely a low auroral arch, or accompanied by coruscations. If a brilliant display, whether a cupola or dome is formed a little south of the zenith; and if formed, whether oscillatory among the stars. The hour of its occurrence when seen as a diffused light; if there be floating patches of luminous haze or cloud, &c.

Solar and Lunar Halos.—When visible, the quarter of the heavens where they appeared, and how long they remained visible.

Mock-suns and Complicated Circles of Light.—Their form and position with respect to the sun or moon; whether prismatic.

Meteors, or Falling-stars.—Their apparent size, shape, colour, path amongst the stars, velocity and duration; whether accompanied by a streak of light, or separate fragments; if large, whether a streak of light remained after the meteor itself had disappeared; and after bursting, whether any noise of explosion be heard—if so, how many seconds after the meteor itself had burst; the time of appearance, &c. These observations should more especially be attended to from the 6th to the 16th of August, and from the 9th to the 14th of November.

Gales of Wind.—Their direction, and estimated force; when they commenced and terminated; the height of the barometer during its continuance.

Snow.—Note when it fell, how deep in inches on the ground, and the form of the snow-crystals. To sketch the crystals, a magnifying-glass is requisite.

Hail.—The shape of the stones, &c.

The times of breaking up of long dry periods, and frosts; the termination of rainy periods, the commencement and duration of fogs, wind changes, &c.

Solar Eclipses.—During their continuance, and before and after, record the temperature in sun and shade repeatedly. Expose for ten seconds every five minutes slips of Mr. Talbot's sensitive-paper, to ascertain the effect of the diminution of sunlight on this paper.

Requisite Tables of Reduction.—1st. Glaisher's Hygrometrical Tables (2nd edition). These splendid tables enable the observer, with comparatively little labour, to calculate the temperature of the dew-point,—the elastic force of vapour, the weight of vapour in a cubic foot of air, the additional weight of vapour required to saturate a cubic foot of air, the degree of humidity; the whole amount of water in a vertical column of the atmosphere; the weight of a cubic foot of air, and also to separate the pressure due to vapour from that due to the gases, for any temperature from 10° to 100° F. On page 5 there is also a table for reducing the readings of the barometer to the level of the sea. Mr. Glaisher has calculated this table from the fact determined by M. Regnault, that air expands $\frac{1}{491 \cdot 13}$th part for every increase of 1° of heat.

2nd. Table of the Corrections for Temperature to Reduce Observations to 32° F. for Barometers with Brass Scales, by J. Glaisher, Esq. It is absolutely requisite to reduce the readings of the barometer to a certain acknowledged temperature, otherwise the true pressure of the air could not be ascertained; for it must be remembered that, besides the pressure of the air on the mercury, the mercury itself obeys the same law which is pointed out to us by the thermometer, *i.e.* expands by heat and contracts by cold. Thus, suppose the actual pressure of the air to be stationary, the barometer will be seen to rise or fall, if there be an increase or decrease in the temperature of the air. In like manner, the metal scale of the barometer is subject to expansion and contraction by an increase of heat or cold; and this, as Mr. Glaisher says, explains the apparent anomaly that, although the readings are said to be reduced to 32° (or the freezing-point), the point of no correction is $28\frac{1}{2}$°. As metal bars will vary in length with every degree of temperature, it is apparent that a certain temperature should be determined upon at which the standard unit of measure must be referred to.

Now this temperature has been fixed at 62° F.; therefore above 62°, as the metal will expand, this will make the divisions on the scale of the barometer too large, and consequently the barometer will read lower than it should do; on the contrary, below 62°, the metal contracting, will bring the index divisions closer together, and the barometer will read too high, unless corrected. Thus, owing to this cause alone, at the temperature of 32° the barometer is made to read ·009 of an inch too high.

The great use of the reduction for temperature will be at once apparent when an example is given: thus, suppose a person has two barometers, one in a room heated artificially and the other as cold as possible:—

Reading of barometer at temperature of 90° . = 30·200
Correction for temperature . . . — 0·165

Reading corrected for temperature . . . 30·035 inches.

Reading of barometer at temperature of 40° . = 30·066
Correction for temperature . . . . — 031

Reading corrected for temperature . . . 30·035 inches.

The difference ·134 inch between the two readings being due to the expansive action of heat.

These tables have been calculated from Schumacher's formula, which is here copied:—

$$-z \times \frac{m\,(t - 32^\circ) - s\,(t - 62^\circ)}{1 + m\,(t - 32^\circ)}$$

z = reading of barometer.
m = the expansion in volume of mercury for 1° F. = 0·0001001.
t = the temperature of the mercury and the scale.
s = the expansion of the brass scale in length for 1° F. = 0·000010434 (the normal temperature being 62°).

Thus the formula becomes—

$$-z \times \frac{0{\cdot}0001001 \times (t - 32) - 0{\cdot}000010434 \times (t - 62)}{1 + 0{\cdot}0001001 \times (t - 32)}$$

3rd. Table of Corrections to be applied to Meteorological Observations for Diurnal Range, prepared by the Council of the British Meteorological Society. These tables are of the utmost importance, as they enable an observer, from one, two, or three readings daily, to find from them the true monthly means; in fact, to make his observations represent a reading taken every hour day and night. Thus, if a reading of the barometer is made daily at 3 A.M. in March, the mean will be ·023 too low, or, at 11 A.M., ·015 too high. The necessity of this reduction becomes very evident from hourly readings of the thermometer; for, suppose the readings are made in June, at 4 A.M., the mean will be 9°·3 too low, or, if at 2 P.M., 8°·6 too high.

The only correction requisite for the reduction of meteorological observations not found in the three above-mentioned tables is that for capillarity—the capillary action of the tube of a barometer depressing the mercury by a quantity inversely proportional to the diameter of the tube. The following table will be found sufficient for this reduction: it is copied from the work published by the Committee of Physics and Meteorology of the Royal Society:—

Correction to be added to barometer readings for capillary action.

Diameter of tube. Inch.	Correction for unboiled tubes. Inch.	Correction for boiled tubes. Inch.
0·60	+ 0·004	+ 0·002
0·50	+ 0·007	0·003
0·45	0·010	0·005
0·40	0·014	0·007
0·35	0·020	0·010
0·30	0·028	0·014
0·25	0·040	0·020
0·20	0·060	0·029
0·15	0·088	0·044
0·10	0·142	0·070

The following reductions for meteorological observations will supply examples of every reduction necessary:—

Barometer Reductions.—To find the mean pressure of the barometer for the month of February, 1856 (height above the sea-level, 281 feet).

Sum of all the readings made at 9 A.M., 867640; at 10 P.M., 867528.
Divide the above by the number of observations.

29)867640(29·918 inches.
58
287
261
·266
261
··54
29
250
252
— ··2

29)867528(29·915 inches.
58
287
261
·265
261
··42
29
138
145
— ··7

Sum of all the readings of the attached thermometer at 9 A.M., 13435; at 10 P.M., 13745.

29)13435(46°·3 temp. of mercury.
116
·183
174
··95
87

29)13745(47°·4 temp. of mercury.
116
·214
203
·115
116
— ··1

Mean pressure at 9 A.M.	= 29·918
Correction for temperature of 46°·3	= — 047
Mean pressure corrected for temperature	= 29·871
Index error	— ·002
Mean pressure further corrected for index error . . .	29·869
Corrections for capillarity, the mercury being boiled . .	+ 002
Correct reading for 9 A.M.	= 29·871
Correction for diurnal range for February	— 008
Approximate mean pressure	= 29·863
Mean pressure at 10 P.M.	= 29·915
Correction for temperature of 47·4	= — 050
Mean pressure corrected for temperature . . .	29·865
Index error	— 002
Mean pressure further corrected for index error . . .	= 29·863
Correction for capillarity, the mercury being boiled . .	+ 002
Correct reading for 10 P.M.	29·865
Correction for diurnal range for February	— 007
Approximate mean pressure	29·858
Ditto ditto	29·863
Sum of the two observations	2)59·721
Adopted mean pressure for the month	= 29·8605

To reduce the mean pressure of the month to the sea-level, the adopted mean temperature of the air being 36°·0, and the cistern of the barometer 281 feet, the adopted mean pressure 29·860 inches.

In Table 2 of Glaisher's Hygrometrical Tables (page v.), showing the volume of a mass of dry air after expansion from heat for each degree of Fahrenheit's scale, it will be seen that a stratum of air 90 feet in thickness will balance a column of mercury 0·1 inch in height.

The factor for 36° is 1·008
Multiply this by 90 feet 90

feet.
90·720 = 90·7)281·0(·3098 of an inch.
2721

··8900
8163

·7370
7256

·114

Adopted mean pressure for altitude of 281 feet . . .	29·860
Correction to reduce to sea-level	+ 310
At sea-level the mean pressure is	30·170 inches.

$$\text{As } \overset{\text{in.}}{90{\cdot}7} : 0{\cdot}1 :: \overset{\text{feet.}}{281} : = \frac{281 \times 0{\cdot}1}{90{\cdot}7} = 0{\cdot}310$$

Another method, based upon the theorem of Sir George Shuckburgh and the calculations of Regnault, has been described by Dr. Drew, of Southampton, who has constructed a table showing the height, in feet, of a column of air equivalent in weight to a column of mercury one inch in height, at different temperatures, under a pressure of thirty inches of mercury. This table is copied from Dr. Drew's "Practical Meteorology."

Temp.	Feet.	Temp.	Feet.	Temp.	Feet.	Temp.	Feet.	Temp.	Feet.
30	865·1	40	882·8	50	900·5	60	918·2	70	935·8
31	866·8	41	884·5	51	902·2	61	919·9	71	937·5
32	868·5	42	886·2	52	903·9	62	921·6	72	939·3
33	870·3	43	888·0	53	905·7	63	923·4	73	941·1
34	872·1	44	889·8	54	907·5	64	925·2	74	942·9
35	873·9	45	891·6	55	909·3	65	927·0	75	944·7
36	875·7	46	893·4	56	911·1	66	928·8	76	946·5
37	877·5	47	895·2	57	912·2	67	930·6	77	948·3
38	879·3	48	897·0	58	914·7	68	932·4	78	950·1
39	881·1	49	898·8	59	916·5	69	934·1	79	951·8

For any temperature above that given in the table, the addition of 1·7 feet for every degree; and for any temperature below that given in the table, the subtraction of 1·7 feet for every degree, will give the factor required.

To work out the addition required to reduce to sea level, let T represent the tabular number opposite the temperature of the air, z the reading of the barometer at f feet above the sea-level, and x the correction required; then

$$x = \frac{f}{T} \times \frac{z}{30}$$

Dr. Drew gives the following practical example:—The barometer being 29·500 inches, the temperature being 50°, and the height above sea-level 60 feet?

$$x = \frac{60}{900{\cdot}5} \times \frac{29{\cdot}5}{30} = 0{\cdot}065 \text{ correction required.}$$

$\therefore$ 29·500 + 0·065 = 29·565 inches (the pressure reduced to the sea-level).

Thermometer Reductions.—To find the mean temperature for the month of December, 1855, from observations made at 9 A.M. and 10 P.M., and from self-registering thermometers.

Sum of all the readings made at 9 A.M. 10915; and at 10 P.M. 11017.

31)10915(	35°·2 mean at 9 A.M.	31)11017(	35°·5 mean at 10 P.M.
93	+ 0°·9 cor. for diurnal range.	93	+ 0°·5 correction for diurnal range.
161	36°·1 approx. mean for month.	171	36°·0 approx. mean for month.
155		155	
65		167	
62		155	
3		12	

Sum of all the readings of a self-registering minimum thermometer, 9365; and maximum thermometer, 12759.

31)9365(	30°·2 mean minimum temp.	31)12759(	41°·2 mean maximum temp.
93	+ 0°·2 index error.	124	— 0°·2 index error.
65	30°·4 corrected for index error.	35	41°·0 corrected for index error.
62		31	
—		49	
		62	
		— 13	

30·4 mean minimum corrected.
41·0 mean maximum corrected.

2)71·4 sum of the two series.

35°·7 mean of the two series.
0·0 correction of diurnal range.

35·7 approximate mean from self-registering instruments.
36·1 approximate mean from hourly observations at 9 A.M.
36·0 approximate mean from hourly observations at 10 P.M.

3)107·8 sum of the three series.

35°·9 adopted mean temperature for December, 1855.

To find the mean temperature of the wet bulb thermometer, for the month of December, 1855, from daily observations made at 9 A.M., and 10 P.M.

Sum of all the readings at 9 A.M., = 10509; at 10 P.M., = 10658.

31)10509(	33°·9 mean at 9 A.M.	31)10658(	34°·4 mean at 10 P.M.
93	+ 0 ·6 cor. for diurnal range.	93	+ 0 ·2 cor. for diurnal range.
·120	34 ·5 approximate mean.	·135	34 ·6 approximate mean.
93		124	
·279		·118	
279		124	
...		—..6	

Approximate mean from observations made at 9 A.M. = 34 ·5
" " " " " at 10 P.M. = 34 ·6

Sum of the series . . . . 2)69 ·1
Adopted mean temperature of the wet bulb . . = 34°·5

To find the mean temperature of evaporation.

Adopted mean temperature of the air from dry bulb . . = 36·0
Adopted mean temperature of the wet bulb . . . = 34·5

Difference . . . . = 01·5
Adopted mean temperature of air . . . . . . = 35·9

Difference, or mean temperature of evaporation . . 34·4

To find the mean temperature of the dew-point, the mean dry bulb* being 35°·8, and the mean wet bulb 34°·5.

Example 1.—In the hygrometrical table for 35°,

The dew-point opposite to 34° wet bulb is . . 32·4 . 32·4
The dew-point opposite to 35° wet bulb is . . 35·0

Difference on the increase in dew-point for an increase of 1° in wet . . . . . . 2·6
Proportional part of the increase for 0°·5 is . . . . . . + 1·3

Temperature of the dew-point corresponding to 35° dry, and 34°·5 wet, is 33·7
In the fourth column the decrease of dew-point for an increase of 1° in the dry bulb is — 1°·5, the proportional part for 0·8° is . — 1·2

The adopted temperature of the dew-point for 35°·8 dry, and 34°·5 wet, is = 32·5

Example 2.—To find the mean temperature of the dew-point for the month of December, 1855, dry bulb being 36°·0, and wet bulb 34°·5.

In the hygrometrical table for 36°,

The dew-point opposite to 34° wet bulb is . . 31·0 . . 31·0
The dew-point opposite to 35° wet bulb is . . 33·5

Difference . . . . 2·5
Proportional part of the increase for 0°·5 is . . . . . + 1·2

Mean temperature of dew-point . . . . = 32·2

The same tables, and the same manner of reduction, will find "the elastic force of vapour," "the weight of vapour in a cubic foot of air," "the additional weight required to saturate a cubic foot of air," and the "degree of humidity." To render the tables clear, one example of each will be worked out for a temperature of 35°·8 dry bulb, and 34°·5 wet bulb.

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* The hourly readings of the thermometer, which are made at the same time as those of the wet bulb, are called the 'dry bulb.'

To find the elastic force of vapour of the temperature of 35°·8, the wet bul being 34°·5.

In the hygrometrical table for 35°,

	Inch	Inch
The elastic force of vapour opposite to 34° wet bulb is	0·184	0·184
The elastic force of vapour opposite to 35° wet bulb is	0·204	
Difference, or the increase for an increase of 1° in wet	0·020	
Proportional part of the increase for 0°·5 is		+ 0·010
Elastic force of vapour corresponding to 35° dry, and 34°·5 wet is		0·190
In the 6th column, the decrease of the elastic force of vapour for an increase of 1° in the dry bulb, is — 0·010; the proportional part for 0°·8 is		— 0·008
Mean elastic force of vapour		= 0·182

To find the whole amount of water in a vertical column of the atmosphere, *i.e.* from the surface of the earth to the top of the atmosphere.

This is found by multiplying the elastic force of vapour by the constant 1383.

1383 constant.
182

2766
11064
1383

2·51706 inches.

Thus the whole amount of water in a vertical column of the atmosphere, if precipitated on the earth at one time, would be in this instance 2·5 or 2½ inches.

To find the weight of vapour in a cubic foot of air.

In the hygrometrical table for 35°,

	Grains.	Grains.
The weight of vapour in a cubic foot of air opposite 34° wet bulb is	2·1	2·1
The weight of vapour in a cubic foot of air opposite 35° wet bulb is	2·4	
Difference, or the increase in weight of vapour for an increase of 1° in wet is	0·3	
Proportional part of the increase for 0°·5		+ 0·1
Weight of vapour in a cubic foot of air corresponding to 35° dry and 34°·5 wet is		2·2
In the 8th column, the decrease of weight of vapour for an increase of 1° in the dry bulb is 0·2, the proportional part for 0°·8 is		— 0·2
The adopted weight of vapour for 35°·8 dry and 34°·5 wet is		2·0

To find the additional weight of vapour required to saturate a cubic foot of air.

In the hygrometrical table for 35°,

The dry bulb being 35°·8 and the wet bulb 34°·5.

Additional weight of vapour required to saturate a cubic foot of air opposite 34° wet bulb is . . . . Grain. 0·3 . . Grain. 0·3

Additional weight of vapour required to saturate a cubic foot of air opposite 35° wet bulb is . . . . 0·0

Difference, or the decrease in amount required to saturate a cubic foot of air for an increase in 1° in wet bulb is 0·3

Proportional part of the decrease for 0°·5 . . . . — 0·2

Additional weight of vapour required to saturate a cubic foot of air corresponding to 35° dry and 34°·5 wet is . . . . = 0·1

In the 10th column, the increase in the weight of vapour required to saturate a cubic foot of air for an increase in 1° dry is + 0·3, the proportional part for 0°·8 is . . . . + 0·2

The adopted additional weight of vapour required to saturate a cubic foot of air for 35°·8 dry and 34°·5 wet is . . . . = 0·3

To find the degree of humidity, the temperature being 35°·8 and the wet bulb 34°·5, complete saturation = 100.

In the hygrometrical table for 35°.

Degree of humidity opposite 34° wet bulb is . . . . 90 . . 90

Degree of humidity opposite 35° wet bulb is 100

Difference, or the increase of humidity for an increase of 1° in wet is 10

Proportional part of the increase for 0°·5 is . . . . + 5

Degree of humidity corresponding to 35° dry and 34°·5 wet is . . 95

In the 12th column, the increase in the degree of humidity for an increase of 1° in the dry bulb is 9, the proportional part for 0°·8 is . . — 7

Adopted degree of humidity for 35°·8 dry and 34°·5 wet is . . . = 88

To find the weight of a cubic foot of air, the mean pressure of the barometer being 29·742 inches, dry bulb 35°·8, and wet bulb 34°·5.

In the hygrometrical table for 35°.

In column 13, the weight of a cubic foot of air (the barometer being 29·0 inches) opposite 34° wet is . . . . Grains. 543·4

In column 14, the decrease of weight for an increase of 1° in dry is — 1°·1, the proportional part for 0°·8 is . . . . — 0·9

542·5

In column 14, the increase of weight for an increase in the reading of the barometer for one inch is + 18°·7 grains.

Opposite 7 in the table, under 18°·7 in last column, is . . . . 13·1

Opposite ·04 in the table, in right-hand corner of the page, is . . 0·7

The adopted weight of a cubic foot of air is . . . . . . 556·3

To find the mean pressure of dry air, or that due to the gases when separated from the water contained in the air.

Subtract the adopted elastic force of vapour (which is the pressure of the water contained in the air) from the adopted pressure of the barometer.

Example.—If the mean pressure of barometer is . . .	= 29·742 inches,
And the elastic force of vapour is	= 0·186 inch,
The pressure of dry air (of that due to the gases) will be .	= 29·556 inches.

To find the monthly range of temperature, &c., deduct the coldest temperature from the hottest, observed during the month. Thus—

Hottest temperature	50°·8
Coldest temperature	12°·0
Monthly range of temperature . . .	38°·8

To find the mean daily range of temperature, deduct the mean of all the readings of the minimum thermometer from the mean of all the readings of the maximum thermometer.

Mean maximum temperature . . .	41°·0
Mean minimum temperature . . .	30°·4
Mean daily range of temperature . . .	= 10°·6

To find the amount of terrestrial radiation, deduct the reading of a minimum thermometer placed on the grass from that of a minimum thermometer placed four feet above the grass. Thus—

Greatest cold four feet above the grass . .	36°·5
Greatest cold on the grass	27°·8
Amount of terrestrial radiation . . .	= 8°·7

To find the amount of solar radiation, deduct the reading of a maximum thermometer (with a blackened bulb) placed in full sunshine from the greatest heat in shade. Thus—

Greatest heat in sunshine . . .	= 59°·3
Greatest heat in shade	= 34°·1
Amount of solar radiation	25°·2

To find the greatest heat and greatest cold of the wet bulb thermometer. This is obtained by attaching the muslin and cotton conductor to *self-registering* thermometers, instead of to the ordinary thermometer. Thus—

Greatest cold of dry bulb .	34°·0	Greatest heat of dry bulb .	46°·7
Greatest cold of wet bulb .	32°·5	Greatest heat of wet bulb .	42°·8
Difference .	°·5	Difference	3°·9

To find the range of temperature of the wet bulb thermometer, deduct the greatest heat from the greatest cold recorded. Thus—

Greatest heat . . . . . . 42°·8
Greatest cold . . . . . . 32°·5

Range of wet . . . . . . 10°·3

To find the mean amount of cloud.

This, by practice, is accomplished very accurately by estimation, 10 being considered an overcast sky and 0 a cloudless sky. It must be remembered, in making the estimate, that, with a partially covered sky, the forms of the clouds, and the space they cover, are only correctly seen in the zenith; the nearer the horizon we approach, the more obliquely do we look upon them; and, consequently, near the horizon the sky will appear to be more overcast than it is in reality. The observer's judgment should, therefore, be more especially confined to the upper half of the sky.

Observations made at 9 A.M. and 10 P.M., December, 1855.

Sum of all the estimates at 9 A.M., 2158; and at 10 P.M., 2024.

31)2158(6°·96 mean at 9 A.M.
186 — 0°·1 cor. for diurnal range.

298 6°·86 corrected amount.
279

190
186

. . 4

31)2024(6°·5 mean at 10 P.M.
186 + 0°·2 correction for diurnal range.

164 6°·7 corrected amount.
155

. . 9

corrected reading at 9 A.M. 6°·9
corrected reading at 10 P.M. 6°·7

sum of the two series 2)13°·6

adopted mean amount of cloud . . 6°·8

Classes of Clouds.—Mr. Luke Howard, the well-known meteorologist, was the first to classify the clouds; and these classes have been very conveniently abbreviated by Mr. Glaisher. They are—

Cirrus = ci . . . feathery-looking, the most lofty cloud.
Cumulus = cu . . . mountainous-looking.
Stratus = st . . . the ground-cloud—forms at sunset and disappears at sunrise.
Cirro-cumulus = ci-cu . . rounded masses, or woolly tufts.
Cirro-stratus = ci-st . . horizontal masses.
Cumulo-stratus = cu-st . . an accumulation of cumuli, sometimes fungus-shaped.
Nimbus = ni . . . rain-cloud.
Scud = sc . . . broken, flying nimbi.

In recording the class of clouds, the interest is increased by also recording the direction in which the clouds are moving, the colour of the clouds, and their height and velocity. The height may be conveniently estimated by supposing 6 to represent very high clouds, and 0 those floating along the ground; he velocity, by supposing 6 to represent those moving at the greatest speed, and 0 those motionless.

To find the mean daily amount of rain. Whole amount of rain collected during the month of December, 1855, 0·764 of an inch.

31)0·764(0·025 of an inch being the mean daily amount.
62
144
155
— 11

To find the mean daily amount of evaporation for December, 1855. Whole amount evaporated, 0·610 inch.

31)0·610(0·0197
31
300
279
210
217
— · · 7 Therefore, 0·020 inch is the daily amount.

To find the amount of evaporation in rainy weather.

Suppose 1·000 inch of water is placed in the evaporator, and that a rain-gauge, of the same diameter as the evaporator, and placed at the same level, has recorded 0·510 inch of rain since last observation, whilst the evaporator is found to contain 1·444 inches. Then

1·444 inches the amount in evaporator.
0·510 amount of rain.
0·934 difference.
1·000 amount of water placed in the evaporator.
0·066 of an inch is the amount due to evaporation.

To estimate the force of wind.

Anemometers being expensive, the majority of meteorologists estimate the wind's force. It is recommended that 0 represent a calm and 6 a hurricane, for this estimate is easily converted into lb. pressure on the square foot; the square of the estimate will represent the lb. pressure on the square foot; viz.—

0 ≡ 0 lb.
1 ≡ 1
2 ≡ 4
3 ≡ 9
4 ≡ 16
5 ≡ 25
6 ≡ 36

By practice a near approximation to the truth can be obtained.

Mr. Belville, in his Manual of the Barometer, gives the following concise table of factors for deducing the temperature of the dew-point, from the temperature of the air and that of the temperature of evaporation; this table originally appeared in the Greenwich Magnetical and Meteorological Observations for 1844. The dew-point deduced in this manner, is a close approximation to that obtained by Glaisher's hygrometrical tables.

Temperature.	Factor.	Temperature.	Factor.	Temperature.	Factor.
28° to 29°	5·7	34° to 35°	2·6	55° to 60°	1·9
29° „ 30°	5·0	35° „ 40°	2·4	60° „ 70°	1·8
30° „ 31°	4·6	40° „ 45°	2·3	70° „ 80°	1·7
31° „ 32°	3·6	45° „ 50°	2·2	80° „ 85°	1·6
32° „ 33°	3·1	50° „ 55°	2·1	85° „ 90°	1·8
33° „ 34°	2·8				

Multiply the difference between the wet and dry bulb by the factor corresponding to the temperature of the dry bulb, and subtract the product from the dry bulb, which will be the temperature of the dew-point. T the temperature, W wet bulb, f factor, x the product, and D the dew-point.

$$T - W \times f = x$$
$$\text{and } T - x = D.$$

Thus:—temperature 50 and wet bulb 45°,

$$50 - 45 = 5$$
$$5 \times 2{\cdot}1 = 10{\cdot}5$$
$$50 - 10{\cdot}5 = 39^\circ{\cdot}5 \text{ the dew-point.}$$

By Mr. Glaisher's tables this dew-point is 39°·7.

Recommendations and Precautions.—Preserve, as much as possible, the continuity of the observations. It is desirable not to change the positions of the different instruments, nor even to alter the method of reading and registering. As it is probable when two persons are employed in taking observations, that each will read slightly different, a series of simultaneous readings should be made, in order to find the personal error of the observers. If, from any cause, the continuity of the register should be broken, on no account attempt to fill the blank so caused by estimation. Be punctual to the hours determined upon for observations, and read off the instruments in the same way every day; by doing this, it is less likely that an observation of any one instrument shall be overlooked. It is convenient to rule and mark off the form of observation upon a slate, to be transferred to the observatory book, after the whole observations have been made. Before calculating the means, it is recommended to examine each column, to ascertain that no evident error of entry has been made;—an inch in the reading of the barometer is a common error. The maximum reading of the thermometer is also sometimes entered in the wrong column, being placed in that of minimum; and *vice versa.* Decimal arithmetic should always be used.

Before fixing the barometer, it should be ascertained that the space above the mercury is free from air. Incline the instrument slightly from its vertical position; if the mercury, in striking the upper end of the tube, produce a sharp rap, the vacuum is perfect; if the tap be dull, or not heard, there will be air above the mercury, which must be driven into the cistern by inverting the instrument and then tapping it gently. If the observer does not succeed in producing this sharp report by tapping, the instrument will require the aid of the maker. In fixing the barometer, adjust the tube vertically by the aid of a plumb-line. In reading the instrument, place the eye on the exact level of the top of the column of mercury, so that each side of the index, and the top of the column, shall be in the same horizontal plane.

The thermometers should be protected from rain; and in making a reading the observer should do it quickly, and whilst doing so avoid touching, breathing on, or in any way warming the thermometer by the near approach of his person.

Sir John Herschel recommends that every meteorologist should take an observation every hour throughout the twenty-four, on four stated days in the year; viz. March 21, June 21, September 21, and December 21, excepting when one of these days occurred on Sunday, then to substitute for this date the 22nd. The observations to commence at 6 A.M., and terminate at 6 A.M. next morning.

Thermometers should be frequently compared with a standard instrument, in order to ascertain whether the freezing-point has remained at the temperature as marked off on the scale. It is a well-known fact that the zero point moves, ascertained from the circumstance that after a great change in temperature, the glass requires a considerable time to enable it to return to its normal condition.

Newman's Standard Barometer form of Rutherford's thermometer differs in the following manner from that already described:—A platinum tube is drawn over a steel wire, which is said to prevent the index from fixing by oxidation. Not having had this instrument at work, I am unable to speak of its advantages from practice. An improvement has also just been accomplished with Negretti and Zambra's rain-gauge. I conceived it was liable to have the water in the canal surrounding it emptied into the graduated glass with the rain to be measured. At my suggestion this has been altered; the canal is now placed much lower down the gauge, and there seems no possibility of an erroneous measurement. The gauge may, therefore, be now said to be perfect.

Of late years two new barometers have appeared,—viz. the *Aneroid* and *Burdon's.* They are both good indicators of atmospheric pressure, but cannot take the place of a Standard barometer. In the first place, the metal is influenced by temperature; and in the second, there is a chance of the box of the *Aneroid* and the tube of the *Burdon* losing their vacuum. As a household instrument they are preferred to the common wheel-barometer; but I have not had an opportunity of testing their respective merits.

At the time of the Great Exhibition of 1851, when the jury were examining the meteorological instruments, a remark was made that a more perfect maximum and minimum thermometer was required, both of which should be *mercurial;* and on the counsel-medal being presented to Messrs. Negretti and Zambra, their attention was called to this suggestion. Not many months had elapsed before the *patent maximum* was produced, and within four years the *patent minimum.* The latter was sent for trial to a few meteorologists six months ago, and one of these instruments came to the Beeston Observatory. The experiments made with it have been perfectly successful; indeed, so much so, as to have astonished all who have used it. The ordinary minimum thermometers do not work uniformly with this new instrument, owing to the alcoholic vapour contained in the upper portion of their tube, and which is more or less developed according to the temperature. Two such important improvements have not taken place since the invention of the thermometer; and it is creditable to them that both should have emanated from the same persons who invented the enamelling of fine tubes.

Professor C. P. Smyth, the Astronomer Royal of Scotland, has caused the electric telegraph to work in mete orology. A wind dial at the one extremity of a wire is made to turn another simultaneously at the other extremity. The time will come when all large towns will have buildings devoted to these observations, and in which dials will be seen in every direction, some labelled Edinburgh, others Liverpool, Dublin, London, Paris, York, &c., and where the public will be enabled to see the direction of the wind at the same instant at most remote places. The benefit to the farmer and the navigator will be great from such an arrangement. Were such stations to be thickly scattered throughout the country, every change of wind, and every shower, could be traced and recorded, and a knowledge imparted, the benefit of which could not be sufficiently appreciated.

To be enabled to announce the approach of a thunder-storm, however, at a time when the sky is free from clouds, and to ascertain its speed so as to foretel when it may be expected in any given place, would afford the farmer an opportunity of so benefiting by the information that he would gladly pay a small rate in order to take advantage of it. The world is slow in appreciating any new invention until its usefulness is experienced; let us, however, hope that one or two such stations may speedily be established, and we venture to predict that, at no very distant period, every conspicuous eminence will have its *road station*, to impart the information collected at the principal establishments, where the electric wires are made to record the changes as they occur. Our knowledge of meteorology would then make rapid advances; laws of the weather would be unfolded; and predictions of coming changes, which are now mere guesses, as often wrong as right, would be based upon truth.

It is a common expression that nothing is more changeable than the weather; yet that all these changes are governed by certain laws, is as certain as that gravitation binds the heavenly bodies together. Were there no laws to keep the changes within certain limits, we should at one period experience cold, and at another heat so intense, that existence would be intolerable; the earth would be deluged with rain, and anon parched up with drought; the sky would be cloudy for months, perhaps years together, and then cloudless for as long a period; in short, the laws which govern the weather keep the extreme changes within proper bounds.

As the more complicated machinery of a meteorological observatory cannot be expected to be found except in our principal establishments, it will be requisite to mention what instruments are absolutely necessary for the ordinary observer. These are—

A standard barometer.
A wet and dry bulb thermometer.
A maximum and a minimum thermometer.
A rain-gauge.
An evaporator.
A thermometer-stand.
A wind-vane.

These would cost from £17 to £30, according to which barometer was selected. The following additional instruments are also desirable (the expense would be £4 or £5):—The solar and terrestrial radiation thermometers, Glaisher's electrometer, an ozonometer, and an extra rain-gauge.

Snow Gauge.—The gauge used here consists of a thin metal cylinder, eight inches in diameter and twelve inches deep, graduated upon one side to a quarter of an inch. This cylinder will penetrate through the snow, scarcely disturbing it, and the depth in inches is at once seen. By careful manipulation, if the cylinder is turned round, all the enclosed snow can be lifted from the ground. It is desirable to melt it in a wide-mouthed bath, being previously corked to prevent evaporation, as it frequently happens that snow is blown out of the mouth of the rain-gauge before it has had time to melt; consequently, the result of melted snow, as shown by the rain-gauge, will be too little in amount.

Calendar of Nature.—Every meteorologist should endeavour, as much as possible, to record the arrival and departure of migratory birds, the dates of trees coming into and losing their leaves, the blooming of plants, the ripening of fruit and seeds, the building of birds'-nests, the first appearance of various insects, diseases amongst animals and plants, the appearance of abundance or otherwise of crops of fruit, corn, &c. If such registers were extensively kept and carefully recorded, the effect of the weather upon the animal and vegetable kingdoms would be well seen. It is extremely desirable that every precaution should be taken, in order that, year after year, the same object should be the special one on which the remarks are based, and that one species is not mistaken for another. The following examples will show that it is essential to use the utmost care:—

First, "the elm is said to lose its leaves on a certain date." Such an observation is useless. It is requisite to mention the particular kind of elm; thus, the broad-leaf elm is the first tree to become leafless, which it frequently does in September; the Siberian elm, on the contrary, will remain green after all other trees have become leafless,—sometimes it is in leaf as late as December. It will also be found that the same species, in a group whose boughs touch each other, will come into leaf at different dates. In no tree is this more strikingly exhibited than in the beech; two beeches growing close together may be seen to vary a couple of weeks in their period of coming into leaf. The age of the tree also causes a difference to occur. In the different kinds of lilacs and laburnums, there will be a range of some days in their time of coming into bloom. Amongst herbaceous plants, none that have been transplanted should be the objects of record.

In migratory birds, the swallow, sand-martin, and white-martin will appear, at different dates, in places so near together, that a flight of one minute would enable them to reach it. The swallows are seen near the Trent some days previous to coming here, although only a mile distant. The cuckoo and the landrail are invariably heard earlier in the season three or four miles west of this place.

Amongst the observations on the ripening of fruits, the strawberry will serve as an example: the variety called black prince will be ripe before Kean's seedling, Kean's seedling before British Queen, and British Queen before the Elton pine.

In entering the flowering of plants, it is advisable to give the dates when they first come into bloom, as well as the dates when in full glory of flower, and when the blooming is over.

The most conspicuous objects should be entered in a book, space being left which may occupy the remarks for several years. Every observer who, for a course of years, pursues such a course of observation, will find that he has done some good to his kind; and if any plan could be devised for recording and bringing together such a body of observations, they would form a valuable collection of facts for the naturalist and meteorologist to generalize upon.

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