METEOROLOGY

INTRODUCTORY TEXT-BOOK

OF

METEOROLOGY

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PREFACE.

In this Introductory Treatise the leading facts and principles of Meteorology are stated in a simple and connected form. As the atmosphere is the subject with which the science deals, the distribution of its mass over the globe, or its pressure, is particularly described and illustrated by Charts. The motions of the atmosphere, or the prevailing winds, are detailed at length; and it is farther shown that these are the simple result of the relative distribution of its pressure—the direction and force of the prevailing winds being the flow of the air from a region of higher towards a region of lower pressure, or from where there is a surplus to where there is a deficiency of air.

On this broad and vital principle Meteorology rests. It is thus of universal application throughout the science, in explanation not only of prevailing winds, but of all winds, and of weather and weather changes generally. By it the climates of the different regions of the earth may be ascertained and explained; for climate is practically determined by the temperature and moisture of the air, and these are dependent on the prevailing winds, which come charged with the temperature and moisture of the regions they have traversed.

Hence the value of Meteorology as an instrument and element of education. The exposition of the dependence of its several parts on each other may be turned to account as a mental discipline, higher than results from the collecting and assorting of natural objects; whilst the broad generalisations now arrived at group into easily-remembered forms the details of this great branch of terrestrial physics, a knowledge of which is indispensable to the student of Physical Geography and Geology.

Since, as is here pointed out, the distribution of the earth's atmosphere depends on the geographical distribution of land and water in their relations to the sun's heat in different seasons, and since the relative pressure determines the direction and force of the prevailing winds, and these in their turn the temperature, moisture, and rainfall, and in a very great degree the currents of the ocean, it is evident that we have here a principle applicable not merely to the present state of the earth, but to different distributions of land and water in past time. It is only by the aid of this principle that any rational attempt, based on causes having a purely terrestrial origin, can be made in explanation of those glacial and warm epochs through which the climates of Great Britain and other countries have passed. Hence the geologist must familiarise himself with the nature of the climatic changes which necessarily result from different distributions of land and water, especially those changes which affect most powerfully the vegetable and animal life of the globe.

EDINBURGH, *May* 1871.

NOTE ON CONSTRUCTION OF THE CHARTS.

The ISOBARIC CHARTS (Plates I., II., and III.) are taken from the author's Paper published in the '*Transactions of the Royal Society of Edinburgh*,' vol. xxv. p. 575, which may be referred to for fuller information on this subject. The Arrows showing the Prevailing Winds are taken from the same paper, supplemented by additions obtained from '*Pilot Charts of the Atlantic*,' published by the Admiralty, and '*Hand-Book of Physical Geography*,' by Keith Johnston, junior. As no Winds are delineated on the Charts but such as are based on trustworthy averages, large portions of the globe, especially the Pacific and Indian Oceans, are necessarily left blank.

The ISOTHERMAL CHARTS (Plates IV., V., and VI.) have been drawn from Observations of Mean Temperature, which have been obtained from the following among other sources:—A very large selection from Dove's '*Klimatologische Beiträge*,' and his other Papers on Temperature; Dr Wojeikof's Mean Temperature of Places in the Russian Empire; Meteorological Reports of the Director-General, and of Observations made at Stations of the Royal Engineers; Blodget's Climatology of the United States in the '*Army Meteorological Register*,' 1855; Sir John Richardson's Temperatures of the Arctic Regions, and those of Sir J. C. Ross, and others, of Antarctic Regions; Glaisher's '*Meteorology of India*;' the invaluable Abstracts of Observations made at places in distant parts of the globe, published at various times by Dr Jelinek, Dr Hann, Dr Buys Ballot, P. Secchi, and the Smithsonian Institution; and the Publications issued by the Meteorological Societies, Institutes, or Observatories of Scotland, England, Norway, Sweden, Russia, Austria, Prussia, Denmark, Holland, Belgium, Switzerland, France, Spain, Portugal, Italy, Greece, Algiers, Canada, United States, St Helena, Cape of Good Hope, Mauritius, India, Australia, Tasmania, New Zealand, &c. &c.

For a proper comparison of temperatures, Observations made for, or reduced to, the same years, were, so far as possible, made use of in drawing the Isothermals for the same country or region. Thus, the same 13 years were adopted for the British Islands; the past 10 years for Norway; 9 years, ending 1867, for Sweden; 30 years for Russia; 20 for Prussia; 18 for Austria; 5 years, ending 1866, for Tasmania; 5 years, ending 1870, for New Zealand, &c. The averages for these years were further compared with longer averages of places in the same and surrounding regions, where such averages were available.

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LIST OF CHARTS.

METEOROLOGY.

CHAPTER I.

HISTORY AND SCOPE OF METEOROLOGY.

1. METEOROLOGY (Gr. *meteōros*, lofty, and *logos*, discourse) is the science of the weather. The term was originally applied to the consideration of all appearances in the sky, astronomical as well as atmospherical; but it is now restricted to that department of natural philosophy which treats of the phenomena of the atmosphere that relate to weather and climate, and the laws to which they are subject.

2. From the nature of the subjects which make up the science of meteorology, we may infer that they occupied men's minds from a remote antiquity. The splendid and ever-varying panorama of the sky, and the variations of temperature through the days and the seasons, together with the other atmospheric changes constituting weather which affect in so powerful a manner the necessities and comfort of man, are of a nature well fitted to arrest his attention. From the time spent in the open air during the early ages, and from the imperfect protection then afforded against the inclemency of the seasons, the appearances which were found by experience to precede changes of weather were recorded and handed down in the sententious form of weather proverbs. In this way many valuable facts were ascertained and passed current from hand to hand, so that there is perhaps no science of which more of the leading facts and inferences have been so long incorporated into popular language. But Meteorology remained in a dormant condition for ages, and no progress

was made till proper instruments were invented for making real Observations with regard to the pressure, the temperature, the humidity, and the electricity of the atmosphere.

Invention of Meteorological Instruments.

3. *The Barometer.*—The invention of the barometer (Gr. *băros*, weight, and *metron*, a measure) by Torricelli in 1643, and the experimental proof of the weight of the atmosphere by means of it, a few years after, by Pascal, was undoubtedly the first step in the progress of meteorology toward the rank of a science. This memorable discovery, in disclosing, by the elevations and depressions of the mercurial column, what passes in the more elevated regions of the atmosphere, largely extended our knowledge of this element. The value of the barometer as an indicator of weather gave an additional impetus to the study of the science.

4. *The Thermometer.*—The invention of the *air-thermometer* (Gr. *thermē*, heat, and *metron*, a measure) by Sanctorio of Padua, in 1590, ranks second in importance in the science, since it pointed to an exact determination of the temperature of the air, which is by far the most important element of weather in its relation to our welfare and interests. Improvements were made on the instrument by an Italian artist about 1655, who used wider tubes, terminating in bulbs, and filled with alcohol; and by Römer, who used mercury, and, starting from the melting-point of ice, divided the tube into degrees, each intended to represent the 100,000th part of the bulb.

5. But the great improver of the thermometer was **Fahrenheit**. In the year 1714 he constructed thermometers, employing two fixed points in graduating them—one indicated by the melting-point of ice, and the other by the boiling-point of water at the mean pressure of the atmosphere. The former point he called 32°, the latter 212°. Any improvements that have since been made on thermometers, such as self-registration, are merely matters of convenience or detail. In so far as concerns the principle of construction, the thermometer may be regarded as having come perfect from the hands of Fahrenheit, since the instrument he invented can be reproduced at pleasure, the indications being in all cases absolutely the same. This great invention soon bore fruit. Small portable thermometers were constructed by Fahrenheit, which were taken by travellers and medical men to different parts of the world. By the observations made with these, the comparative temperatures of different countries became known.

and the exaggerated accounts of travellers with regard to the excessive heat and cold of foreign countries could be valued at their proper worth. Thermometers were further turned to excellent account in the arts of brewing and horticulture, and to objects affecting public health, and thus substantial additions were made to our comforts and luxuries.

6. *The Hygrometer.*—The expansion and contraction of vegetable and animal substances with the varying quantity of moisture in the atmosphere, would appear to have suggested the idea of the hygrometer (Gr. *hygros*, wet, and *metron*, a measure), an instrument of great value in indicating the quantity of vapour in the air, and, inferentially, the changes of weather resulting from such variation. These substances were used as hygrometers by the earlier meteorologists, especially by De Saussure, whose ingenious and extensive researches, conducted with the simple hair hygrometer, entitle him to be considered the founder of this department of meteorology.

7. From the period of the invention of these instruments, the number of meteorological observers was greatly increased, and a large body of well-authenticated facts began to be collected. The climates of particular parts of the earth were inquired into, and compared together; and the science made great and rapid advances by the investigations undertaken by distinguished philosophers into the laws which regulate atmospheric phenomena.

Important Discoveries and Discussions.

8. The theory of the *Trade-Winds* was first propounded by George Hadley in the 'Philosophical Transactions' for 1735; and it may be mentioned as a curious fact that it remained altogether unnoticed for half a century, when it was independently arrived at by Dalton, and published in his essays.

9. The publication of Dalton's 'Meteorological Essays' in 1793 marks an epoch in meteorology. It was the first instance of the principles of philosophy being brought to bear on the explanation of the complex phenomena of the atmosphere. The idea that vapour is an independent elastic fluid, and that all elastic fluids, whether alone or mixed, exist independently; the great motive forces of the atmosphere; the theory of winds, and their relation to the barometer, to temperature, and to rain; observations on the height of clouds, on thunder, and on meteors; and the relations of magnetism and the aurora borealis,—are some of the important questions discussed in these remarkable essays.

10. One of the most interesting and fruitful subjects of inquiry that long engaged the attention of meteorologists was the origin of *Dew*. Pictet of Geneva, Le Roy of Montpellier, Six of Canterbury, and Patrick Wilson of Glasgow, contributed valuable observations and experiments which did much to elucidate the subject. Of these, the first place is unquestionably due to Patrick Wilson, whose 'Memoirs of Certain Great Frosts at Glasgow,' about 1780, show a fidelity of observation, and a skill in interrogating nature, which have rarely been surpassed. But it was reserved for Dr Wells to arrange the different observations into a coherent whole, and account for them by the theory of dew he propounded—a theory so just and so complete that succeeding observation and inquiry have only confirmed it. 'The Theory of Dew' was published by him in 1814, and must always be regarded as one of the greatest contributions to meteorology.

11. In 1823 Daniell published his 'Meteorological Essays and Observations,' in which he discussed in a masterly manner the hygrometry of the atmosphere, solar and terrestrial radiation, the barometric measurement of heights, the trade-winds, evaporation, and natural and artificial climates. While in all these departments he contributed largely to our knowledge, his attention was most successfully turned to the investigation of the hygrometry of the atmosphere, which is indebted to him more than to any other philosopher.

12. A most important addition to our knowledge of the vapour of the atmosphere was made in 1862 by Professor Tyndall in his experiments on radiant heat, especially as regards the gases, by which it is shown that the vapour of water exerts extraordinary energy as a radiant and an absorbent of heat. As a consequence, the vapour dissolved in the air serves as a covering or protection to the earth, shielding it from the sun's heat by day, and from the chilling effects of its own radiation during night. It can only be by a more intimate knowledge of the relations of atmospheric vapour to heat and pressure that many questions in meteorological science will be explained.

13. Humboldt's treatise on 'Isothermal Lines' (Gr. *isos*, equal; *thermē*, heat), published in 1817, marks an important epoch in experimental meteorology. Dové has since continued the investigation, and in his splendid work 'On the Distribution of Heat on the Surface of the Globe,' gave charts of the world, showing the mean temperature for each month and for the year, together with charts of abnormal temperature. It is scarcely possible to over-estimate the value of this work; for, though to some extent the lines are hypothetical, there can be no doubt that

a close approximation to the march of temperature and its distribution over the globe through the year was laid down. The work has been carried out with greater fulness of detail by the Government of the United States of America, in the Charts of Temperature and Rainfall published in 'The Army Meteorological Register' for 1855. In these charts, the temperature and rainfall during the different seasons, for every part of the United States, are laid down from observations. Temperature Charts of the British Islands for the months and for the year have also been published by the Scottish Meteorological Society, constructed from the mean temperatures of 170 places.

14. In connection with terrestrial temperature, the laborious investigations cf Dové, Sabine, Buys Ballot, Jelinek, Hann, Quetelet, Hansteen, Mohn, Kupffer, Forbes, and Glaisher, in calculating the mean temperature of places for periods of five or of two days, or for each day of the year, deserve to be specially noticed. An examination of these mean daily temperatures brings out the interesting fact that, over extensive parts of the earth's surface, interruptions occur, at stated times in the year, in the regular rise and fall of temperature, thus pointing to widespread disturbing causes, the explanation of which will doubtless lead to a juster conception of the disturbing forces of the atmosphere.

15. In 1868, Charts showing by Isobaric Lines (Gr. *isos*, equal, and *bắros*, weight) the distribution of the mass of the earth's atmosphere, and by Arrows the direction of the prevailing winds over the globe, for the months and for the year, were published. By those charts, the motions of the atmosphere, and the proximate causes of these motions, were for the first time approximately stated, and an insight was thereby obtained into some of the more intricate problems of meteorology. As winds bring with them the temperature and vapour of the regions they have traversed, these charts may be regarded as furnishing the key to the climates of the globe, since the temperature and rainfall of the different seasons may be thus approximately known.

16. On the 15th of June 1752, Benjamin Franklin, by the happily-conceived experiment of flying a kite, identified lightning and electricity, thus giving an interest and an impetus to electrical observations. The brilliant discoveries which have recently been made on the mutual relations of electricity, magnetism, heat, motion, and the other forces of matter, lead us to indulge the hope that the application of these results to meteorology will be attended with discoveries equally brilliant and important.

Meteorological Societies and Storm-Warnings.

17. The establishment of Meteorological Societies during the last twenty-five years must also be commemorated as contributing in a high degree to the solid advancement of the science, which, more than any other, depends on extensive and accurate observations. In this respect the United States stand pre-eminent, the observers there numbering about 800. Great Britain is also well represented in the English and Scottish Societies, which together number about 150 observers. In Austria, Switzerland, France, Prussia, Italy, Russia, Norway, Sweden, Denmark, Belgium, the Netherlands, Spain and Portugal, Algeria, Cape Colony, India, and the Australasian colonies, meteorology is being widely cultivated. In Austria alone the number of stations is 118, and in Switzerland 83. Considerable attention has also been given to the rainfall in Great Britain and Ireland; and, chiefly through the great exertions of Mr G. J. Symons, London, about 1500 rain-gauges are now registering the rainfall of the British Islands.

18. A special object of meteorological inquiry is to ascertain the degrees of heat, cold, and moisture peculiar to different localities, and the usual periods of their occurrence, with a view to discover their effects on the health of the people, and on different agricultural products. With regard to questions of such general interest affecting the health and food of the people, these Societies have already collected much valuable information, which but for their aid could not have been obtained.

19. But perhaps none of the arts have benefited to so large an extent by the labours of meteorologists as navigation. The knowledge thereby acquired of the prevailing winds in different parts of the earth during the different seasons of the year, the region of calms, the parts of the oceans swept by devastating storms at particular seasons, and the laws of storms, has saved innumerable lives and much property; and by pointing out the quickest routes to be followed, has shortened voyages between distant countries. In connection with this department of the science, the name of Maury will always be remembered with gratitude for the signal service he has rendered to navigation. The good work thus begun by him has rendered intercourse among nations safer and more expeditious; and when future observation has supplied the materials requisite to enable us to correct the inevitable mistakes and fill up the blanks of his ocean charts, the benefits this celebrated meteorologist has conferred on the human race will more conspicuously appear.

20. *Prediction of Storms.*—Another fruit of the multiplication of meteorological stations is the prediction of storms and the foretelling of the weather. It is impossible to over-estimate the value of storm-warnings to the shipping interests. In the north temperate zone, observation shows that storms almost invariably come from some westerly point, and thence follow an easterly course. In the United States of America, it is easy to warn seaports of the approach of storms ; for as soon as a storm appears in the western States bordering on the Rocky Mountains, it may be intimated to the central office in Washington, followed in its march by the telegraph, and timely warning of its approach sent to the coasts which it will visit. The United States of America is thus in a favourable position for effectually carrying out a system of storm-warnings.

21. On the contrary, Great Britain, France, and the rest of Western Europe, are unfavourably situated to allow of timely warning being given of coming storms. If no warning be sent till the storm has made its appearance, it is too late for the western seaports. In Europe, however, stormy weather is accompanied by a diminution of atmospheric pressure, which, after traversing more or less of the Atlantic, arrives on the coast of Europe. The existence of this diminished pressure is made known by the barometer while the maximum depression is still at a considerable distance out in the ocean ; and collateral information, pointing to an advancing storm, may be obtained from the direction of the wind and the cirrus cloud. Here, then, we have the materials for foretelling the approach of storms on the west coast of Europe. For though we do not possess the same advantages towards arriving at the degree of certainty of the American predictions, and so of telegraphing to ports on the west coasts that a storm is *actually seen advancing on them*, yet from the premonitions afforded by the barometer, the wind, and the cirrus cloud, we can warn them to prepare for a storm likely to visit them. The giving practical effect to this idea constitutes the splendid contribution to meteorology made by Admiral Fitz Roy in February 1861, by the system of storm-warnings which, in its essential points, has since been generally adopted—a service which has entitled him to be considered as a public benefactor.

22. To ascertain the course storms usually follow, and the causes by which that course is determined, so as to deduce, from meteorological phenomena observed, not only the certain approach of a storm, but also the particular course it will take in its passage over Europe, is the first problem of meteorology. In carrying out this great work, the 'Bulletin International,' begun by Le Verrier,

published daily in Paris, if supplemented by additional observations from places in the British Islands, and in Northern, Eastern, and South-Eastern Europe, will furnish the required materials. This admirable publication, which must be regarded as the latest important step taken in the progress of meteorology, shows graphically the atmospheric pressure, and the direction and force of the winds, each morning over Europe, together with tables of temperature, rainfall, cloud, and sea disturbance.

23. In the schools of the United States of America, Meteorological Observations, and the keeping of Meteorological Registers, form a part of the common education of the people. Also in the higher schools of France, and some other European countries, systematic instruction is communicated on this subject. But in this country few even of the liberally educated classes are able to read from a vernier; they are ignorant of the use of the movable cistern of a barometer; they have not the elementary knowledge to give an intelligible interpretation to the fluctuations of the barometer as indicative of coming changes of the weather; and when required to send their barometers to a distance for repair, so ignorant are they of their construction, that they forward them by rail as ordinary parcels, thus almost to a certainty securing their destruction. This state of things is the necessary consequence of the general neglect which meteorology and science generally receive in our educational system. The objects of meteorology can never hold that place in the public mind to which they are entitled, till the science becomes, as in America, a recognised branch of education. When the law of storms begins to be generally understood, and, as a consequence, the value of observations of the barometer, of the direction of the wind, and of the appearances of the clouds, comes to be appreciated as heralding changes of the weather, we cannot doubt that this very practical age will take steps to provide for the instruction of the people in the elementary facts of meteorology, and in the use of the different meteorological instruments.

CHAPTER II.

THE WEIGHT OR PRESSURE OF THE ATMOSPHERE.

24. THE *Barometer* (Gr. *băros*, weight, and *metron*, a measure) is the instrument used for measuring the height of a column of mercury supported by the pressure of the atmosphere. From this height the weight of the atmosphere is ascertained. The fundamental principle of the barometer cannot be better illustrated than by Torricelli's experiment. Take a glass tube (fig. 1), about 33 inches in length, open at one end; fill it with mercury; and, closing the open end with the finger, invert it, and plunge the open end into a bowl (*c*) also containing mercury. The column will fall in the tube to about 30 inches above the surface of the mercury in the bowl, if the experiment be made near the level of the sea. The fluid is upheld in the tube by the air outside of it pressing on the mercury in the bowl; and since the one thus balances the other, it is evident that the mercurial column will serve as an accurate indicator of the varying pressure of the air. The space *a b* in the tube above the mercury is one of the nearest approaches to a vacuum that can be made. It is called the *Torricellian vacuum*.

Fig. 1.

25. The heights of the columns of two fluids in equilibrium are inversely as their specific gravities; and as air is 10,784 times lighter than mercury, the height of the atmosphere would be 10,784 times 30 inches, or nearly five miles, if it were composed of layers equally dense throughout. But since, from its great elasticity and the diminished pressure, air becomes less dense as we ascend, the real height is very much greater. At the height of 50 miles, the atmosphere is so rare that

the effect on the twilight is nearly inappreciable; but from the observations of the aurora and shooting-stars, it is inferred that there is still an appreciable atmosphere at a height of from 200 to 300 miles, or even greater.

26. Other fluids may be used in constructing barometers, which, being lighter than mercury, have columns proportionally longer. Thus, if water, which is nearly 14 times lighter than mercury, be used, the barometric column is about 35 feet long. The advantage *Water Barometers* might be supposed to possess in showing changes of atmospheric pressure on a large scale, is more than counterbalanced by a serious objection. The space in the tube above the water is far from being a true vacuum, but is filled with aqueous vapour, which presses on the water with a force varying with the temperature. If the temperature be 32°, the column is depressed half an inch, and if it be raised to 75° it is depressed a foot. In mercurial barometers the space in the top of the tube is no doubt filled with the vapour of mercury, but its pressure is so slight that it could not be measured by the most finely graduated vernier.

27. The tubes of barometers must be filled with pure mercury. If the mercury be not pure the density will differ, and consequently the length of the column will not be the same as that of a barometer in which pure mercury has been used; and, moreover, impurities will soon appear in the mercury, causing it to adhere to the tube, and, thus impeding its action as it rises and falls, will render the instrument useless for accurate observation. In filling tubes, air and moisture are mixed up with the mercury, which must be expelled by boiling the mercury in the tube. As it is essential that a barometer be quite free from air and vapour, it should be tested some time after it has been boiled, and before it is used. This is done by gently inclining it, so that the mercury may strike against the top of the glass tube. If there be no air within, a sharp metallic click will be heard; but if the sound be dull, the air has not been completely expelled.

28. Barometers are commonly divided into two classes—*cistern barometers* and *siphon barometers*, the best being the cistern barometer. Fig. 1 shows the *Cistern Barometer* in its essential and simplest form, and it only requires a scale, extending from the surface of the mercury in the cistern to the top of the mercury in the tube, to make it complete. Cistern barometers are subject to two sorts of error, the one arising from capillarity (Lat. *capillus*, hair), and the other from changes of level in the cistern as the mercury rises and falls in the tube.

29. The laws of the equilibrium of fluids hold good when

the tubes are of considerable diameter; but when they are very small, the laws of equilibrium are quite different. If a tube of small diameter, open at both ends, be plunged into a fluid which wets it, the fluid is elevated within and upon the outside, and maintained at a height which is greater as the diameter of the tube is smaller. But if the tube does not become wet, as in the case of mercury, the fluid is depressed in the tube, and the smaller the diameter of the tube the greater is the depression. Thus, if the diameter of the tube be half an inch, the error arising from capillarity is only .003 inch; if the diameter be $\frac{1}{3}$ inch, the error is .012 inch; if the diameter be $\frac{1}{4}$ inch, the error is .020 inch; and if the diameter be $\frac{1}{8}$ inch, the narrowest tube that should ever be used, the error is .070 inch. Since the effect of capillarity is to depress the barometric column, cistern barometers require an addition to be made to the observed height to give the true height.

30. The other error is called the *error of capacity*, which arises in this way: The height of the barometer is the distance between the surface of the mercury in the cistern and the upper surface of the mercury in the tube. Now, suppose the barometer falls from 30 inches to 29 inches, an inch of mercury must *flow out of the tube, and pass into the cistern*, thus raising the level of the cistern; if, on the other hand, it rises from 29 inches to 30 inches, mercury must flow from the cistern into the tube, thus lowering the level of the cistern. Hence, then, owing to the incessant changes in the level of the cistern, the readings on the *fixed scale* are sometimes too high and sometimes too low. The simplest and rudest way of compensating for this error is to ascertain (1) the *neutral point* of the instrument—that is, the height at which it stands when the zero of the scale is on a level with the surface of the mercury in the cistern, or when it agrees with a standard barometer; and (2) the rate of the error as the column rises or falls above this point, and apply a correction proportioned to this rate. This is both a clumsy method and gives rise to frequent mistakes. The error is the less the more the area of the surface of the cistern exceeds that of the column in the tube, because the mercury which flows into, and out of, the cistern, is spread over a larger surface. For this reason the cisterns of barometers should be made as large as possible.

31. The barometer in which the error of level is entirely got rid of is one invented by FORTIN; and since it is the best cistern barometer, we here describe it, or rather the modification of it which is in very general use, figs. 2 and 5. In fig. 2, B is a brass box containing the cistern, C, the walls of which are of boxwood,

but the bottom of flexible leather. This cistern contains the mercury into which the glass tube is plunged. P is a screw, which works through the bottom of the brass box, B, against the flexible bottom of the cistern, by which the level of the mercury may be raised or depressed. F is a small ivory piston, to the foot of which is attached a float, resting on the surface of the cistern, which moves freely between the two ivory supports, I. There are horizontal lines on the ivory float and supports, *which are drawn so as to lie in the same straight line only when the surface of the mercury in the cistern is at the zero-point* from which the scale, G, of the instrument is graduated. Hence, then, with every observation, the screw, P, must be turned either way till these lines lie in one and the same straight line. The glass tube, the lower part of which is seen plunged into the mercury in the cistern at T, is enclosed in a brass tube, which extends continuously from the brass box, B, to the top of the instrument. This brass tube is made with two opposite slits for the purpose of showing the height of the mercury. In these slits is placed a vernier, V, which slides up and down by turning the screw, H. When the height of the barometer is to be observed, the screw, H, is turned till the horizontal edge of the vernier forms a tangent to the convex curve of the mercury, as at fig. 4. Care must be taken to avoid a mistake not unfrequently made, in shutting off the whole light; that is, instead of making the vernier a tangent to the mercurial curve, as it should be, it is made the arc of that curve.

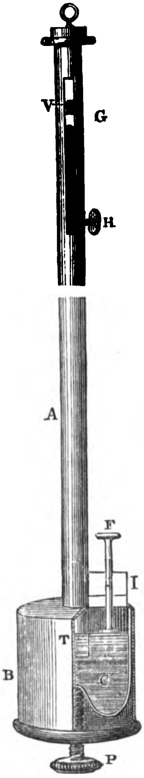

Fig. 2.

32. A *Travelling Barometer*, fig. 3, has been constructed by Adie of London, which possesses several advantages as a practical instrument. The error of capillarity is allowed for in fixing the zero-point of the scale. The error of capacity is obviated by making the inches of the scale not true inches, but just so much less as exactly to counterbalance the error of capacity. The diameter of the glass tube is generally contracted in its middle part, by which the risk of breakage as it is conveyed from place to place is so much lessened that the instrument may be sent as a parcel by rail, if ordinary care be taken in

removing it in and out of the carriages. When the tube is very much narrowed through the greater part of its length, it forms the *Marine Barometer.* It is also frequently made with an air-trap, at A, fig. 2, by which any air that may accidentally find its way into the tube by the cistern is arrested in its ascent towards the top, and the instrument sustains no damage from the accident.

33. As common cistern barometers are liable to be deranged by the introduction of air into their tubes on being removed from place to place, or in being unskilfully handled, it is useful to know how the air may be expelled. First, close up the cistern, fig. 2, so as to prevent the escape of the mercury, by fixing the ivory piston, F, which acts as a stopper to the cistern on being screwed up tight; then by the screw, P, raise the mercurial column to about half an inch from the top of the tube; and having slowly inverted the instrument, place the top of it against a yielding substance, such as the boot, and tap gently on the cistern with the palm of the hand, so as to induce the air to ascend to the cistern, whence it escapes. Since there is the weight of two atmospheres (the mercury in the barometer and the weight of the air outside) pressing on any air that may be inside the tube, it is usually a tedious process to get it wholly expelled. The clear metallic click of the mercury, when struck against the top of the tube, by gently inclining the barometer, will show when the air has been got rid of. On hanging up the barometer, care must be taken to lower the mercury in the tube

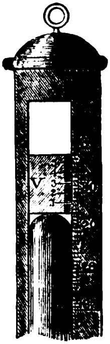

Fig. 4.

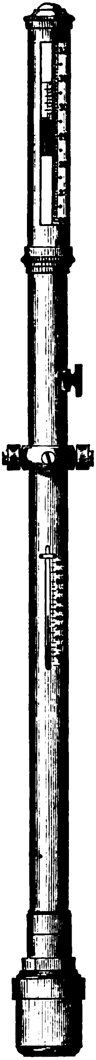

Fig. 3.

Fig. 5.

by turning the screw, P, before unfastening the float, F; for if this be not attended to, the pressure applied by the screw, P, will cause the mercury to flow out at the aperture of the float, thus seriously damaging the instrument.

34. In hanging or fixing the barometer, a perfectly perpendicular position must be secured. If this be not done, the readings will be higher in proportion to the amount of the deviation from the perpendicular. Thus, if instead of hanging in a perpendicular line it slant a little, it may read a tenth or more above what it ought to read. Hence, to obviate this risk of error, it is always preferable that barometers swing in position.

35. The *Siphon Barometer* (Gr. *siphōn*, a tube), fig. 6, is made of a tube bent in the form of a siphon, and of the same diameter throughout. A graduated scale passes along the whole length of the tube, and when an observation is made, the readings at the lower and upper limbs are taken, and the difference between them is the height. There is another form of this instrument, in which, by means of a screw acting from below, the tube is made to slide along the scale; and hence, in observing, it is only necessary to set the zero-point of the scale at the same height as the surface of the mercury in the lower limb, and the height is observed at once from the upper limb. Since in siphon barometers the capillary attraction at both surfaces is the same, no error arises from this cause; and, still further, there is no error of capacity from difference of level as in cistern barometers. But these advantages are counterbalanced by two disadvantages: 1. The trouble of taking two observations, and the mistakes which must frequently arise in taking the difference of the two; 2. The free contact of the lower open limb with the air, by which the mercury contracts impurities, and the working of the instrument is thereby interfered with. In narrow tubes this becomes a very serious objection.

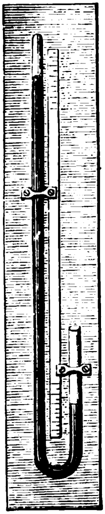

Fig. 6.

36. The common *Wheel Barometer*, the popular form of the *weather-glass*, is a modification of the Siphon Barometer. A small weight, glass or iron, floats on the mercury in the lower limb of the siphon: to this weight a thread is attached, which is led round a horizontal axis, a small weight being suspended at its free extremity to keep it tight. The glass float rises and falls with the fluctuations of the barometer, and a pointer fixed to the horizontal axis being turned by this means, indicates the pressure by figures on a dial. Since the mercury

only rises or falls in the open end of the siphon to the extent of half the oscillation, a cistern is added to the top to increase the amount of the variation in the lower limb. The lengthening and shortening of the thread with the dampness or dryness of the air, and the friction of the different parts, are causes of large and uncertain errors in this form of the barometer, and hence it cannot be used where accuracy is required. It is, however, useful in showing roughly the more marked atmospheric fluctuations by which changes of the weather are indicated.

37. It may be proper to refer here to what opticians have called the *Fitz Roy Barometer*, which is a modified form of the Siphon Barometer. The lower limb is blown into a moderately-sized bulb, which forms a cistern. Since the price (20s.) is too low to admit of good tubes being used and the mercury boiled in them, and since the error of capacity is not got rid of, the instrument is of no use for scientific purposes. It is useful as a weather indicator, in which respect it is an improvement on the ordinary Wheel Barometer.

38. The principle on which the *Aneroid Barometer* (*Gr. a*, without; *nēros*, moist or fluid; and *eidos*, form) depends is the varying pressure of the atmosphere upon an elastic metallic chamber partially exhausted of its air, and so constructed that by a system of levers a motion is given to a pointer which travels over a graduated dial. As it is very portable, and not liable to be broken, it is well adapted for nautical purposes, and for measuring heights. It requires, however, to be repeatedly compared with a standard mercurial barometer, being liable to variation from the elasticity of the brass of the chamber changing, or from changes in the system of levers which work the pointer. Though aneroids may be constructed showing great accuracy in their indications, yet none can lay claim to the exactness of mercurial barometers. The internal machinery is liable to get fouled, in which state they may change 0.300 inch in a few weeks, and indicate pressure so irregularly that no confidence could be placed in them even for a few days.

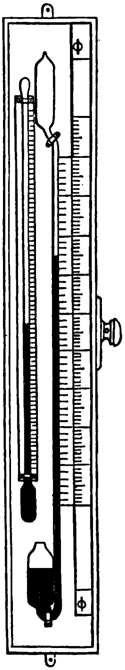

Fig. 7.

39. The *Sympiesometer* (Gr. *sympiezo*, I compress, and *metron*, a measure), fig. 7, was invented by Mr Adie of Edinburgh. It consists of a glass tube, 18 inches in length and ¾ inch in diameter, with a small

chamber at the top, and an open cistern below. The upper part of the tube is now filled with common air, and the lower part and cistern with glycerine. Hence, when the pressure of the atmosphere is increased, the air is compressed, and the fluid rises; but when it is diminished, the air expands and the fluid falls. To obviate error from the increased pressure of the gas when its temperature is raised, a thermometer and sliding scale are added to the instrument, so that it may be adjusted to the temperature at each observation. It is a very sensitive instrument, and well adapted for use at sea and by travellers, but it is not suited for exact observation.

40. *How to use the Vernier.*—A vernier (so called from the inventor M. Peter Vernier) is an instrument for reading off the graduated scale of the barometer true to the $\frac{1}{100}$th or $\frac{1}{500}$th part of an inch. It consists, figs. 8 and 9, of a piece similar to the scale of the barometer, along which it slides. It will be observed from fig. 8, that ten divisions of the vernier are exactly equal to eleven divisions of the scale—that is, to eleven-tenths of an inch. Hence each division of the vernier is equal to a tenth of an inch, together with a tenth of a tenth, or a hundredth, or to ten hundredths and one hundredth—that is, to eleven hundredths of an inch. Similarly two divisions of the vernier are equal to twenty-two hundredths of an inch, which, expressed as a decimal fraction, is 0.22 inch; three divisions of the vernier to 0.33 inch, &c. Suppose the vernier set as described and figured at p. 13—that is, having the zero-line of the vernier a tangent to the convex curve of the mercury in the column. If the vernier and scale occupy the relative positions as in fig. 8, then the height of the barometer is 30.00 inches. But if they stand as in fig. 9, we set about reading it in this way: 1. The zero of the vernier being between 29 and 30, the reading is more than 29 inches, but less than 30 inches, we obtain the first figure—

29 inches.

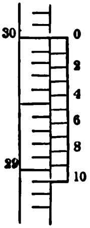

Fig. 8.

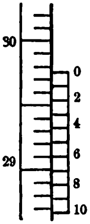

Fig. 9.

2. Counting the tenths of an inch from 29 upward, we find that the vernier indicates more than 7 tenths, and less than 8 tenths, giving the second figure—

7 tenths, or 0.7 inch.

3. Casting the eye down the scale to see the point at which a division of the scale and a division of the vernier lie in one and the same straight line, we observe this to take place at figure 6 of the vernier; this gives the last figure—

6 hundredths, or 0.06 inch.

And placing all these figures in one line, we find that the height of the barometer is 29.76 inches. This sort of vernier gives readings true to the hundredth of an inch. If the inch be divided into half-tenths or twentieths, and 25 divisions of the vernier equal 24 divisions of the scale, it follows that the difference of these divisions is two thousands of an inch. This vernier is always used with the best barometers, and though a little troublesome to read at first, yet if the method of reading the simpler one just described be understood, the difficulty will be easily overcome.

41. *Reduction of Barometric Readings to* 32°.—Mercury expands $\frac{1}{9990}$ of its bulk for every degree of Fahrenheit's thermometer. If, then, a barometer stands at a height of 30 inches when the temperature of the instrument is 32°, it will stand at $30\frac{1}{10}$ inches if the temperature be raised to 69°. This increase of the length of the column by the tenth of an inch is not due to any increased pressure, but solely to the greater expansion of the mercury under a higher temperature as compared with the expansion of the glass tube which contains it, and of the brass scale by which the height is measured. In order, therefore, to compare together barometric observations with exactness, it is necessary to reduce them to the heights at which they would stand at some uniform temperature. The temperature to which they are generally reduced is 32°.

42. Table I., at the end, gives the temperature corrections, adopted by the Royal Society of London, in decimals of an inch for every degree from 29° to 90°, and for every half-inch of pressure from 27.0 to 30.5 inches. The scale is supposed to be brass, extending from the cistern to the top of the column, the difference between the expansion of brass and mercury being allowed for in the table. Since the standard temperature of the English yard is 62°, and not 32°, the difference of expansion of the scale and the mercurial column carries the point of no correction down to 28°.5. The table may be used for temperatures lower than 28°.5, by noting how many degrees the given temperature is below 28°.5, and then looking at the temperature which is just so far above 28°.5, the correction will be found, but it must be added instead of being subtracted. Thus, suppose we wish to find the temperature correction at 20°.0, the height of the barometer being 30 inches. Looking for the correction at 37°.0, which is as far above 28°.5 as 20°.0 is below it, we find it to be —.023; and hence the correction for 20°.0 is +.023.

43. The column of mercury in the tube is supported above the

level of the mercury in the cistern by the pressure of a column of the atmosphere having a base equal to that of the column. Hence the weight of this atmospheric column equals that of the column of mercury. Now, if we suppose the mercurial column to be 30 inches, which is probably near the average height of the barometer at sea-level, and its base equal to a square inch, it will contain 30 cubic inches of mercury; and since one cubic inch of mercury contains 3426¾ grains, the weight of 30 cubic inches will be nearly 14.7 lb. avoirdupois. Thus the pressure of the atmosphere generally on a square inch of the earth's surface is 14.7 lb.

44. *Mode of estimating Atmospheric Pressure.*—The pressure of the atmosphere is not expressed by the weight of the mercury sustained in the tube by that pressure, but by the perpendicular height of the column. Thus when the height of the column is 30 inches, we do not say that the atmospheric pressure is 14.7 lb. on the square inch, but that it is 30 inches, meaning that the pressure will sustain a column of mercury at that height.

45. In England and America the height of the barometer is expressed in English inches, and in Russia by *half-lines.* As a half-line equals half an English decimal line, or the twentieth part of an English inch, the Russian barometric observations are reducible to the scale of English inches by dividing by 20. In France and most countries of Europe the height is expressed in millimetres—a millimetre being the thousandth part of the French metre, which equals 39.37079 English inches. The old French scale, in which the unit is the French or Paris line (0.088814 inch), is still in use in a few countries on the Continent. Table II. will be found useful in comparing millimetres with English inches, and Table III. in comparing Paris lines with English inches. In the old French barometer, Paris lines are frequently written in Paris inches, 12 lines being equal to an inch. Hence 300 lines equal 25 inches, 312 lines 26 inches, 324 lines 27 inches, and 336 lines 28 inches, &c. The English measure of length being a standard at 62° Fahr., the old French measure at 61°.2, and the modern French at 32°, it is necessary, before comparing observations taken with the three barometers, to reduce them to the same temperature, so as to neutralise the inequalities arising from the expansion of the scales by heat.

46. *Correction for Height.*—Since in rising above the level of the sea a portion of the atmosphere is left behind, the pressure is thereby diminished and the height of the column is less. Hence an addition requires to be made proportional to the height of each station above mean sea-level. This addition is called "*correction for height.*" Its amount is determined by the height of the place

above the sea; the atmospheric pressure, temperature, and humidity at the time; and the distance from the centre of gravity of the earth, which is known from the latitude and height above the sea.

47. The correction for *decrease of gravitation* at the high station, as compared with the force of gravity at sea-level, is small, amounting only to about 0.001 inch per 400 feet. Since the force of gravity is diminished in proportion to the square of the distance from the centre of gravity, the rate of its decrease with the height varies in different latitudes. Places at the equator being farther from the earth's centre than places at the poles, it follows that the force of gravity diminishes at a less rapid rate as we ascend at the equator than at the poles. Now, since at the equator gravity diminishes least rapidly with the height, the air of the atmosphere will at any given height weigh more there than anywhere else on the globe at the same height as compared with what it would do at sea-level. Hence, to bring it to the average, a subtraction requires to be made at the equator, which diminishes in amount as we proceed towards the poles, till it falls to zero at latitude 45°, where the mean rate of decrease of gravity with the height is attained. For higher latitudes an addition is required which constantly increases till it reaches the maximum at the poles. This correction is also small, being, for 1000 feet, less than 0.001 inch in Great Britain, and less that 0.003 inch at the equator and at the poles.

48. Since air is denser when the pressure is 30 inches than when it is 28 inches, the correction for height will be considerably greater in the one case than in the other. And again, since air is denser at 32° than at 60°, the correction for height is greater at 32° than at 60°. A column of air 87.51 English feet in height balances one-tenth of an inch of mercury (0.100 inch), when the mean temperature is 32°, and the pressure at the base of the column 30.000 inches. The coefficient expressing the expansion of air by heat, according to Gay-Lussac, is 0.0021 of its bulk for one degree Fahrenheit. Hence, if the temperature be raised to 50°, the height of the column of air necessary to balance one-tenth of an inch of mercury will be 91.01 feet—that is, the raising of the temperature from 32° to 50° has pushed the air up 3½ feet above places at a height of 87½ feet; and the atmospheric pressure being thus increased by the weight of the 3½ feet raised above them, and consequently pressing on them, the correction for height becomes less. Let H be the height in feet of a column of air at the given temperature required to balance 1 inch of mercury; f the height of the place above sea-level; h' the reading

of the barometer reduced to 32°, and h the height of the barometer at the sea-level, then—

$$\text{The correction for height} = \frac{f \times h'}{H \times h}$$

49. Table IV. gives the corrections for heights computed from the constants of Laplace's formula, the barometric coefficient being 60,345.51 English feet, and the coefficient for expansion of moist air 0.004; the correction for decrease of gravity for a vertical being included. The table gives the corrections for heights up to 1000 feet, and for every 10 degrees of temperature from 0° to 90°. The height of the barometer has been assumed to be 30 inches in constructing the table.

50. It will be observed that the numbers for which corrections are given in the table begin at 10, and run thus, 10, 20, 30, &c. The corrections for the digits may be obtained from those for 10, 20, 30, &c., by simply shifting the decimal point one place to the left; and for the intermediate numbers by adding the correction for the digits to those for the even tens. Example: At a temperature of 50° and at a height of 388 feet the correction will be,—

Correction for 380 feet	0.412 inch.
„ 8 „	0.009 „
388 „	0.421 „

Up to 500 or 600 feet, and when the pressure at sea-level is about 30 inches, the table may be considered sufficiently accurate as it stands; but for greater heights, and when the pressure at sea-level differs materially from 30 inches, the figures require some alteration.

51. 1°. *For Temperature.*—The temperature strictly is not the temperature of the higher station, nor the temperature at sea-level, but the mean of the two; or rather, the mean temperature of the whole stratum of air from the higher station down to sea-level. Since the temperature may be assumed to fall 1° for every 300 feet of elevation, the temperature of the air will require to be increased 1° for every 600 feet the higher station is above the sea. Thus, suppose the temperature of a place 1200 feet in height to be 48°, in calculating the correction we should add 2° to it, thus making it 50°.

52. 2°. *For Low Pressures at Sea-level.*—When the barometric reading reduced to 32° and sea-level would be less than 30 inches, the correction is too large; and if greater, the correction is too small. To compensate for this error a column of "differences" is

added to the table, giving the amounts to be added to or taken from the corrections for each inch which the pressure* at sea-level falls short of or exceeds 30 inches. With these modifications the table may be extended to include heights of 2000 feet where very great accuracy is not required, or where it is not possible to be attained. But in reducing to sea-level the mean barometric observations made at high situations during a number of years, and where consequently the mean temperature of the air is closely approximated to, more accurate methods of reducing barometric observations to sea-level require to be employed.

53. *Examples showing the Reduction of the Barometer to* 32° *and Sea-level.*—At Edinburgh, during June 1867, the mean daily height of the barometer was 29.820 inches, the attached thermometer 61°.7, and the mean temperature of the air 56°.6, the height of barometer above mean sea-level being 270 feet.

Observed mean height,	29.820	inches.
Correction required at 61°.7 (Table I.),	—.088	,,
Reduced to 32°,	29.732	,,
Correction for height, 270 feet, air being 56°.6 (Table IV.),	+.289	,,
Reduced to 32° and sea-level,	30.021	

Hence, if the Edinburgh observations during June 1867 had been made at sea-level, and the temperature remained at 32°, the mean barometric height for the month would have been 30.021 instead of 29.820.

54. *Barometric Measurement of Heights.*—It would be out of place here to give the more exact formulæ for determining heights by means of barometric observations, since to be of any value they require to be accompanied by series of tables quite beyond the scope of an elementary treatise. Table IV. may be used for the determination of heights with sufficient accuracy for general purposes, and it may be easily enlarged so as to include all places and heights in Great Britain. A double set of observations made simultaneously is necessary—one at the place, the height of which is sought, and the other at the level of the sea. At each place the height of the barometer, the attached thermometer, and the temperature of the air *in shade*, require to be observed. The problem is made simpler by reducing both barometers to 32°. To take a simple case:—Suppose the barometer at a lower station, or at the sea-level when reduced to 32°, to be 30.000 inches, and temperature of the air 51°; and the barometer at the higher station 29.510

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* Found approximately from the table by applying the correction for the height.

inches, and temperature of the air 49°. The mean of the two temperatures being 50°, and the difference of the barometers .490 inch, we shall find, if we cast our eye down the column of the temperature of 50°, that .490 inch stands opposite 450 feet: the height is therefore 450 feet above the sea. In cases when simultaneous observations cannot be had at sea-level, the height may be determined from observations made at some known height above the sea, with which, being reduced to sea-level, the observations at the higher place may be compared.

55. *Variations of the Barometer.*—The variations observed in the pressure of the air may be divided into two classes—viz., periodical and irregular. The periodical variations recur at regular intervals, whilst the irregular variations observe no stated times. The most marked of the periodical variations is the *daily variation*, the regularity of which in the tropics is so remarkable that, according to Humboldt, the hour of the day may be ascertained from the height of the barometer without an error of more than 15 or 17 minutes on the average. This horary (Gr. *hōra*, an hour) oscillation of the barometer is masked in Great Britain by the frequent fluctuations to which the atmosphere is subjected in these regions. It may, however, be detected by taking the means of a series of hourly observations conducted for some time. The results show two maxima occurring from 9 to 11 A.M. and from 9 to 11 P.M., and two minima occurring from 3 to 5 A.M. and from 3 to 5 P.M.

56. At Calcutta, where, as in other tropical climates, the hourly variation of the barometer is well marked, the following are the extreme variations from the daily mean pressure, with the periods of their occurrence in the four months of the year which may be regarded as representing the seasons. They are the means of the three years, 1862-64.

	A.M.		P.M.		DAILY RANGE.
	MIN. at 3.30.	MAX. at 9.30.	MIN. at 4.30.	MAX. at 10.30.	
January, . . .	—.019	+.076	—.051	+.008	.127
April, . . .	—.020	+.068	—.071	+.013	.139
July, . . .	—.017	+.039	—.054	+.026	.093
October, . . .	—.027	+.061	—.048	+.020	.109

Thus the greatest maximum occurs at Calcutta at 9.30 A.M., and the greatest minimum at 4.30 P.M., the lowest maximum at 10.30 P.M., and the smallest minimum at 3.30 A.M. Hence the two maxima occur when the temperature is about the mean of the day, and the minima when it is near the highest and the lowest respectively—thus suggesting a connection between the daily barometric oscillation and the daily march of temperature.

57. The surface of the globe is always divided into a day and night hemisphere, separated by a great circle which revolves with the sun from east to west in twenty-four hours. These two hemispheres are in direct contrast to each other in respect of heat, and consequently evaporation, which depends on the temperature. The hemisphere exposed to the sun is warm, and the hemisphere turned in the other direction is cold. Owing to the short time of each revolution, the period of greatest heat is not at noon, when the sun is in the meridian, but about two or three hours thereafter; similarly, the period of greatest cold occurs about four in the morning. As the hemisphere under the sun's rays becomes heated, the air, expanding upwards and outwards, flows over upon the other hemisphere where the air is colder and denser. There thus revolves round the globe from day to day a wave of heat, from the crest of which air is constantly flowing towards the meridian of greatest cold on the opposite side of the globe.

58. The barometer is influenced to a large extent by the elastic force of the vapour of water invisibly suspended in the atmosphere, in the same way as it is influenced by the dry air (oxygen and nitrogen). But it is probable that the vapour of water exerts a pressure on the barometer in another way. Vapour tends to diffuse itself equally through the air; but as the particles of air offer an obstruction to the vapour, it is accumulated or pent up in the lower stratum of the atmosphere about 9 or 10 A.M., when evaporation is most rapid, and, being impeded in its ascent, its elastic force is increased by the reaction, and the barometer consequently rises. When the air falls below the temperature of the dew-point, part of its moisture is deposited in dew; and since some time must elapse before the vapour of the upper strata can diffuse itself downwards to supply the deficiency, the barometer falls—most markedly at 10 P.M., when the deposition of dew is greatest.

59. Hence, as regards temperature, the barometer is subject to a maximum and minimum pressure each day,—the maximum occurring near the period of greatest cold, and the minimum near the period of greatest heat. And as regards vapour in the atmosphere, the barometer is subject to two maxima and minima of pressure—the maxima occurring, the first at 10 A.M., when, owing to the rapid evaporation, the accumulation of vapour near the surface is greatest; and the second about sunset, or just before dew begins to be deposited, when the absolute amount of vapour

in the atmosphere is greatest; and the minima in the evening, when the deposition of dew is greatest, and before sunrise, when evaporation and the absolute quantity of vapour in the atmosphere is smallest.

60. Thus, taking both causes into consideration, the maximum in the forenoon may be supposed to be owing to the rapid evaporation arising from the dryness of the air and the increasing temperature, together with the overflow of air in the upper regions of the atmosphere from the wave of heat which has been going on for some hours. But as the vapour becomes more equally diffused and the air more saturated, evaporation proceeds more languidly; the air becomes also more expanded by the heat, and tends to flow away towards the diurnal wave of cold advancing from the eastwards, and the pressure falls to the afternoon minimum. From this time the temperature declines, the air approaches more nearly the point of saturation, and the pressure being further increased by accessions of air from the warm wave, the evening maximum is attained. As the deposition of dew proceeds, the air becomes drier, the elastic pressure of the vapour is greatly diminished, and the pressure falls to a second minimum about 4 A.M.

61. If the pressure on the barometer due to that of the aqueous vapour of the atmosphere be subtracted from the whole pressure, the pressure of the dry air which remains shows the smaller maximum and minimum less decided. This peculiarity appears to be more strongly marked the farther any place is from the sea and the higher the mean temperature—that is, at those places where the influence of temperature is most felt and its effects on the daily barometric pressure least disturbed by large evaporating surfaces, or by moist winds. Thus the smaller maximum and minimum are apparent in the curve of dry air at Calcutta; at St Petersburg they are very faintly marked; whilst at Nertchinsk, in Siberia, they have totally disappeared. At Nertchinsk the curve of dry air for the mean of July 1861 and 1862 attained the maximum 27.050 inches at 5 A.M., whence it fell steadily to the minimum 27.020 inches, and then rose uninterruptedly to the maximum.

62. The amount of the daily barometric variations, as the accompanying table will show, diminishes from the equator towards either pole, for the obvious reason that they depend, directly or indirectly, on the heating power of the sun's rays:—

TABLE SHOWING THE DAILY VARIATIONS AND RANGE OF THE BAROMETER IN DIFFERENT LATITUDES.

	LAT.	A.M.		P.M.		RANGE.
		MIN.	MAX.	MIN.	MAX.	
		Inches.	Inches.	Inches.	Inches.	Inches.
Atlantic Ocean, .	0.0	—.056	+.069	—.045	+.045	.125
Pacific Ocean, .	0.0	—.032	+.040	—.045	+.028	.085
Sierra Leone, .	8.28 N.	—.022	+.032	—.038	+.031	.070
Lima, . . .	12.3 S.	—.071	+.065	—.067	+.050	.186
Port Louis, Mauritius,	20.10 S.	—.020	+.033	—.040	+.029	.073
Calcutta, . .	22.33 N.	—.021	+.061	—.056	+.017	.117
Rio Janeiro, . .	22.57 S.	—.036	+.040	—.040	+.030	.080
Pekin, . . .	39.53 N.	—.038	+.047	—.052	+.014	.099
Padua, . . .	45.24 N.	—.004	+.012	—.014	+.007	.026
Great St Bernard, .	45.51 N.	—.010	+.005	—.003	+.012	.022
Plymouth, . .	50.21 N.	—.007	+.006	—.010	+.010	.020
Barnaul, . .	53.14 N.	—.008	+.016	—.007	+.005	.024
St Petersburg, .	59.58 N.	—.003	+.008	—.004	+.002	.012
Bossekop, . .	66.58 N.	—.007	+.006	—.002	+.003	.013

Thus, while at the equator the daily fluctuation is 0.125 inch, in the south of England it is only a sixth part of that amount. It is very small in the high latitudes of St Petersburg and Bossekop; and in still higher latitudes, at that period of the year when there is no alternation of day and night, the diurnal variation probably does not occur.

63. Since the whole column of the atmosphere, from the sea-level upwards, expands during the heat of the day, thus lifting a portion of it above all places at higher levels, it is evident that the afternoon minimum at high stations will be less than at lower stations, especially when the ascent from the one to the other is abrupt. Thus, at Padua, in Italy, the afternoon minimum is 0.014 inch, but at Great St Bernard it is only 0.003 inch. On the other hand, the cooling and consequently condensing of the air during the cold of night lowers a portion of the atmosphere below the level of St Bernard, and hence its minimum when the temperature is at the minimum of the day falls 0.010 inch; whereas at Padua the same minimum amounts only to 0.004 inch.

64. The daily variation is less in winter when the temperature is low, than it is in summer, unless when rains in summer occur to diminish it. Thus, at St Petersburg, the variation in January is only 0.009 inch, whereas in July it is 0.023 inch. At Nertchinsk it is 0.028 inch in January, but in July it is 0.044 inch. Rains, as just stated, diminish it; thus, at Calcutta it is 0.127 inch, but in the rainy season in July it is only 0.093 inch, and these proportions are maintained each year. It will be also observed that it is much larger in the dry climate of Nertchinsk than it is

at St Petersburg. In the generally wet climate of Great Britain there appears, from Glaisher's Table for Greenwich, to be little difference between the winter and the summer months.

65. The mean pressure at Calcutta of the three Januarys (1861-63), as determined by observations made every hour, was 30.009 inches. At the same place and for the same time, the mean at 9 A.M. and 9 P.M. was 30.046 inches. Hence, if observations had been made at these hours only, the mean, deduced from them, would have been 0.037 inch too high. It is one of the chief uses of hourly observations to find from them the corrections for range to be applied to observations made at different hours, in order to reduce them to the true mean of the day. Such corrections, when found, serve an important end, especially in tropical regions where the daily variation is great; but they may also be, nay, frequently are, applied in cases to which they are not applicable, thus leading to much confusion. They can be legitimately used only in correcting long averages.

66. *Annual Variation.*—In so far as concerns the dry air of the atmosphere, barometric pressure might be expected to be least in the summer and greatest in the winter of each hemisphere. But the production of aqueous vapour by evaporation being most active in summer, the pressure on the barometer will be increased from this cause. As the aqueous vapour is transferred to the colder hemisphere it is condensed into rain, and being thereby withdrawn from the atmosphere, atmospheric pressure is diminished; but the dry air which the vapour brings with it from the warm hemisphere remains, thus tending to increase the pressure. The annual variation may be seen by comparing Plates I. and II.

67. In the neighbourhood of the equator, where temperature and moisture differ little in the course of the year, the variation in the mean pressure from month to month is small. Thus, at Cayenne, the pressure in January is 29.903 inches,* and in July 29.957 inches.

68. At Calcutta, 22° 33′ N. lat., the pressure is 29.538 inches in July, and 30.022 inches in January, thus showing a difference of 0.484; and at Rio de Janeiro, 22° 57′ S. lat., it is 29.639 inches in January (summer), and 29.897 inches in July (winter), the difference being 0.258 inch. The large annual variation at Calcutta is caused jointly by the great heat in July, and by the heavy rains which accompany the south-west monsoons at this season; while in January the barometer is high, owing to the northerly monsoon, by which the dry cold dense air of the continent is conveyed southward over India.

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* None of the following pressures are reduced to sea-level.

69. At places where the amount of vapour in the air varies little from month to month, but the variations of the temperature are great, the difference between the summer and winter pressures is very striking. Thus, at Barnaul and Irkutsk, both in Siberia, the pressures in July are respectively 29.104 inches and 28.192 inches, and in January 29.807 inches and 28.777 inches, the differences being upwards of six-tenths of an inch. The great heat of Siberia during summer causes the air to expand and flow away in all directions, and the diminished pressure is not compensated for by any material accessions being made to the aqueous vapour of the atmosphere ; and, on the other hand, the great cold and small rainfall of that region during winter cause high pressures to prevail during that season. The same peculiarity is seen, though in a modified degree, at Moscow, St Petersburg, and Vienna.

70. At Stykkisholm, in Iceland, the pressure in June is 29.700 inches, and in January 29.300 inches ; at Sandwick, Orkney, 29.786 inches and 29.535 inches ; and at Sitka, in what was Russian America, 29.814 inches and 29.551 inches. In all these places the distribution of the pressure is just the reverse of what obtains in Siberia, being least in winter and greatest in summer. The low winter pressures are due to the comparatively high winter temperatures causing an *outflow towards adjoining countries,* and to the large amount of moisture in the air, and the heavy rainfall which, by setting free the latent heat, still further augments and accelerates the outflow by the upper currents.

CHAPTER III.

ATMOSPHERIC PRESSURE, ITS DISTRIBUTION OVER THE GLOBE.

71. THE scientific and practical value of a knowledge of the distribution of atmospheric pressure over the globe during the different months of the year is evident; since it is impossible to discuss satisfactorily the inquiries which relate to prevailing winds, the varying temperature, and the rainfall over the world, till the isobaric lines for the months have been drawn. These lines may be justly regarded as furnishing the key to nearly every question of meteorological inquiry. In the charts (Plates I., II., and III.) showing the atmospheric pressure over the globe for January, July, and the year, the isobaric lines are drawn for every tenth of an English inch in the difference of the pressure. The lines representing 30 inches of pressure and upwards are coloured red, and the lines representing pressures lower than 30 inches are coloured blue. Thus the red lines show at a glance those portions of the globe where the pressure is above the average (30 inches).

72. MEAN ATMOSPHERIC PRESSURE FOR JANUARY.—It will be seen from Plate I. that the highest pressures in January are over the continents of the northern hemisphere, and the larger the continental mass, the greater the pressure; and that the lowest pressures are distributed over the northern parts of the oceans of the Northern Hemisphere, and over the Antarctic Ocean. An extraordinary excess of atmospheric pressure extends over Central and Northern Asia, rising in the centre of that region to upwards of 30.400 inches. It is here that at this season the greatest degree of terrestrial cold known to exist takes place, the mean temperature falling to —41°.4 at Yakutsk, 285 feet above the sea. Since the winds on the earth's surface everywhere flow out of this region, the inference is inevitable that the sources of this high mean pressure can only be in upper currents flowing towards it and over it from the four regions

of low pressure,—lying respectively to the east, the south-east, the south, and the west. This area of high barometer is continued westward through Europe south of the Baltic, North Sea, and the north of Africa; the North Atlantic between 5° and 45° lat.; North America, except the north and north-west; and the Pacific for some distance on each side of latitude 15°. Its breadth, as might be expected, is doubled in North America, as compared with the Atlantic, and in Asia the breadth is still greater. The influence of the Mediterranean, Black, and Caspian seas, which are at this season warmer than the surrounding land, in lowering the mean winter pressure, and thus breaking the continuity of the isobaric line of 30 from the Pacific to the mouth of the river Lena in Siberia, is well deserving of attention.

73. In addition to the antarctic and equatorial depressions, there are four areas of diminished pressure: two caused chiefly by their high temperature—viz., South America and South Africa; and the other two by there being vast reservoirs of moist air—viz., the northern part of the Atlantic, and the northern part of the Pacific, and parts of the continents adjoining. In the South Atlantic, between the two regions of low pressure, there is seen a space of high pressure, which has its origin in the overflow of air by the upper currents which set in towards it from the belt of calms and from the heated regions of South Africa and South America.

74. Over the North Atlantic there occurs an extensive diminution of pressure, which deepens northwards till the greatest depression, 29.340, is reached in Iceland. The low pressure of this region is due to the saturated state of its atmosphere and to the copious rainfall resulting from it. The flow of the Gulf Stream north-eastwards through the Atlantic to at least Novaia Zemlia, and the large amount of vapour poured into the atmosphere from its warmer waters, tend still further to lower the pressure. It is this low pressure over the North Atlantic, together with the high pressure to the eastward over Asia, which forms the key to the winter climates of Europe. Another remarkable depression occurs in the North Pacific, having its greatest depression, 29.6 inches, in the ocean between Kamtchatka and Sitka, in what was formerly Russian America. The singularness of this depression consists in its close proximity to the high pressure of Siberia. The position of the lowest equatorial pressure in the Indian Ocean, which determines the region of calms and constant rains, probably does not lie parallel to the equator, as might have been expected, but slants from Tamatave in Madagascar, 18° S. lat., to the coast of Sumatra, in 5° S. lat. It is in this trough that nearly all the tropical storms of the Indian Ocean have their origin.

75. **Mean Atmospheric Pressure for July.**—Since, speaking generally, the same conditions which bring about a low atmospheric temperature in winter from the effects of terrestrial radiation, also bring about a high atmospheric temperature in summer from the effects of solar radiation, we should expect to find the relation of the two hemispheres to each other reversed, in respect of atmospheric pressure in July as compared with January. An inspection of Plates I. and II. shows that such is the case. It will be seen from Plate II., that in July the lowest pressures are distributed over the continents, and the larger the continental mass the greater the depression; and that the highest pressures are distributed over the ocean between 50° N. and 50° S. lat. Of these high pressures, the highest occur in those parts of the ocean which are most completely enclosed by the continents.

76. The most extensive of the areas of low pressure is that broad tract which extends almost from the Gulf of Guinea in a north-easterly direction through Africa and Asia to the north of Siberia, reaching the greatest depression, 29.468 inches, near Irkutsk. A region of low pressure also occurs in North America. The pressure is under the average in the north of South America, and thence westward across the Pacific till it join on to the low pressure of Southern Asia. Round the north pole, where, at this season, the sun never sets, the pressure is also under the average. In the Antarctic Ocean the pressure is abnormally low throughout the year, with perhaps a slight tendency to an increase in winter (July).

77. There are two areas of high pressure of very unequal magnitude. The first includes the eastern part of North America, the Atlantic between latitudes 50° N. and 50° S., the south-west of Europe, the west and south of Africa, the greater portion of the Indian Ocean, and Australia, from which a belt of about 20° in breadth passes eastward across the Pacific and central parts of South America, where it joins the high pressure of the South Atlantic. The regions of highest pressure occur in the centre of the North Atlantic between lat. 25° and 40°, and in the South Atlantic between 10° and 35°. In these spaces the pressure rises to a maximum of 30.348 inches at 35° N. lat., and to about the same height at 20° S. lat. The other region of high pressure is comparatively insignificant, stretching from California westward across the Pacific to probably 170° E. long.

78. **Mean Atmospheric Pressure for the Year.**—In Plate III., the sums of the influences at work throughout the year in increasing or diminishing the weight of the atmosphere, are seen

in the areas of high and the areas of low mean pressure in different parts of the globe. There are two regions of high pressure — the one north and the other south of the equator — passing completely round the globe as broad belts of high pressure. They enclose between them the low pressure of the tropics, through the centre of which runs a narrower belt of still lower pressure, towards which the trade-winds blow. Since these belts of high pressure can only be maintained by air flowing in upon them in the upper regions of the atmosphere, it is towards these belts of high pressure that the upper currents of the air must flow. The southern belt of high pressure lies nearly parallel to the equator, and is of nearly uniform breadth throughout; but the belt north of the equator has a very irregular outline, and great differences in its breadth and in its inclination to the equator,—these irregularities being due to the unequal distribution of land and water in the northern hemisphere.

79. Considered in a broad sense, there are only three regions of low pressure—one round each pole, bounded by, or contained within, the belts of high pressure just described, and the equatorial belt of low pressure. The most remarkable of these, in so far as it is known, is the region of low pressure surrounding the south pole. The depression round the north pole is divided into two distinct centres, at each of which a diminution of pressure, very much further below the average pressure, prevails. These two centres are the north part of the Atlantic and the north part of the Pacific Oceans. Their relation to each other, and as parts of the great north polar depression, would be better seen if drawn on a polar projection of the northern hemisphere. There is a smaller area of diminished pressure in Hindostan, which is entirely due to the low summer pressure of that region during the summer monsoon.

80. The whole of the above depressions may be regarded as due to the presence of an excessive amount of moisture in the atmosphere. The influence of high temperatures in lowering the mean annual pressure over any portion of the earth's surface is small in comparison with the depressing influence of the vapour of the atmosphere,—almost the only instances being the slight depression in Central Asia, caused entirely by the summer depression, and the lower pressure which prevails over part of Africa and of Southern Asia. It may therefore be concluded that THE CHIEF DISTURBING INFLUENCES AT WORK IN THE ATMOSPHERE ARE THE FORCES CALLED INTO PLAY BY ITS AQUEOUS VAPOUR—thus giving to this element a paramount claim on our regard in studying winds, storms, and other atmospheric changes.

CHAPTER IV.

TEMPERATURE, HOW OBSERVED AND CALCULATED.

81. THE temperature of the air is ascertained by the *Thermometer* (Gr. *thermē*, heat, and *metron*, a measure), fig. 10, which consists of a small closed glass tube, having a bulb at one end, and partially filled with mercury or spirits of wine. Of these fluids mercury is the best, owing to its uniform expansion by heat, the readiness with which it indicates changes of temperature, and the great range of its fluidity. Since mercury freezes at —37°.9,* a spirit thermometer must be used when the temperature falls below this point. Spirit thermometers are also of great use for registering the greatest cold. Owing to the changes to which they are subject, thermometers should occasionally be compared with a standard thermometer, or have their freezing-point tested by plunging them in melting ice.

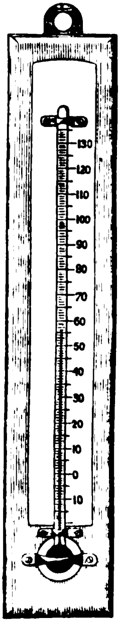

Fig. 10.

82. *Division of Thermometer Scales.*—Before the indications of thermometers can be compared with each other, it is necessary that there be two fixed points on their scales, each of which indicates precisely the same temperature. The points which have been adopted are the temperature at which water freezes, and the temperature at which it boils when the barometric pressure is 29.905 inches reduced to 32°. In both cases distilled water must be used; for if the water contain salts or other impurities, it will freeze and boil at different temperatures. If the pressure exceed 29.905 inches, the temperature of the boiling-point will be higher,

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[*] The minus sign is used to indicate temperatures which fall below 0°.0 on the zero of Fahr. scale.

but if less it will be lower, the proportion being one degree of Fahrenheit for every 0.589 inch of pressure at moderate heights. Thus, if the barometer is 28.000 inches, water will boil at 208°.6 instead of 212°. At Bogota, which is 8727 feet high, the atmospheric pressure is 22.061 inches, and water boils at 197°.5; in Mexico, at 7000 feet high, it boils at 200°; and at Quito, 9000 feet, it boils at 194°.

83. Advantage is taken of this circumstance *to measure approximately the heights of mountains.* The temperature at which water boils is observed, from which the pressure of the air is deduced, and compared with the pressure observed at the same time at some neighbouring place, the height of which is known. From the difference of the two pressures the height is calculated. An observation should be made at a lower level where the height is known before ascending the mountain whose height is to be measured, and another observation in descending, so that errors arising from fluctuation in the pressure may be compensated for. The hour of the day of each observation must be noted, so that the correction for daily variation may be applied. Casella's *hypsometer* (Gr. *hypsos*, height, and *metron*, a measure) is admirably adapted for making these observations with the greatest accuracy.

84. The space on the scale between the two fixed points has been divided in different ways. FAHRENHEIT, a native of Dantzic, fixed the zero-point at the greatest cold then known to have occurred, in Iceland, supposing that lower temperatures would seldom require examination. The space from freezing to boiling he divided into 180 equal parts; and since his zero-point is 32 of these parts below freezing, the freezing-point of water is 32°, and the boiling-point 212°. This is the scale in common use in England and America, and it possesses considerable practical advantages over other scales.

85. Celsius, a professor at Upsal, divided the scale between the two fixed points into 100 parts, the freezing-point being zero This thermometer is generally called *Centigrade*, from the division of its scale into 100 parts. It is used in France and most other Continental countries, and for scientific purposes.

86. In Reaumur's thermometer the same space is divided into 80 parts, the freezing-point being zero. It is in use in Germany and Russia, but is being gradually superseded by the Centigrade thermometer.

87. It is often required to convert temperatures expressed in the Centigrade or Reaumur's scale into Fahrenheit's scale, and *vice versâ.* Since the space between the two standard points

is divided in Fahrenheit's thermometer into 180 parts, in Centigrade into 100 parts, and in Reaumur's into 80, the proportions are—

F : C : : 9 : 5   F : R : : 9 : 4, &c.

Hence, to convert Centigrade degrees to Fahrenheit, we multiply them by 9 and divide by 5, and add 32° to the result, because 32° on Fahrenheit's scale is the zero of the Centigrade scale; and to convert Fahrenheit into Centigrade, first subtract 32°, multiply by 5, and divide by 9. In Table V. the Centigrade thermometer is compared with Fahrenheit's and Reaumur's from 122°.0 to —41°.8 F.

88. *Self-Registering Thermometers.*—The most important temperatures in their relation to climate and most other inquiries are the highest that occur during the day and the lowest that occur during the night, to record which, various thermometers have been devised, well known as maximum (Lat. *maximum*, greatest) and minimum (Lat. *minimum*, least) thermometers.

89. *Maximum Thermometers.*—The maximum thermometers generally used are Rutherford's, Phillips's, and Negretti and Zambra's. *Rutherford's Maximum Thermometer* has a movable steel index in the tube above the mercurial column. When the instrument is in use, it is hung horizontally, and as the temperature rises, the mercury pushes the index before it, but as it falls the index is left, thus registering the highest temperature. It is set by bringing the steel index to the surface of the mercury by means of a magnet; or by simply holding the instrument upright so as to allow the index to fall gently down on the mercury, shaking or tapping it slightly if required. The objection to this thermometer consists in its liability to go out of order by the index oxidising, and then getting plunged into the mercury; and so certain is this to take place in a few years at most, that the instrument cannot be recommended. The end of the index next the mercury may be covered with a coating of glass, by which its tendency to oxidisation is prevented. A maximum thermometer thus constructed forms perhaps the best that has yet been invented, because the index is not easily shaken out of its position, and it may be set with a magnet without requiring to be removed from the hook to which it is attached, thus lessening the risk of breakage.

90. In *Phillips's Maximum Thermometer*, fig. 11, a portion of the mercurial column is detached and kept separate from the other part by a minute air-bubble. When in position it is hung horizontally. As the temperature rises the whole column moves along the scale, but when it begins to fall the detached portion is left behind at the point to which it had been pushed, thus regis-

tering the greatest heat. This is an excellent thermometer. Care, however, should be taken to select one in which the detached portion is about 1½ inch in length; for if it is longer, its weight in the tube makes it easily shaken out of its place; and if shorter, it is so troublesome to set, that in striking it so as to send down the detached part to the mercury, the risk of breaking it is considerable.

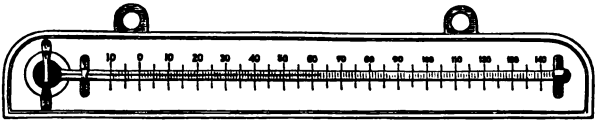

Fig. 11.

91. In *Negretti and Zambra's Maximum Thermometer*, the tube is bent at the part of the tube near the bulb, and the bore of the tube is contracted at the angle. It is hung horizontally; with a rising temperature the column is pushed along the scale, but when the temperature begins to fall, the column of mercury breaks at the angle where the bore is narrowed, thus leaving the mercury in the tube at the highest point to which it has been driven. It is also an excellent thermometer; but since the detached portion of mercury in the tube is always of very considerable length, and consequently of some weight, it is liable to be shaken out of its place.

92. In selecting a Phillips's, or a Negretti and Zambra's thermometer for the registration of very high temperatures, such as are recorded by thermometer exposed to the sun's rays, care must be taken to see that the thermometer registers sufficiently high. For these thermometers only register properly up to a certain point; the reason being, that there is almost always a portion of air, however small, in the top of the column, and hence when the mercury has risen to near the top of the tube, and the temperature begins to fall, the elastic force of the enclosed air pushes back the mercury in the tube, thus causing it to act like a common thermometer. If the mercury be heated till it rises nearly to the top of the tube, and be then allowed to cool, the height to which it registers correctly may be ascertained.

93. *Minimum Thermometers.—Rutherford's Minimum*, fig. 12, is the best. In this thermometer the fluid used is spirit of wine, in which there is immersed a steel index. When in use, it is hung horizontally. As the temperature falls, the spirit drags the index with it, but when the spirit rises it freely passes the index and leaves it lying at the lowest point to which

it had been dragged, thus registering the greatest cold. This thermometer is set by bringing the index close up to the top of the spirit, by raising the bulb end of the instrument, or by a magnet.

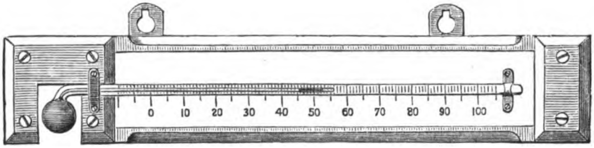

Fig. 12.

94. There are no instruments for meteorological purposes so liable to go wrong as spirit thermometers, owing to part of the spirit evaporating and settling in the top of the tube. This frequently happens with spirit thermometers exposed on grass; indeed I have seen them out of order to the extent of 3°, and more rarely 8°, or upwards. Such thermometers ought therefore to be frequently examined, to ascertain whether any of the fluid has lodged in the top of the tube. This remark applies also to spirit thermometers exposed for common purposes outside windows, which if not frequently examined will get so deranged as to indicate a cold 12°, or more, too great. Spirit thermometers kept in the shade are also liable to the same derangement, but to a much less degree, since they are better protected from great heat. Generally the quantity of spirit evaporated is small, though sometimes it amounts to a degree or more. Special attention should be given to this point, since it is by the temperatures recorded by these thermometers that one of the chief elements of climate is determined.

95. *How to Unite the Broken Column of Spirit Thermometers.*—Spirit thermometers may be easily set right when the column of spirit chances to separate. Let the thermometer be taken in the hand by the end farthest from the bulb, raised above the head, and then forcibly swung down towards the feet; the object being, on the principle of centrifugal force, to send down the detached portion of spirit till it unites with the column. A few throws or swinging strokes will generally be sufficient, after which the thermometer should be placed in a slanting position, to allow the portion of the spirit still adhering to the sides of the tube to drain down to the column. But another method must be adopted if the portion of spirit in the top of the tube be small. Heat should then be applied slowly and cautiously to the end of the tube where the detached portion of spirit is lodged; this being turned into vapour by the heat, will condense on the surface of the unbroken

column of spirit. The heat must not be too quickly applied, for if this be done the tube will break and the instrument be destroyed. The best and safest way to apply the requisite amount of heat is to bring the end of the tube slowly down towards a minute flame from a gas burner; or if gas is not to be had, a piece of heated metal, such as a poker, will serve the purpose.

96. It is evident that if mercurial minimum thermometers were constructed, this source of error would be obviated. Great and partially successful efforts have been made to supply this desideratum. The *Mercurial Minimum Thermometer* of Casella may be referred to as a triumph of science and glass-blowing. It is, however, usually too sensitive, and the mercury too easily shaken along the tube, to be recommended for general use,—some of them being so delicately adjusted that the greatest care and most expert manipulation is required to work them. Hence the best minimum thermometers are spirit thermometers, for they really leave nothing to be desired if only the most ordinary vigilance be exercised in putting them right when the column happens to separate.

97. In *Sixe's Maximum and Minimum Thermometer*, both are combined in one column; but this composite instrument is inferior to the ordinary maximum and minimum thermometers which are separate instruments. This is particularly apparent in registering extreme temperatures of short duration, because the tube is filled with two fluids, mercury and spirit, which expand unequally, owing to their different capacities for heat.

98. No thermometer ought to be used which has not been previously compared with some Standard Thermometer, so that its errors, if any, at the different points of the scale, may be ascertained. This is the more necessary in purchasing cheap instruments, which are not unfrequently from 1° to 3° wrong.

99. *Box for Thermometers.*—In order to ascertain the temperature of the air, it is necessary that thermometers be protected from the direct and reflected rays of the sun, and at the same time have the benefit of a free circulation of air. No possible arrangement can completely fulfil both these conditions. For if they be completely protected from solar radiation, the circulation of the air must be unduly interfered with; and if the circulation of the air be quite unimpeded, the thermometers are unduly exposed to radiation. All, therefore, that can be secured is a compromise between protection and circulation. The best and cheapest contrivance yet devised to meet these requirements is the *Louvre-Boarded Box for Thermometers*, constructed by Mr Thomas Stevenson, C.E., Edinburgh, and now largely used

by the observers of the Scottish Meteorological Society, and other meteorologists. A figure of the box, fig. 13, is here given, with the door let down to show the hanging of the thermometers inside. Fig. 14 shows the simple and ingenious method by which the louvre-boards are fixed.

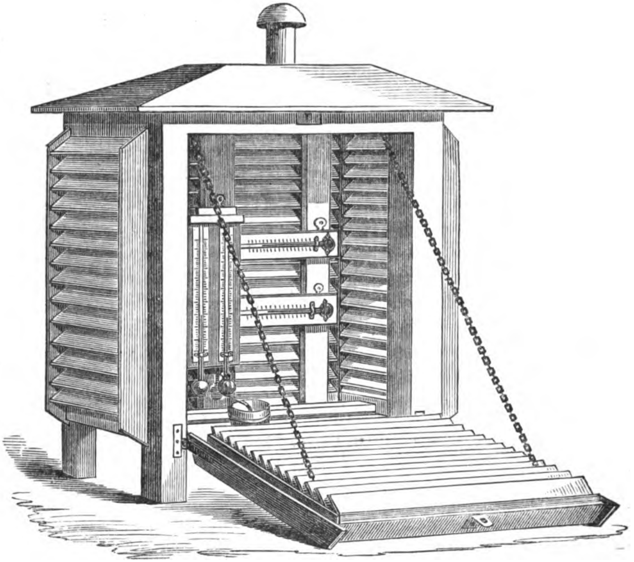

Fig. 13.

100. The box is screwed to four posts firmly fixed in the ground, and these posts and the box itself are painted white,—the colour which absorbs least of the sun's heat. The posts are of such a length that when the minimum thermometer is hung in its place it is exactly four feet from the ground. This height is an essential point in the arrangements of the observatory, owing to the very great differences which frequently obtain between the temperature of the air at a height of four feet, as compared with the temperature at the surface of the earth, and at intermediate points.

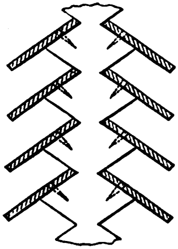

Fig. 14.

101. *Placing of the Thermometer-Box.*—The box should be

placed at some distance from walls or other objects; in an open space; and over old grass to which the sun has free access during the greater part of the day. If it be placed on the north side of walls or buildings, the thermometers do not indicate a sufficiently high day temperature nor a sufficiently low night temperature; or a sufficiently high summer temperature, or a sufficiently low winter temperature. In other words, the wall acts as a refrigerator when the sun is heating the air during the day and during summer; and is a source of heat when the temperature falls during the night and in winter. Hence the daily range of temperature indicated by thermometers so placed is always small; and, what is more serious, since the range and the daily march of the curve of temperature differ with the nature of the buildings against which they are placed, uniformity is not secured. If the box be placed over black soil, which is more highly heated during day, and cooled to a greater degree during night than grass, the maximum temperature will be too high, and the minimum too low.

102. *Directions for taking Observations with the Thermometers.*—Having let down the lid of the box as in fig. 13, the chief thing to attend to is, to take all the observations before touching one of the instruments. The dry and wet bulbs of the hygrometer are to be read first, so that their temperature may not be affected by the heat of the person standing near them. The minimum thermometer is read by noting down the degree on the scale at which the end of the index farthest from the bulb is lying. Beginners sometimes "read off" the degree at which the top of the column of spirit happens to be at the time, which is not the lowest temperature that has occurred during the night, but the temperature at the time of observation. The maximum thermometer is read by noting the degree at which the end of the index next the bulb is lying, if it is Rutherford's maximum; but in the case of the other two maximum thermometers described above, the reading is taken from the point on the scale at which the end of the mercury furthest from the bulb is lying. When this is done the maximum and minimum thermometers should be "set" as already explained, and the box then closed.

103. *Mean Daily Temperature.*—If the thermometer be observed once every hour, or twenty-four times a-day, and the sum of the observations be divided by 24, we shall obtain the *mean temperature* of that day. Observations of this nature, extending over considerable periods, have been made at Leith, Rothesay, Greenwich, Rome, Calcutta, Madras, Bombay, St Helena, Toronto, Melbourne, several places in the Russian Empire, and in other parts of the world, and the hourly means for each month have been

calculated and published. These tables show that there are two times in the day when the temperature is at the mean, occurring generally in winter between 9 and 10 in the morning, and between 9 and 10 in the evening, and in summer about an hour earlier.

104. It might have been supposed that the *daily minimum temperature* would have occurred at the rising of the sun, or just before its rays had begun to heat the air; but observations are unanimous in showing that the minimum happens some time before the sun rises. Within the tropics, and in temperate regions during summer, it occurs about half an hour before sunrise; but in temperate regions during winter generally two hours, and at some places as much as three hours, before sunrise.

105. Within the tropics, and in temperate regions during winter—in other words, where the daily range of temperature is small—the *daily maximum temperature* occurs about an hour and a half after the sun has passed the meridian at noon. But in temperate climates during summer the maximum does not take place till from 2.30 P.M. to 3.30. P.M.

106. To this general law of the time of its occurrence there are several interesting exceptions. At many places in tropical countries it occurs about noon, or sometimes a little earlier, when the temperature at the coast is lowered by the sea-breeze, which begins to blow before noon; and during the rainy season the temperature at this hour is still further lowered by the clouds which then begin to overspread the sky. At the Hospice of the Great St Bernard, 8130 feet above the sea, the daily maximum temperature occurs within an hour after twelve o'clock. The air being comparatively rare at this great height, the effects of solar and terrestrial radiation are more immediately felt than at lower levels. Hence, though the heat received by bodies exposed to the direct rays of the sun at noon is very great, yet the dispersion of the heat by terrestrial radiation is so rapid that in an hour after the sun has passed the meridian, the temperature of the air begins to fall. At the Great St Bernard, at 3.30 P.M., the temperature is 1°.0 lower than it is about noon, whereas at lower situations it is from 1°.5 to 2°.0 higher.

107. Sir David Brewster investigated the hourly observations at three Scottish stations, and drew interesting and important conclusions from them. By dividing the mean annual curve of daily temperature into four portions, at the points representing the two daily means and the two extremes, he found that the four portions have a striking similarity to parabolas, calculated on the supposition of the temperatures being the abscissæ of parabolas, and the hours the ordinates. The coincidence between the ob-

served and calculated results is so remarkable that the calculated parabolic temperatures never differ from the real temperatures more than one quarter of a degree of Fahrenheit.

108. He also established a most important modification of the law of the daily march of temperature, consequent on the form of the visible horizon at the place of observation. If a hill rises to the north of the place, by which the sun's rays are never obstructed, it has little or no influence on the thermometer; but if one or more hills obstruct the sun's rays after it has risen above the true horizon, that obstruction affects the temperature at the place of observation at the hours corresponding with the azimuth of the hill. Thus, owing to the hills which break the horizon at Rothesay, the observed temperatures fall short of the calculated temperatures to the extent of 0°.38 at 10 A.M., and 0°.43 at 5 P.M.; whereas at Leith and Inverness, where the horizon is open, the observed and calculated temperatures do not differ so much as 0°.25 at any hour.

109. It is a singular coincidence that the means of observations of hours of the same name, such as 8 A.M. and 8 P.M., 9 A.M. and 9 P.M., 10 A.M. and 10 P.M., &c.—do not differ much from the mean of the day. The hours which come nearest the mean are the following: 9 A.M. and 9 P.M., 10 A.M. and 10 P.M., 3 A.M. and 3 P.M., and 4 A.M. and 4 P.M. The mean of four hours at equal intervals gives a result still nearer the true mean.

110. *Best Hours for Observation.*—Hence the best hours for making observations are the following, the convenience of observers being considered: For two observations, 9 A.M. and 9 P.M.; for four observations, 3 A.M., 9 A.M., 3 P.M., and 9 P.M., or an hour later in all these cases is nearly as suitable. For certain practical purposes, when only two or three observations can be made daily, and where there are no maximum and minimum thermometers, it is most desirable to include an observation at 3 P.M., when the temperature is near the maximum of the day.

111. An important use of maximum and minimum temperatures arises from their relation to *mean temperature,* which may be assumed to be the mean of the twenty-four daily observations. I have compared these for a considerable number of places over the globe where such double series of observations have been simultaneously made, and have found that the mean temperature deduced from the mean of maximum and minimum observations is generally about half a degree above the true mean. So uniform on the whole is this difference, that it may be accepted as the rule, unless where it is modified by peculiar changes of climate in different seasons and localities.

112. It is from the vague and uncertain meaning attached to the phrase *mean temperature,* that not a few writers of Local Climatologies are led to claim for particular watering-places a general amenity or mildness of climate over other sanatoria, which has no existence in fact. It is not by their excess of mean temperature, but by their situation and local surroundings, that our principal British sanatoria have their repute. Thus, Bridge of Allan owes its celebrity not to any difference in its mean temperature, which doubtless is the same as that of the district around it, but to the well-wooded heights behind it, sheltering it from the east winds, and to the sloping nature of the ground on which it is built. From its sheltered position, the east wind passes over it at a reduced rate and force, and there being consequently less evaporation, our bodies are deprived of less heat, and thus the sensation of greater warmth which we feel is a reality. Again, being built on rising ground, the cold air flows down to the valley below it, so that excessive cold rarely occurs. Ventnor, in the Isle of Wight, possesses similar advantages in the protection afforded by the Undercliff, and in its proximity to the sea, towards which its cold heavy air flows, and being there counteracted by the higher temperature of the sea, low temperatures rarely occur. These advantages not only give greater facility for open-air exercise, but by offering, to a great extent, protection from the hurtful effect of the weather most trying to invalids—viz., east winds, and the severe cold of winter—are far more to be prized than would be an annual temperature several degrees higher.

113. *Value of Extreme Temperatures.*—Self-registering thermometers are of great value in recording the extreme temperatures, which, in reference to their effects on health and vegetation, must be regarded as the most important elements of climate. The subject of extreme temperatures is one of paramount importance, especially where the transitions of temperature are sudden and violent. In the north-western parts of the United States of America the temperature in spring often rises to 83° during the day, and falls to freezing during the night. Under such a climate the vital functions of plants, the tissues of which abound in sap, are called into activity during the day; but the sap being frozen during the night, the vessels containing it are ruptured by expansion, and the plant, if not totally destroyed, is so seriously injured, that its successful cultivation becomes precarious and uncertain. The same risk is seldom incurred in such places as Great Britain, where the seasons shade into each other by nice and almost insensible gradations. It is, however, everywhere desirable to arrive at some definite knowledge as to the probability of occurrence of certain

extreme temperatures that may take place in the different seasons, and this can only be done by observations of extremes carefully made and recorded from day to day.

114. *Importance of resolving Mean Temperature into the Extremes which compose it.*—Every mean temperature may be considered as a composite element, made up of the mean temperature of the day and the mean temperature of the night. Hence the same mean temperature often stands for two things essentially different. Thus, Madrid in the centre of Spain, and Mentone on the Gulf of Genoa, had the same mean temperature of 72°.8 during September 1865. But the climates of the two places were widely different; for the temperature at Madrid during the warmest period of the day was on an average 86°.2, whereas at Mentone it was only 77°.6; and during the coldest period of the night the temperature was 59°.5 at Madrid, whilst at Mentone it was as high as 68°.0.

115. Again, in the same country and in the same month, but in different years, the same mean temperature, when resolved into the extremes that compose it, represents very different things. Thus, the mean temperature of Scotland in August 1860 was 54°.4, and in the same month of 1864 it was also 54°.4; but in 1860 the mean of the highest day temperatures was 60°.8, whilst in 1864 it was 62°.5. This higher day temperature in 1864 was the chief cause of the productive harvest of that year, and the lower day temperature of 1860 was the chief cause of that year's deficient harvest, and yet the mean temperature of both years was the same. Thus, in considering the relations of mean temperature to health or to agriculture, it is most essential to know the separate elements which compose it.

116. *Range of Temperature.*—This points out the importance of considering the daily range of temperature, or the difference between the extreme day and night temperatures. Everywhere the range of temperature is least in winter, augments rapidly in March and April, reaches the maximum in May or June, continues high during summer, and diminishes rapidly in October and November to the minimum in the winter months. As regards climates, it is least in wet climates, and in the tropics and polar regions; and greatest in dry climates and in temperate countries. Hence it is less in Ireland than in Scotland, greater in England than in both these countries, and still greater on the continent of Europe. In Shetland, Orkney, and the Hebrides, whose climates are perhaps the most strictly insular in Europe, the summer range is only about 10°; on the west of Great Britain it rises to 12° and 14°; in the central districts to 15°; and in the south to 20°. At Paris, Utrecht, Vienna, and other places on the Continent, the range is

still higher. In the dry climate of Jerusalem, in Syria, it amounts to a mean of 22°.5 from May to October inclusive, and during October 1865 the mean was 24°.6; in the still drier climate of Madrid a range of 27°, and in one month 31° was observed in 1865. A similar high range is frequently recorded in the Russian and Siberian steppes. At Trivandrum, in Southern India, during the dry season in January, the daily range is about 17°, but during the rainy season in July it is only half that amount. The greatest differences among the months, as compared with each other, are observed in the polar regions. Thus, in Spitzbergen and Boothia Felix the range in winter varies from 1° to 0°; in May, when the sun has reappeared and continues to rise and set, it is about 14°; but in July, when the sun does not set, the range is only 10°.

117. In comparing climates there is not a more misleading element than range, if the different circumstances under which the range has been obtained be not taken into consideration. Thus, in the above instances the term has been employed to signify the difference between the mean of the maximum and the mean of the minimum temperatures at whatever hour these may chance to happen from day to day. This is the true daily range of temperature. In some books, however, the daily range of temperature means the difference between the mean of the coldest and the mean of the warmest of the twenty-four hours, and is therefore always less than the former.

118. Again, the amount of the range depends to a great extent on the degree to which the thermometers are protected from, or exposed to, direct or indirect radiation, and also to their height above the ground. For if the louvre-boarded box containing the thermometers be placed behind a wall to which the sun has little or no access, the range will be several degrees less than in an open situation on which the sun shines during most of the day—that is, of the district where the observations are made; the range will be greater in a hollow than on a knoll; greater over a soil of sand than of loam; greater over black earth than over grass; greater over long grass than over short grass; greater with, than without, a proper ventilation to the box; greater the more the louvre-boards are apart; greater if the box be always kept open to the north than if louvre-boarded all round; and greater the nearer the thermometers are to the ground. Hence the extreme desirableness of uniformity of observing in all parts of the world. On considering these different conditions under which temperature may be observed, it is evident that if any of the above conditions were adopted as a standard the results could not be comparable. The arrangement least open to objection is that already recommended

in par. 99 to 101, which has the great merit of being easily carried out in all places.

119. The most important question in connection with low temperature is *the occurrence of frost.* Both to the farmer and to the physician it is of the utmost moment to know how often and with what severity frost may be expected to occur, and when for all practical purposes it ceases to occur, or happens so seldom as to cause no alarm, and call for no precaution on the part of those whose interests may be affected by it. It is pretty generally believed, that if the temperature fall below 40°, the growth of vegetation is arrested during the next day. Hence an inquiry into the occurrence of this temperature and its effects would lead to valuable results. On the other hand, the question to be inquired into, in an investigation of high temperatures as affecting agriculture, is not so much injury received as advantage gained by their occurrence. The growth and maturing of crops depend chiefly on the heat they receive from the sun. And in countries such as Scotland, whose mean summer temperature but barely exceeds the minimum heat required for the proper ripening of the staple objects of agriculture, the inquiry becomes invested with a peculiar interest, especially in examining places and localities differing in latitude, proximity to the sea, exposure, and elevation. As regards Great Britain, if the day temperature rises occasionally to 65°, the degree of heat thus received by the grain crops may be looked upon as sufficient for their growth up to the period of flowering; but after this a higher temperature is required, and a frequent day temperature of 70° is necessary to produce the finer qualities of wheat and barley. For other countries different temperatures would require to be investigated—namely, those essential to the successful cultivation of their staple products.

120. In order to render tables of this description practically as well as popularly useful, the occurrence of the critical temperatures should be given separately for every week of the year. In this way a storehouse of the most valuable information would be collected, by which agriculturists might arrive at a knowledge of the character of the climate they have to deal with; and by which physicians might reason with more certainty than at present regarding the spread of diseases, the rates of mortality peculiar to different countries, and the places to which invalids may be sent, so as to secure the greatest safety or receive the greatest advantage that can be procured from a change of climate.

CHAPTER V.

TEMPERATURE—SOLAR AND TERRESTRIAL RADIATION.

121. THE interchange of temperature among bodies takes place by conduction, convection, and radiation. The communication of heat by *conduction* (Lat. *conductio*, a bringing together) proceeds from particle to particle, and implies contact with, or very near approach to, a hotter body. As a class, metals are the best conductors; solids are better conductors than liquids; and liquids better than gases, which are thus the worst conductors.

122. The most important illustrations of conduction in meteorology, are the propagation of the changes of temperature downwards through the earth's strata, from the surface, as it is heated during the day or cooled during the night; and the communication of the same changes of temperature to the lowest stratum of the atmosphere which rests on the surface. Dense soils, or soils having their particles closely packed together, are much better conductors of heat than loose porous soils, because the latter imprison large quantities of air in the interstices between the particles, thus diminishing the conducting power of the soil. In accordance with this, light loose soils are subject to higher temperatures, and to a greater degree of frost, *near the surface*, than dense heavy soils; but, on the other hand, frosts and extreme temperatures do not penetrate so far down into light soils as into heavy soils. In Scotland, for a period of nine years, the temperature at three inches below the surface fell to 26°.5 in loose sandy soils, and at a depth of twelve inches the freezing-point was only once observed. But in clay soils, at three inches the lowest was 28°, whilst at twelve inches the temperature often fell to freezing; and even at twenty-two inches, in clay soils, 32° was once recorded.

123. Damp air is a much better conductor of heat than dry air. Damp air consequently feels colder than dry air of the same temperature, in the same way as a marble mantelpiece feels colder

than the carpet, though both be at the same temperature, because the heat is conveyed away from our bodies more rapidly. At the breaking up of the great frost which prevailed in Great Britain in December 1860, when the temperature had risen to 32°, and the air become moister, the weather felt more disagreeably chilly than when the temperature was below zero, or from 30° to 40° lower.

124. Snow being composed of crystals, which have a large quantity of air entangled among their interstices, is on this account one of the worst conductors of heat. Hence it protects the soil in winter in two ways—(1) It prevents the escape of heat from the earth to the air; and (2) it sets a limit to the depth to which severe frosts penetrate, thus protecting the roots of plants from injury.

125. Though fluids and gases are bad conductors of heat, yet they may be quickly heated by a process of circulation of their particles which is called *convection* (Lat. *convectio*, a carrying). When heat is applied to the bottom of a vessel containing water, the particles at the bottom become lighter and rise to the surface, and other particles descend to take their place. Two currents are thus formed, the hotter ascending through the centre of the vessel, and the colder flowing down the sides. This circulation continues until the whole of the water attains the same temperature.

126. The communication of heat by convection is seen on the most extensive scale over the globe in the winds and in the currents of the ocean. It is seen in the ascending and descending currents of the atmosphere everywhere, which are caused by the daily changes of temperature of the surface of the earth; for when the surface is heated by the sun, the air immediately resting on it becomes heated and ascends, and colder particles descend to occupy its place. Under the tropics the air becomes highly heated, ascends, and flows off towards the poles, whilst colder currents flow towards the equator. The great and beneficial effect resulting from aerial and oceanic currents is a more equal distribution of temperature, thereby mitigating the rigours of the polar regions, and moderating the scorching heat of the tropics.

127. An interchange of heat is constantly going on among bodies freely exposed to each other, whether their temperature be the same as, or different from, that of the bodies which surround them. If we stand before a fire we feel the influence of its heat, though standing at some distance from it. This mode by which heat is communicated is called *radiation* (Lat. *radius*, a ray).

Radiant heat proceeds in straight lines, which diverge in all directions from the source, is only to a limited extent affected by the air through which it passes, and is not diverted from its straight course by the wind. Its intensity is proportioned to the temperature of the source, is inversely as the square of the distance from the source, and is greater according to the degree of inclination of the surface on which the rays fall.

128. If a body be placed in the presence of other bodies, some colder and some hotter than itself, it will from this mutual interchange of temperature receive more heat from the hotter bodies than it radiates to them, and thus become warmer; but it will receive less heat from the colder bodies than it radiates to them, and its temperature will consequently fall. This is the condition in which the earth is placed. When its surface is turned towards the sun, it receives more heat than is radiated from it; but when it is turned from the sun towards the cold regions of space, it gives out more heat than it receives. These two conditions under which the earth is placed are so essentially distinct that the subject of radiation falls naturally under two heads—viz., *solar radiation* and *terrestrial radiation.*

129. SOLAR RADIATION.—(1.) *On Land.*—Of the solar (Lat. *sol,* the sun) heat which arrives at the surface of the earth, that part which falls on land may be regarded as wholly absorbed by the thin superficial layer exposed to the heating rays; and since there is no mobility in the particles of the land, the heat can be communicated downward only by conduction. While the temperature of the surface increases, a wave of heat continues to be propagated downward through the soil. The intensity of the daily wave of temperature rapidly diminishes with the depth—the rate of diminution depending on the conducting power of the soil—until at about four feet from the surface it ceases to be perceptible.

130. In considering the influence of the solar heat on the temperature of the air, it is the temperature of the extreme upper layer of the surface which requires almost exclusively to be attended to, seeing it is chiefly by contact with the surface that the temperature of the air rises or falls. Badly-conducting surfaces have the greatest influence in raising the temperature of the air. For this reason, and on account of the absence of vegetation by which part of the heat would be spent in vaporising the sap, the surface temperature of the sandy deserts of the tropics frequently rises to 120°, 140°, and, more rarely, to 200°. When these hot particles of dust are lifted into the air by the winds, the temperature of the air itself

has been known to rise to 125° in the shade; and it is this which gives the sirocco and simoom of the desert their dreaded name. It is in the deserts of Africa, Arabia, Persia, and the Punjab, where the highest temperature on the globe occurs, the mean summer temperature of these regions ranging between 92° and 95°. The surface of loam and clay soils is not heated in so high a degree as sandy soils, and the surface of rocks to a less degree, because, being better conductors, the heat is not left to accumulate on the surface, but is more quickly conveyed downwards.

131. When the ground is covered with vegetation, the whole of the solar heat falls on the vegetable covering; and as none of it falls directly on the soil, its temperature does not rise so high as that of land without any covering to protect it. The temperature of plants exposed to the sun's rays is not so high as that of the soil under the same circumstances, partly because a portion of the solar heat is lost in the process of evaporation from the pores of the plants, and partly because the heat does not accumulate on the surface of the plants as it does on the soil. For the leaves being thin, and the greater part of their substance being on that account in immediate contact with the air which envelops them, they are quickly robbed of their heat; and the heated air, being lighter, constantly flows away and gives place to colder air. Hence one chief difference between the climates of two countries, the one covered with vegetation and the other not, lies in this, that the heat is more distributed over the twenty-four hours in the former case, and is therefore less intense during the warmest part of the day.

132. *Influence of Forests on Climate.*—The effect of vegetation in changing the hours of the distribution of the highest and lowest daily temperatures is most strikingly exemplified in the case of forests. Trees are, like other bodies, heated and cooled by solar and terrestrial radiation. They do not, however, acquire their maximum temperature till a little after sunset. This occurs in summer at 9 P.M., while the maximum temperature of the air occurs between 2 and 3 P.M. Hence trees may be regarded as reservoirs in which the heat of the day is stored up against the cold of the night. Changes of temperature take place very slowly in the tree, but in the air they are more rapid. From this it follows that the influence of forests on the daily temperature is to make the nights warmer and the days colder,—in other words, they communicate to the climate of countries clad with trees something of the character of insular climates. Evaporation goes on slowly from the damp ground usually found under trees, being screened by them from the sun's heat. But since the air among

the trees is little agitated or put into circulation by the wind, the vapour which arises from the soil is mostly left to accumulate above it among the trees. Hence it is probable that forests diminish the evaporation but increase the humidity of climates. It also follows that forests keep the summer temperature lower and maintain the winter temperature higher than it would otherwise be. This enables us to understand how forests may increase the rainfall. For suppose an extensive forest to have its temperature 2° lower than that of the surrounding district, this lower temperature will affect the rain-bringing winds in much the same way as if a low range of hills opposed their course, and condensed their vapour into rain. In two large districts, one wooded and the other bare, the distribution of the rainfall during the months of the year and during the hours of the day may be expected to differ materially from each other.

133. The valley of Aragua, in Venezuela, is shut in on all sides, and the rivers which water it, having no outlet to the sea, unite and form Lake Tacarigua. This lake during the last thirty years of the past century showed a gradual drying up, for which no cause could be assigned. In the beginning of the present century the valley became the theatre of deadly feuds during the war of independence, which lasted twenty-two years. During that time, land remained uncultivated, and forests, which grow so rapidly in the tropics, soon covered a great part of the country. In 1822 Boussingault observed that the waters of the lake had risen, and that much land formerly cultivated was at that time under water. The drying up of the river Scamander in the Troad, and the contracting of the Euphrates in its channel, may be referred to as illustrations of the same effect of the cutting down of forests, and of diminished vegetation.

134. (2.) *On Water.*—When the sun's heat falls on water, it is not, as in the case of land, arrested at the surface, but penetrates to a considerable depth; and, since water is a bad conductor, the heat cannot penetrate lower down by conduction as it does through land, but can only be communicated by the agitation caused by currents or winds. Thus the heat received daily by the ocean from the sun is diffused through a considerable depth.

135. *Specific Heat of Water in relation to Climate.*—The specific (French, *spécifique*) heat of a substance is the number of units of heat required to raise the temperature of one pound of it by one degree. For example, the same amount of heat that will raise one pound of water one degree will raise one pound of mercury 33°. If therefore we call the specific heat of water 1000, the specific heat of mercury is only 33. Of all known substances

water has the greatest specific heat. As compared with the specific heat of the soil and rocks which compose the earth's crust, water is in the proportion of about 4 to 1. It follows that the surface of the sea cannot be raised to nearly the same degree of heat by the sun's rays as that of the land; and that when the temperature is falling the sea cools much more slowly than the land. Thus, while the surface temperature of the soil has been frequently observed to be as high as 140°, the surface of the sea has in only a few instances been observed to exceed 85°. It is to the great specific heat of water that the enormous effects of the ocean in modifying climate are due.

136. The instrument used in observing the temperature of the surface is a *Maximum Black-bulb Thermometer*, which is an ordinary maximum thermometer, having its bulb covered with a thin coating of lamp-black, and quite exposed to the sun and air. It should be placed horizontally over short grass, so near the ground as just to be above the grass, and in such a position that the sun may shine directly on the bulb for as large a portion of the day as possible. This is best done by making the bulb project a little beyond the framework of the thermometer, and point directly to the sun at twelve o'clock. It is only by attending to such directions as these that any tolerable uniformity can be obtained among black-bulb observations. Observations do not admit of comparison where the exposure and duration of exposure of the bulbs of the thermometers to the sun, their height above the surface, and the character of the surface, are different. *Black-bulb thermometers* enclosed in thin glass tubes, hermetically sealed, are also used by meteorologists.

137. TERRESTRIAL RADIATION.—Since the mean temperature of the earth remains practically the same, it is evident that the earth must part with the enormous quantity of heat which is poured on it from the sun from day to day. It is by terrestrial (Lat. *terra*, the earth) radiation, or by radiation from the earth into space, that the earth parts with this heat,—a process which goes on by day as well as by night. During the day the heat radiated from the earth is less than that received from the sun, and as long as this continues the temperature rises. But as the sun sinks near the horizon, its beams fall more aslant, and less heat begins to be received by solar than is given off by terrestrial radiation. For a time the loss thus sustained by the surface temperature is compensated for by heat rising to the surface from the heated strata immediately below it; but this continues only for a short time, because the escape of heat by radiation is much more active than

the propagation of heat by conduction. As soon, then, as the radiation from the surface exceeds all sources of supply, the temperature begins to fall, and continues to do so till it is arrested, or till the sun again returns. Since, then, during night, and during the winter, the cooling of the air is brought about by contact with the chilled surface of the earth, it follows that up to a certain elevation the temperature of the air will increase with the height.

138. There is another source from which the chilled surface receives accessions of heat—viz., when the air at the surface is cooled down to the temperature of the dew-point; for when this point is reached dew is deposited, and latent heat given out.

139. When the sky is wholly or partly covered with clouds, a large portion of the heat radiated from the earth to the clouds is radiated back again from the clouds to the earth; and thus on cloudy nights the loss of heat by radiation is not so great as on clear nights, and not so great when the clouds are low as when they are high.

140. But the vapour of water obstructs radiation, not only when in a visible form as clouds, but also when it is diffused in an invisible state through the air; and hence the drier the air is, the colder is the temperature during night.

141. The surface of the earth is cooled by radiation to a greater degree during calm than during windy nights, because, owing to the agitation caused by the wind, it is warmed by contact with the air of the upper as well as of the lower strata of the atmosphere. The amount of heat radiated is the same, but the effects are not, as on calm nights, chiefly confined to the surface, but are more generally diffused through the air itself.

142. The degree to which the temperature of objects is reduced by radiation, is proportioned to the amount of sky exposed to the free view of the object. Thus if houses or trees be near—that is, if they cut off a part of the sky from the field of view—the temperature will not fall to the same extent. A cloud passing over raw wool much cooled by radiation, has been observed by Mr Glaisher to raise the temperature of the wool 15° in the quarter of an hour.

143. *Means of Measuring the Cold of Radiation.*—This is usually done by the ordinary *Minimum Black-bulb Thermometer*, which is a common minimum thermometer having its bulb blackened. As in the case of the maximum black-bulb, it is laid over grass with its blackened bulb freely exposed, and in such a position as to command a view of the whole of the sky, or as much of it as possible. If it does not command a view of the whole, the amount cut off by surrounding objects should be

noted. It should always be placed just above the ground, never on an object at some height above the surface; it should also be laid on grass kept short; and the blackened bulb should project a little beyond the scale, so as to be freely exposed all round.

144. The degree to which the temperature falls depends on the radiating and conducting powers of the surface over which the thermometer is placed, and is greater as the radiating power is greater and the conducting power less, and *vice versâ*. We give below the relative cooling powers of a few of the more important substances, as determined by Mr Glaisher from extensive experiments made by him,—long grass being 1000:—

Hare-skin, . . .	1316	Glass, ...	864
Raw white wool, . .	1222	Snow, ...	657
Flax, ...	1186	Garden mould, . . .	472
Raw silk, . . .	1107	Sand, ...	454
White cotton wool, . .	1085	Stone, ...	390
Lamp-black powder, .	961	Gravel, ...	288

145. One of the most instructive examples illustrative of this subject that could be given is the result of Mr Glaisher's observations on the different temperatures of long and short grass. A thermometer placed on long grass was found to be on a mean 1°.1 lower than one on short grass, whilst the temperature of the soil under long grass was 1°.1 *higher* than under short grass. The temperature was thus the same amount in excess under the long grass as it was in defect over it. Hence the difference of temperature over the long and the short grass was entirely due to the greater quantity of heat conducted from the soil to the top of the short grass over that conducted to the top of the long grass, and not to any difference in the radiating powers of the grasses. The experiments were extended, and it was found that the temperature varied with every variation of length, fineness, and closeness of texture of the blades of the grass.

146. *Dew.*—When a glass of cold water is brought into a warm room, the surface of the glass is soon covered with small globules of water, provided the temperature of the glass be below the dew-point of the air of the room. This phenomenon takes place on a grand scale over the earth's surface every night when the atmosphere is comparatively clear and calm. For, as the earth is cooled down by radiation, as soon as the temperature of the dew-point is reached by any body, the vapour of the air begins to be condensed into dew on its surface. The quantity of dew which is deposited is in proportion to the degree of cold produced, and the quantity of vapour in the air. Hence, from what has just been said in par. 144, more dew will be deposited on furs, wool, silk,

flax, and cotton, than on grass and vegetable substances generally, and less on glass, mould, sand, and gravel. Thus, by a most beneficient arrangement, dew falls most copiously on those objects on the earth's surface which most require its refreshing influence. It is not deposited in cloudy weather, because clouds prevent the loss of heat by radiation ; nor in windy weather, because wind constantly renews the air in contact with the ground, and thus prevents the temperature from falling sufficiently low. Dew is rarely deposited on the surface of deep water, because its temperature scarcely ever falls below the dew-point. When the temperature is below the freezing-point, the dew freezes as it is deposited, and *hoar-frost* is produced.

147. *Effects of Radiation on Water.*—Heat is freely given off from the surface of water as well as from land. But from various causes the effects of radiation on the surface of water are very different from those on land. Owing to its great specific heat, its temperature falls much more slowly than that of land. This conserving influence of water on the temperature is greatly increased by another peculiarity. For when the particles floating on the surface are cooled by radiation they become heavier and sink, and warmer particles from below rise to supply their place. Thus the surface can only cool as the entire body of water is cooled, and the change of temperature in a body of deep water by radiation from the surface during a night will be almost imperceptible ; consequently the temperature of the air resting on this water will undergo comparatively little depression on calm nights.

148. The mean daily range of the temperature of the sea has been ascertained off the Scottish coast from observations made by Captain Thomas, R.N. On a mean of the year it is as follows :—

Mean of daily Minima .	48°.43	Maximum at 4 P.M. .	49°.02
Mean at 11.20 A.M. .	48°.89	Mean at 1.20 A.M. .	48°.89

Hence the temperature of the sea near the surface only varies on the average about 0°.6 in the day, while in Scotland the air varies 12° on the average. The greatest differences observed on any day in the temperature of the sea were 5°.6 and 5°.3, amounts altogether exceptional ; whilst the temperature of the surface of the land varies not unfrequently as much as 100° during one day. These figures present in a striking light the conserving influence of the ocean on climate as compared with that of the land.

149. It is a well-known general property of matter that bodies expand with heat and contract with cold; but to this law water is one of the remarkable exceptions. Water follows the general law till it falls to 39°.2, after which, as the temperature falls,

instead of contracting it begins to expand, and continues to do so till it reaches the freezing-point. Water is therefore at its maximum density at 39°.2. When it is just falling to 32°, or immediately before it freezes, it occupies as great a space as it did at 46°.3. But if common salt be dissolved in water, the temperature of its maximum density is lowered; and if it be brought to the average degree of saltness of sea-water, the temperature of its maximum density is 26°.2, and of freezing 28°.4.

150. Since, then, sea-water of the average saltness follows the general law in contracting as it is cooled till it freezes, no ice can be formed on its surface till the temperature has fallen through all its depths nearly to freezing. On the other hand, as soon as the temperature of fresh water has fallen to 39°.2 through all its depths, the surface-water becomes lighter as it cools, and consequently no longer descends, but floats on the surface. This circumstance marks an essential distinction between the effects of sheets of salt and fresh water respectively on climate. The surface temperature of sea-water falls very slowly from 39°.2 to 32°, because as it falls the temperature of the whole water through its depths must fall; whilst from 39°.2 to 32° the surface temperature of fresh water falls rapidly, because it is only the portion floating on the surface which requires to be cooled.

151. Owing to its great depth, Loch Ness, Inverness-shire, is not known to freeze. Its temperature being therefore always high, even during intense and protracted frosts, the winter climate along its shores is mild and partially insular in its character. So high is the temperature of the lake, that the Ness does not freeze in its short course to the sea. On the other hand, Loch Leven, Kinross-shire, being shallow, is easily frozen over, and hence it has no effect whatever in moderating the rigours of intense frosts on its banks. As these lakes are small, their influence operates but to a very limited extent. It is in the magnificent system of fresh-water lakes in North America that this influence is most strikingly seen. Owing to the severe cold of the winters, these lakes are partially frozen for some distance from their shores during that season, and hence that region is curiously characterised by a winter climate of almost continental severity, and a summer climate of comparative insular coolness.

152. Advantage was taken of terrestrial radiation *to manufacture ice* during night in Bengal, even though the temperature of the air was above 32°. A piece of ground, nearly level, was divided into square plots, from 4 to 5 feet wide, which were surrounded by little mounds of earth, 4 inches high. In these enclosures, previously filled with dry straw or canes, many broad

shallow unglazed earthen pans were placed, containing pump-water. When the air was still much ice was formed; wind prevented its formation altogether. The object of the excavations and little mounds of earth was to increase the stillness of the air. Since, then, the evaporation must have been small when ice was formed most plentifully, the cooling of the water and the formation of the ice was caused by terrestrial radiation. The object to be obtained in using dry straw was to secure for the pans a badly-conducting substance; when the straw was wetted, and its conducting power thus increased, little or no ice was formed.

153. *Effects of Terrestrial Radiation on Land.*—One of the chief effects of terrestrial radiation on air resting over land, as compared with that over the sea, is to increase the range of the temperature. Thus, while the mean daily variation in the temperature of the air over the sea in the west of Scotland is about 6°.0, on the land it is about 12°.0; and in extreme cases the variation on land is three or four times greater than on the sea.

154. The increase of temperature with the height during cold weather takes place invariably in dry, calm, clear weather, during the night, and in winter, when the temperature of the air is lowered by contact with the chilled surface of the earth. Between the temperature of the air in contact with the surface of the ground, and the air 4 feet above the ground, the difference is frequently 15° or 20° during the night, but above 4 feet the differences are generally small. On the 8th April 1844, at 8 P.M., Mr Glaisher observed a difference of 25°.0 between two thermometers, one placed on raw wool over long grass, and the other at a height of 4 feet; and at 8 feet high the temperature was 3°.5 warmer than at 4 feet. Hence the temperature of the air on the ground was 28°.5 colder than at a height of 8 feet at the same time. From an extensive series of observations made by the same indefatigable meteorologist with thermometers fully exposed to the sky, the means, as compared with those *on long grass*, were as follow:—

At	1 inch	above long grass,		+ 2°.76
,,	3 inches		,,	+ 4°.39
,,	6	,,	,,	+ 6°.02
,,	12	,,	,,	+ 7°.31
,,	24	,,	,,	+ 7°.67
,,	48	,,	,,	+ 7°.81
,,	96	,,	,,	+ 8°.26
,,	144	,,	,,	+ 8°.27

A thermometer at 4 feet above long grass, protected from six-tenths of the sky, stood, on a mean, 8°.39 higher. From experiments made by M. Ch. Martins in the south of France, he found, on a mean of 88 nights, that the temperature at a height of 6½ feet as compared with 2 inches, was 1°.5 warmer; that for every yard between 20 and 96 feet, it was 0°.12 warmer; and between 96 and 162 feet, it was 0°.04 warmer. Hence the necessity of having all thermometers in shade placed at the same height above the ground, for otherwise the results are not comparable.

155. But the rate at which the temperature increases with the height is modified, to a very great extent, by the physical configuration of the surface—that is, whether that surface be level, undulating, or mountainous. To understand how this happens, let us suppose an extent of country diversified by plains, valleys, hills, and table-lands, to be in circumstances favourable to radiation, and each part under the same conditions, except in the single point of position. Radiation will proceed over the whole at the same rate, but the effects of radiation will not be felt everywhere in the same degree and intensity. For as the air in contact with the declivities of hills and rising ground becomes cooled by contact with the cold surface of the ground, it acquires greater density and weight, and consequently flows down the slopes and accumulates on the low-lying ground at their base. Hence places situated on rising ground are never exposed to the full intensity of frosts; and the higher they are relatively to the surrounding ground, the less are they exposed, being protected by their elevation, which provides, as it were, an escape for the cold almost as fast as it is produced. On the contrary, valleys more or less environed by hills or eminences not only retain their own cold of radiation, but also serve as reservoirs for the cold air which is poured down from the neighbouring heights. Hence low-lying places are peculiarly exposed to intense cold. Plains and table-lands are simply affected by their own radiation.

156. This explains why vapour so frequently becomes visible in low places, whilst adjoining eminences are clear. The same fact instinct has made known to cattle and sheep, which generally prefer to rest during night on knolls and other eminences. Along most of the watercourses of Great Britain, during the memorable frost of Christmas 1860, laurels, araucarias, and other trees growing in low situations were destroyed, whereas those growing on higher ground escaped; thus attesting, by unmistakable proof, to the great and rapid increase of the temperature with the height at places rising above the lower parts of the valleys.

157. It is evident that the distribution of temperature over the surface of a mountainous country during calm weather in winter, will be regulated by a different law than that of height above the sea. Sixty-nine Meteorological Stations were established in Swit-

zerland in 1863; and as one of the first-fruits of this Society, a paper was published by Professor E. Plantamour, on the Distribution of Temperature on the surface of Switzerland during the winter of 1863-64. It was observed that when the soil is colder than the air above it, the superficial layers become cold by contact, and a system of descending air-currents sets in over the whole face of the country. The direction and velocity of these descending currents are modified by the irregularities of the ground, and, like currents of water, they tend to converge and unite in the gorges and ravines, down which they flow like rivers in their beds. These currents necessarily give rise to counter-currents flowing over them to supply their place.

158. When the station is on the top of a mountain, as the Righi, the counter-current comes from a great height above the ground, and being therefore warmer, the temperature of such stations is comparatively high. At places situated on the sides of mountains, the influence of the counter-current tends to raise the temperature, though in a less degree than at the top, on account of the descending current from the heights above mixing with it. The Swiss villages being generally built on eminences rising out of the side of the mountains, and bounded on both sides by gorges or ravines, are thus admirably protected from the cold of winter; for the descending currents flow aside into the gorges, and the counter-currents are constantly supplying warmer air from the higher regions of the atmosphere.

159. Though the space occupied by the current of cold air in the bottom of a valley is of greater extent than the bed of a river, it is nevertheless limited, and on all occasions tolerably well defined, so that on rising above it in ascending the slope, the increase of temperature is readily perceptible. The gradual narrowing or contracting of a valley has a very appreciable influence in lowering the temperature; for the valley is thus transformed into a basin almost closed, into which cold currents of air descend from all sides. On such occasions, a cold wind rushes impetuously down the narrow gorge, which serves as an outlet to the basin. It is on this principle that many of the sudden gusts and breezes peculiar to mountain districts, such as *vent du Mont Blanc*, are to be explained. When the basin is a deep lake, the cold which is poured down on its surface, having cooled the surface-water, is thereby conveyed to greater depth, and has therefore scarcely any effect in lowering the temperature of the air resting over the lake. Hence lakes are a source of heat during winter, and places situated at their outlet are not exposed in the same degree to such gusts of cold wind as those referred to above;

and places on their shores do not suffer from those severe frosts which occur during calm weather in winter in other low-lying situations, and which prove so injurious to health and vegetation.

160. *Influence of Forests.*—The temperature is found to be warmer at the base of a mountain, and up its sides, when the slopes above are covered with trees. The beneficial influence of forests appears in two ways—viz., in the diminished radiation from the surface protected by the trees, and in the obstacle they oppose to the descending currents of cold air. On the contrary, the cold of winter is more severely felt in those localities where the slopes above are destitute of vegetation, and consist only of bare soil and rocks, or of snow.

161. This peculiar distribution of the temperature only takes place during comparatively calm weather; during windy and stormy weather the law of the decrease of temperature with the height takes effect.

162. *Situations which afford the best protection against the Cold of Winter.*—In countries such as Great Britain, and, indeed, in temperate countries generally, the majority of the deaths which occur are occasioned, or at least hastened, by low temperatures. In the tables of mortality and temperature, published weekly by the Registrars-General for England and Scotland, we have constant proof of this statement. For when, during the cold months of the year, the temperature happens to fall a few degrees, the death-rate at once rises to a height proportioned to the depression of the temperature. It is thus a matter of most vital importance, especially to invalids, to know the local situations which afford the best protection against the evil influence of low temperatures. From what has been already said regarding the increase of temperature with the height, it is evident that mere local situation may, during periods of great cold, have the effect of maintaining a temperature many degrees higher than what prevails at lower situations close at hand—a difference which must assuage suffering, and not unfrequently save life. The advantage will of course be the greater if the sleeping-apartments be in the higher flats of the house. The dwellings best protected against severe cold are those situated on a gentle acclivity, a little above the plain or valley from which it rises, having a southern exposure, and the ground behind planted with trees.

CHAPTER VI.

THE DISTRIBUTION OF TERRESTRIAL TEMPERATURE.

163. THE distribution of terrestrial temperature may be conveniently treated of under three heads—viz., the temperature of the sea, of the land, and of the air.

The Temperature of the Sea.

164. The whole water of the seas over the globe is one body, and on account of its fluidity a free communication is kept up among its different parts; and since sea-water contracts, and consequently gains in density, as it is cooled until it freezes (par. 149), the cold water tends everywhere to flow towards and settle in the depths of the ocean. From this it follows that the water of the sea will, below a certain depth, fall to one uniform temperature, and *that temperature just as cold as the surface temperatures of the sea over the whole globe can reduce it to.* From recent observations of deep-sea temperatures, with the Miller-Casella thermometer, temperatures as low as 35°.0 have been found in the Atlantic, and other parts of the ocean. Very low deep-sea temperatures have also been observed in the Arabian Sea. It may thence be concluded that the temperature of the sea at great depths is everywhere over the globe at least as low as 35°.0, provided the bed of the ocean permits free communication between the polar seas and these depths. The exact ascertaining of this deep-sea temperature in all oceans is one of the capital questions of physics. Owing to the comparative shallowness of the sea at the Straits of Gibraltar, the deep water of the Mediterranean is not directly in communication with that of the Atlantic, and accordingly it is found that the temperature of the Mediterranean at a depth of 1508 fathoms is 55°.

165. *Surface Temperature of the Sea.*—This is one of the

most important problems of Meteorology and Physical Geography, but it has as yet been worked out only so far as to obtain no more than the very rudest approximation to a solution. The part of the sea whose temperature is best known is that portion round Iceland, Faröe, Scotland, and Norway, from which, owing to the labours of the Scottish and Norwegian Meteorological Societies, we have systematic observations during the last thirteen years. From these observations we learn that the mean temperature at the mouth of Loch Fyne is 49°.0; west of Oban, 48°.7; at Harris, in Lewis, 48°.9; Orkney, 48°.8; Shetland, 48°.4; and the mouth of the Firth of Forth, 47°.8. Hence the Atlantic is 1°.0 warmer than the North Sea off the east coast of Scotland. The sea is also 1°.0 warmer than the air, and among the islands in the north it is 3°.0 warmer. But it is during winter that the difference between the temperature of the Atlantic and the North Sea is greatest. The mean temperature of the Atlantic in July is 54°.4, and in January 44°.7; whilst the North Sea is 55°.5 in July, and 40°.8 in January. And if extreme temperatures be considered, the advantage in favour of the Atlantic is greatly increased, for the lowest temperature to which the Atlantic has yet been observed to fall is 39°.1, whereas at the extremity of Trinity Chain Pier in the Firth of Forth, the temperature of the sea fell to 33°.7 in February 1865. These are the temperatures of deep water; but in shallow water much lower temperatures occur.

166. *Temperature of the Sea in different parts of the Globe.*—Owing to the small change of temperature within the tropics, the temperature of the sea in these parts may be considered as well known. It is generally from 80° to 83°.5. Between the limits of 50° north and 50° south, the mean temperature of the North Atlantic is 71°.6, and that of the South Atlantic 66°.7. The South Atlantic is thus 5° colder, and this difference is nearly uniform for corresponding parallels of latitude. Similarly the mean temperature of the North Pacific is 69°.9, and that of the South Pacific 67°.7 Hence this ocean is colder south of the equator, but the difference is not so great as in the Atlantic. Of the three oceans south of the equator—the Atlantic, the Indian, and the Pacific—the Atlantic is the coldest, being 66°.7; the Indian is the warmest, 69°.3; and the Pacific is between the two, 67°.7. On the other hand, the North Atlantic is 1°.7 warmer than the North Pacific. The mean temperature of the western half of the Mediterranean Sea is about 65°, and that of the eastern half, from 3° to 6° warmer; while that of the Black Sea is only 56°.8. On the other hand, the mean temperature of the Red Sea north of 20° lat. is 77°.4, but south of that parallel it is

81°.5. The great differences between the temperatures of these seas must powerfully influence the climates of Palestine, Asia Minor, and adjacent countries.

167. The highest temperature anywhere yet observed is 94° in the Red Sea, near Aden; the highest temperatures elsewhere are 91°, near Siam, and 89° and 88° in several places in the Indian Ocean near the equator.

168. *Abnormal Distribution of Temperature caused by Currents of the Sea.*—In the accompanying chart (fig. 15), which is adapted from a chart published by Professor Mohn, Christiania, the mean annual temperature of the sea is given with great accuracy for the northern portion of the Atlantic, in which the thermal axis, or line of greatest heat, is seen to pass through the Hebrides in a north-east course. If this line be produced towards the south-west as far as Cuba, it is found to pass through temperatures higher than those which prevail to the eastward or westward of it. Now this anomalous temperature could not be maintained unless there was a general flow of the water of the ocean through the midst of the Atlantic north-eastward into the Arctic Ocean. This line of high temperature marks the course of a powerful ocean-current, which spreads itself north-eastward over the Atlantic. By the warmth it brings from southern latitudes, the British climate is upwards of 20° warmer in winter than it would otherwise be. By the time it arrives at the British Islands, its passage is, no doubt, slow; but from the slow rate at which the temperature of the sea is brought to a complete correspondence

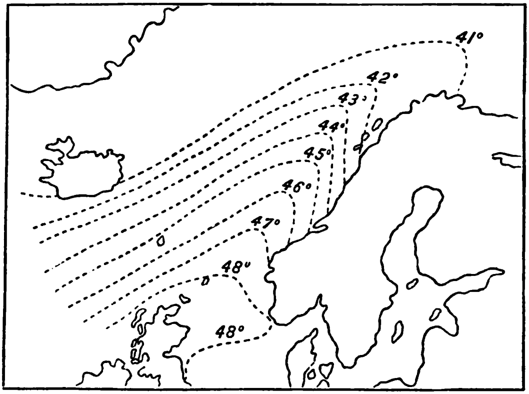

Fig. 15.

with that of the air, it will carry with it enough of its original heat to keep it warmer than the air, though it take some months to traverse the distance from the north of Ireland to Orkney. Observations prove that the temperature of the sea, as compared with that of the air, is about 3° higher in Orkney than it is in the south of Scotland. In the north-west of Iceland the temperature of the sea is 5°.0 warmer than that of the air, and at many places on the coast of Norway the difference in favour of the sea is nearly as great.

169. Off the Gulf of Guayaquil in South America, the temperature of the sea is only 70°, being from 10° to 12° below the average of tropical seas. This extraordinary depression of temperature is brought about by the cold waters transported thither by the great *Humboldt Current* from the higher latitudes of the South Pacific. Proceeding westwards along the equator from Peru to the East India Islands, the temperature rises successively to 75°, 80°, 83°, and 84°.5. The last mean temperature, being the highest anywhere on the globe, occurs a little to the east of New Guinea. From this point to the east coast of Africa, including the whole of the northern half of the Indian Ocean, the temperature ranges from 81° to 84°; except near the mouths of some of the large rivers, where it is 1° or 2° less.

170. South of Sierra Leone, the temperature of the Atlantic is only 75°, but from this westward it rapidly rises to 78°, 80°, 82°, and finally to 83°.5 in the confined waters of the Gulf of Mexico, in the Gulf of Honduras; but as the current traverses the gulf, and mixes with the colder water poured down by the Mississippi, the temperature falls to 76°.

171. The low temperatures on the east coast of North America are caused by the well-known current from the frozen seas of the arctic regions which flows southward over the bank of Newfoundland. On the west coast of North America, the temperature of the sea increases from east to west. Thus, proceeding from the shore westwards, the temperatures of the North Pacific by the ten-degree squares are respectively, between 20° and 30° N. lat., 63°.3, 66°.9, 74°.5, and 77°.7; between 30° and 40° lat., 56°.4, 61°.8, 64°.0, 71°.0; and between 40° and 50° lat., 49°.2, 53°.5, and 59.°0. This distribution of temperature is caused by a cold current passing southward along the west coast of North America.

172. The temperature of the South Atlantic increases westward, showing a flow of the ocean southward along the east coast of South America, thus raising the whole temperature of that coast. The effect of the two opposite currents on the coasts of this continent, is to raise the temperature on the east coast from 8° to

10° above that on the west coast in the same latitude. The southern part of Africa is similarly situated with respect to currents, and the effect on the temperature of the sea is even more marked than in the case of South America,—the temperature in the Gulf of Mozambique being 81°.1, while on the coast of Lower Guinea, in the same latitude, it is only 67°.6, the difference being 13°.5.

173. The sea on the east of Asia from China northwards becomes warmer as we recede eastward from the continent. Thus, between 20° and 30° lat. the temperatures of the squares are 72°.4, 78°.8, and 83°.0; between 30° and 40° lat., 60°.0 and 66°.2; from which northwards in the Sea of Okotsk, it falls to 46°.7 and 34°.5 (?). Thus the east coast of Asia is also chilled by currents descending on it from higher latitudes. Cold currents also set in towards Australia from the south-west, depressing the temperature.

174. The lowest mean temperatures yet observed occur in the Antarctic Ocean, between 60° and 70° S. lat., immediately to the south of the Atlantic Ocean, and Australia and New Zealand. The lowest of these temperatures is 30°.9, occurring in 35° W. long. and 65° S. lat., but lower temperatures no doubt occur in higher latitudes.

175. As regards their influence on climate, ocean-currents raise the temperature of the west of Europe, the east of South America, the east of Africa, and the south of Asia; and depress the temperature on the east and west coasts of North America, the west coast of South America, the west coast of Africa, the east coast of Asia, and the south coast of Australia.

176. It should be remarked that though what is here stated regarding currents of the sea is in many cases of a very general character, yet the service already rendered to navigation by the knowledge thus arrived at has been of the most substantial kind; for, by taking advantage of the currents, distant voyages are now accomplished sooner, and much time and money thereby saved. Much greater would be the advantage if our knowledge of the currents were fuller and more accurate than it is. When the scheme which has been sketched by the British Government, and which is now being worked out by the Meteorological Committee of the Board of Trade, shall be completed, we shall be able to know, with sufficient accuracy for all practical purposes, the prevailing winds in different parts of the ocean; and the different currents of the sea,—their temperature and density—their origin, course, and termination—the rate of their motion—the limits within which they are bounded—and the annual and secular changes to which they are subject.

177. In some cases the bed of the current is very distinctly marked off. The Gulf Stream, as it issues from the Strait of Florida, is a good example of this; and even after it has turned its course some distance to the eastward, it is in some places sharply defined. Thus, when her Majesty's ship Nile was going from Halifax to Bermuda in May 1861, Admiral Sir Alexander Milne found the temperature 70° at the bow, while it was only 40° at the stern, as he entered the Gulf Stream, thus showing a difference of 30° of temperature within the short distance of a ship's length.

178. *Density of the Sea.*—The density of the sea, or the weight of a given quantity of sea-water, at a given temperature, is increased in proportion to the quantity of salt dissolved in it. It is always compared with the density of water, which is considered as unity. The density is ascertained by means of the *hydrometer* (*hydor*, water, and *metron*, measure), fig. 16, which is a glass vessel loaded with mercury or shot, and furnished with a scale. The zero-point is found by floating it in distilled water, at a temperature of 60°, and marking the point on the scale just where it meets the surface of the water.

179. The South Atlantic is a little heavier than the North, their specific gravities being respectively 1.02676 and 1.02664; but the difference between the South and the North Pacific is considerably greater, the South being 1.02658, and the North 1.02548. Hence, of the two oceans north of the equator, the Atlantic is heavier than the Pacific; but this difference may be owing in part to the circumstance, that observations are wanting in the middle of the Pacific, where the density is probably greater than in other parts of that ocean, owing to the higher temperature and the absence of currents from the north. Of the three oceans south of the equator, the Atlantic is the heaviest, the Indian the lightest, and the Pacific intermediate between the two, the specific gravities being respectively 1.02676, 1.02630, and 1.02658.

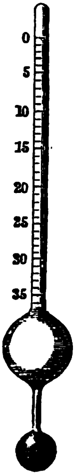

Fig. 16.

180. In the case of land-locked seas, the density falls short of, or exceeds, the above average specific gravities of the sea, according as the evaporation from their surface falls short of or exceeds the amount of fresh water they receive from rain and the rivers which flow into them. Thus the density of the Mediterranean is in excess, and gradually increases from west to east; the mean of the western half is 1.0286, and of the eastern 1.0291. In the Red Sea the density is also great, and increases from south to north,

being in the south 1.0272, and in the north 1.0297. In seas and lakes which have no outlet, and where consequently all the water passes off by evaporation, the greatest degree of saltness is attained;—such are, Tuz Gul Lake in the centre of Asia Minor, 3000 feet above the sea, the saltest lake known, containing 32 per cent of saline matters; the Dead Sea, 24 per cent; and the Salt Lake of Utah, 22 per cent.

181. But in seas whose surfaces are small in comparison to the volumes of fresh water poured into them, the density falls far below the average. Thus the average density of the Black Sea is only 1.0143, the highest recorded is 1.0209, and the lowest, at a distance from the mouths of rivers, 1.0114. The average density of the western division of the Baltic Sea is 1.0112, and of the eastern only 1.0042. In the Baltic the highest yet recorded is 1.0232, and the lowest 1.0003, being nearly the density of fresh water.

182. Heavy rains diminish the density. The lowest specific gravity in the Indian Ocean occurs a little south of the equator, whereas in the Atlantic and Pacific Oceans it is to the north of the equator, in the belt of equatorial rains and calms. At the mouth of Loch Fyne, in Argyleshire, Dr William Rankin observed the density of the sea to be 1.0210. This occurred on the 31st August 1860, after a heavy fall of rain, and at high water; next morning it increased to 1.0250, the usual density of the sea at that place. The effect of heavy tropical rains is often very striking. Thus Dr Ord of H.M.S. Hermes, on the 4th August 1859, at 9 A.M., observed the density to be 1.0266. Heavy rain fell, and in one hour the density was reduced to 1.0193; in two hours it rose to 1.0253, and in other three hours to 1.0266. In land-locked bays and arms of the sea, particularly if surrounded by hills, the very lowest densities are observed after heavy rains. In Hamnaway Loch, in the Hebrides, Captain Thomas has occasionally taken fresh water from the surface of the sea. Even in mid-ocean, within the tropics, fresh water has been taken from the surface of the sea immediately after torrents of rain had fallen.

183. Hence the chief differences in the specific gravity of the ocean arise from local circumstances. It is high where the evaporation is great, as in the region of the trade-winds; and low where much rain falls, and in high latitudes in the neighbourhood of ice. It is highest in confined seas where there are few or no rivers and little rain falls; and lowest near the mouths of large rivers, and in seas like the Baltic, which are supplied with large quantities of fresh water.

The Temperature of the Land.

184. In countries where the rainfall is pretty evenly distributed among the months, and where snow covers the ground but for a short period of the year, the mean temperature of the soil is almost identical with that of the air. But in countries where the year is divided into wet and dry seasons, and also where snow lies a considerable part of the year, the mean annual temperature of the soil may be a little above or a little below that of the air. The greatest difference between the temperature of the soil and that of the air occurs when the surface of the ground is covered for some months of the year with snow. Since snow is a bad conductor of heat, it prevents, on the one hand, the propagation of the cold of radiation downwards into the soil, and, on the other, the escape of heat from the soil into the air. Snow thus depresses the temperature of the air in two ways—(1) by retaining in the air almost the whole of the cold produced by radiation, and (2) by stopping up the supplies of heat which would otherwise be drawn from the soil. Since, for the same reasons, the temperature of the soil is kept warm, it follows that the temperature of the soil greatly exceeds that of the air when snow lies for some time on the ground. In Russia and Siberia the greatest divergence between the curves of these two temperatures is observed. In Russia, about 120 miles south of Archangel, the mean temperature of the air is 32°, whereas that of the soil is 41°; the soil being thus 9° higher. In Semipalatinsk, in the south-west of Siberia, the temperature of the air is 41°, and of the soil 50°, or 9° higher than that of the air.

185. The daily changes of temperature do not affect the soil to greater depths than about three feet. The exact depth varies with the daily range of temperature, by which the amplitude or force of the daily heat-wave is determined, and with the nature of the soil. Similarly the heat of summer and the cold of winter give rise to a larger annual wave of heat propagated downwards, which becomes of less and less amplitude as it recedes from the surface, until it reaches a depth when it ceases to be perceptible. Principal Forbes has shown from the observations made on underground temperature on the Calton Hill, Edinburgh, that the annual variation does not penetrate further than 40 feet below the surface, and that below 25 feet it is very small. The depth at which the annual variation ceases to be observed, and where accordingly the temperature is constant, depends on the conductivity and specific heat of the soil or rocks, and particularly on the difference between the summer and the winter temperature.

186. Owing to the slow rate at which the annual heat-wave is propagated, the highest annual temperature of the trap-rocks of the Calton Hill, Edinburgh, at the depth of 24 feet, takes place about the 4th January, and the greatest cold about the 13th July, thus reversing the seasons at that depth. According to Professor J. D. Everett, who has examined the Greenwich observations of Deep-Sunk Thermometers from 1846 to 1859, the highest temperature at a depth of 25.6 feet occurs on the 30th November, and the lowest on the 1st June; and at a depth of 12.8 feet, the highest occurs on the 25th September, and the lowest on the 27th March.

187. From the results arrived at by the observations of the Scottish Meteorological Society, made at depths of 3, 12, 18, 22, 36, and 48 inches below the surface, it has been found that there is a small but steady increase in the mean temperature at these various depths, from 3 inches downwards. To this conclusion there is no exception at any of the stations where such observations have been carried on. Further, Principal Forbes has shown from the Calton Hill observations, that the mean temperature increases from 3 feet downwards to 24 feet, the latter depth being fully a degree above the former. At 3 feet the mean temperature is 45°.8 ; at 6 feet, 46°.1 ; at 12 feet, 46°.4 ; and at 24 feet, 46°.9.

188. Springs which have their sources at greater depths than that to which the annual variation penetrates, have a constant temperature throughout the year. They may therefore be considered as giving a close approximation to the mean annual temperature of the locality, unless they come from a considerable depth. All experiments made on Artesian wells and other deep borings, prove in the most conclusive manner that the temperature increases with the depth. It has been observed that in the chalk strata forming the lower part of the Paris basin, the temperature increases 1° for every 55 feet. In higher latitudes the increase with the depth is more rapid. Thus at Yakutsk, in Siberia, the temperature at a depth of 50 feet is 15°.1 ; at 77 feet, 16°.5 ; at 120 feet, 21°.0 ; and at 382 feet, 30°.6—giving an increase of 1° in every 21 feet.

189. From observations made in a well at Kentish Town, 1100 feet deep, by Mr G. J. Symons, there is a mean increase of 1° for every 55½ feet. Observations have also been made during the sinking of Rosebridge Colliery, near Wigan, by Mr W. Bryham, which show an increase, from the surface to a depth of 2415 feet, at the rate of 1° for every 54¼ feet. The mean rate of decrease was very far from being uniform through the whole depth, varying from 1° in 31 feet to 1° in 86 feet. The mean rate of increase

over the globe cannot yet be stated, but it may be assumed to be approximately 1° for every 50 English feet of descent.

190. Hence, then, the mean annual temperature increases from the surface as far down into the crust of the earth as man has yet been able to penetrate. It follows from this result that heat must constantly be passing from the interior of the earth to its surface, whence it escapes into space; and hence the temperature of the whole earth must be cooling from year to year. Sir William Thomson of Glasgow has calculated that during the last 96 million years the rate of increase of temperature underground has diminished from 1° for every 10 feet, to 1° for every 50 feet of descent as at present; and adds that, if this action had been going on with any approach to uniformity for 20,000 million years, the amount of heat lost out of the earth would be more than enough to melt a mass of surface-rock equal in bulk to the whole earth; and in 200 million years it would be enough to melt the rocks forming the earth's crust. If this reasoning be just, geologists cannot claim a much higher antiquity for life on the globe than 100 million years.

Distribution of Temperature in the Atmosphere.

191. The distribution of temperature over the surface of the globe is represented by isothermal lines, or lines drawn through all places having the same mean temperature. The mean temperature of January, the coldest month in the northern hemisphere, is shown by the isothermal lines in Plate IV.; of July in Plate V.; and of the year in Plate VI. These systems of lines are called *isocheimals* (Gr. *isos*, equal, and *cheima*, winter), or lines of equal winter temperature; *isotherals* (Gr. *isos*, equal, and *theros*, summer), or lines of equal summer temperature; and *isothermals* (Gr. *isos*, equal, and *thermē*, heat), or lines of equal mean annual temperature.

192. In all the charts the part of the earth's surface where the highest temperature prevails forms an irregularly-shaped belt lying in tropical and partly in subtropical regions, and may roughly be considered as comprised between the north and the south isothermals of 80°. On either side of this warm belt the temperature diminishes towards the poles; and the lines showing successively the gradual lowering of the temperature are, speaking in a loose sense, arranged parallel to the equator, thus illustrating the predominating influence of the sun as the source of terrestrial heat. While the decrease of temperature

in advancing towards the poles corresponds, in a general way, to what may be called the solar climate, there are great deviations brought about by disturbing causes. These disturbing causes are —(1) the currents of the sea; (2) large surfaces of water which are frozen over during part of the year; (3) the unequal distribution of land and water; (4) prevailing winds; and (5) mountain-ranges.

193. The influence of an oceanic current on climate depends on the temperature of the place it leaves, and that of the place towards which it flows. Hence the great equatorial current flowing from east to west does not require to be considered here, inasmuch as the temperature remains generally the same throughout its course. It is those currents which convey the waters of the sea to high or to lower latitudes that require to be considered.

194. *Gulf Stream.*—Of these currents the most important, as well as the best marked, is the Gulf Stream—or more properly the flow of the North Atlantic northwards, as already described, of which the Gulf Stream is the most prominent part—which, by conveying the warm waters of the south to the arctic regions, pushes the isothermals many degrees northward. The effect on the climate of western Europe during the year, and especially during winter, Plate IV., receives striking illustration from the charts. If no more heat were received than is due to the position on the globe in respect of latitude, the mean winter temperature of Shetland would be only 3°, and that of London 17°. But chiefly owing to the heat given out by the Gulf Stream during winter, and carried to these places by the winds, their winter temperatures are respectively 39° and 38°—Shetland being thus benefited 36° and London 21° from their proximity to the warm waters of the Atlantic. In Iceland and the Norwegian coast, the increase thus accruing to the winter temperature is much greater. To all these places the Atlantic may be conceived as a vast repository of heat, in which the warmth of the summer months, and that of more southern regions, are treasured up and reserved against the rigours of winter.

195. *Winter Temperature of the British Islands.*—The Gulf Stream leaves its impress unmistakably on the temperature of each of the months, as shown by the position of the monthly isothermals. In January (fig. 17), the deviation from the normal position of the isothermals, from their east-and-west direction, is greatest. Indeed, as regards Great Britain, the lines are then at right angles to this normal direction, and lie north and south. In Ireland they seem to envelop the island with their folds, which increase in warmth from the centre of the island outward to the

ocean. This points out clearly that the great source of heat from which the climate of Great Britain derives its warmth in winter is in the west; and that it is not to the winds alone, but also to the Atlantic Ocean, that we must look as the cause of almost the whole of this excess of temperature. For if the winds alone were the cause of the higher temperature, there would be a different arrangement of the lines of equal temperature.

196. This peculiar distribution of the winter temperature of the British Islands has important bearings on the treatment of diseases. Since the temperature of the whole of the eastern slope of Great Britain is the same, it is evident that to those for whom a milder winter climate is required, a journey southward is followed by no practical advantage, unless directed to the west coast. And as the temperature on the west is uniform from Shetland to Wales, Scotland is as favourable to weak constitutions during winter as any part of England, except the south-west. The temperature on the south-west of England and Ireland being, however, 4° higher than the west of Scotland, the mildest climates, and therefore the most suitable resorts for invalids who require a mild climate, are to be found from the Isle of Wight westward, round the Cornish peninsula to the Bristol Channel, and from Carnsore Point in Ireland to Galway Bay.

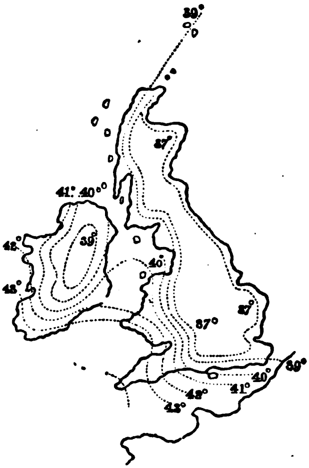

Fig. 17.

197. A similar though much feebler current passes from the North Pacific, through or towards Behring Strait, and there accordingly the isothermals are pushed a little to the northward. Part of this current returns southward by the west coast of America, depressing the temperature, especially the summer temperature, of this region, Plate V. Thus, while at San Francisco, on the coast, the July temperature is 58°.4, at Sacramento, 90 miles inland, it rises to 73°.8; and at Fort Miller, 402 feet above the sea, and 127 miles distant from it, the mean temperature of July is 90°.2. The two great currents in the southern hemisphere flowing northward

from colder to warmer latitudes—viz., Humboldt's, from the Antarctic Ocean to Lima by the coast of Peru, the other from the Cape of Good Hope along the west of Africa—lower the temperature, and thus drive the isothermals nearer the equator. It will be observed in Plate IV., which represents the summer of the southern hemisphere, that Humboldt's current breaks the continuity of the equatorial belt of high temperature bounded by 80°. Again, the great equatorial current, after impinging on the east coast of Africa, turns southward, and by the warmth it imparts pushes the isothermals into higher latitudes along the east of Africa. And for the same reason the current flowing past the Brazil coast southward raises the temperature in the east of that country.

198. In all cases the influence of these currents is most strongly marked in January and July, the months of extreme temperatures. The warm current of the Gulf Stream is most felt in January, when several of the *isocheimals*, or lines of mean winter temperature, are carried by it 1600 miles northwards of their normal position. Similarly the currents from the Antarctic Ocean being coldest in July, the isothermals are most deflected from their normal position during this month, the distance being about 1300 miles nearer the equator. Among the most remarkable displacements of the isothermals is that which occurs on the Labrador and Newfoundland coasts during May and June, caused by the icebergs and cold current which then descend on these coasts from Davis Strait.

199. The great fresh-water lakes of North America—Lakes Superior, Huron, Erie, Michigan, Ontario, Bear Lake, &c.—have an important influence on the climate of the interior of America. For in winter, America, with its either wholly or partially frozen lakes, is to a great extent an unbroken continental mass, and its winter climate may therefore be regarded as continental, except in a few limited localities immediately adjoining the deepest lakes; whereas in summer its numerous large sheets of fresh water communicate to those parts many of the characteristic features of an insular summer climate. At Fort Brady, situated in the district where Lakes Superior, Michigan, and Erie nearly approach each other, the temperature of July is 64°.6; but at Fort Snelling, to the west, in Minnesota, and nearly in the same latitude, it is 73°.4, the difference being chiefly caused by the cooling effects of the inland seas which surround Fort Brady. On the other hand, the temperatures of these two places in January and February are the same. The curving round of the January isothermals of 30°, 20°, and 10° upon the regions surrounding the Baltic, is to

some extent due to the freezing of the shallow, brackish waters of that sea during winter. Had the Baltic been deeper and salter, and not subject to freezing, the winter climate of places round its coasts would have been much less severe.

200. Since winds bring with them the temperature of the regions they have traversed, southerly currents are warm winds, and northerly currents cold winds. Also, since the temperature of the ocean is more uniform than that of the land, winds coming from the ocean do not cause such variations of temperature as winds from a continent. As an atmosphere loaded with vapour obstructs both solar and terrestrial radiation, moist winds from the ocean are accompanied by a mild temperature in winter, and a cool temperature in summer; and dry winds coming from continents, by cold winters and hot summers. Again, the equatorial current, losing heat as it proceeds in its course, is thereby brought nearer the point of saturation, and consequently becomes a moister wind; whereas a northerly current, gaining heat in its progress towards the equator, becomes a drier wind. Hence the S.W. wind in Britain is a particularly moist wind, because it is both an oceanic and equatorial current; whereas the N.E. wind, on the contrary, is peculiarly dry and parching, because it is both a northerly and continental current.

201. The height and direction of mountain-ranges is an important element to be taken into account in estimating the influence of winds on climate. If the mountain-chains be perpendicular to the course of the wind, and are at the same time of considerable height, the effect will be to some extent to divert the winds from their course. But the chief effect mountain-ranges have on the temperature is to drain the winds which cross them of their moisture, and thus to cause colder winters and hotter summers in places to the leeward, as compared with places to the windward, by partially removing the protecting screen of vapour, and thus more fully exposing them to both solar and terrestrial radiation. Of this, Norway and Sweden afford, perhaps, the best illustration; for whilst the difference between the summer and winter temperatures of Hernösand, on the Gulf of Bothnia, is 42°.5, the difference between those of Alesund in the same latitude, but on the other side of the Dovréfeld Mountains on the coast, is only 18°.4. In the British Islands, the same differences between the east and west are considerable; thus, at Greenwich the difference is 26°; whilst at Valencia, on the coast of Kerry, it is only 16°. A large part of this difference is due to the greater dryness of the air in the east as compared with the west.

202. These considerations explain the position of the isother-

mals in the north temperate zone, where the prevailing winds are westerly or southerly. In January, as shown on Plate IV., the western parts of each continent enjoy a comparatively high temperature on account of their proximity to the ocean, whose high temperature the winds waft thither ; and further, they are protected from extreme cold by their moist atmosphere and clouded skies. But in the interior of the continents it is otherwise. For the winds becoming colder and drier as they proceed, the soil is exposed to the full effects of radiation during the long winter nights; and since the ground is for the most part covered with snow, little heat can ascend from the soil to counteract the cold on the surface, and consequently the temperature rapidly falls. In the interior of Siberia, the January temperature falls to —41.°4. This is the greatest mean monthly cold known to occur on the surface of the earth, allowance being made for the height above the sea.

203. On the other hand, the interior of continents is much hotter in summer than their western coasts, because, the land being warmer than the sea at this season, the wind increases in temperature as it passes over it. Since the air is also drier, the heating power of the sun's rays is very great during the long days of summer.

204. Hence regions in the interior and in the east of Asia and America are characterised by extreme climates, and regions in the west by equable climates. At Yakutsk, in Siberia, the temperature in July is 63°.3 and in January —41°.4; whereas at Christiansund, Norway, in nearly the same latitude, these are respectively 54°.4 and 34°.3. Thus the difference between the summer and winter temperature at Yakutsk is 104°.7, whilst at Christiansund it is only 20°.1. The temperature of Sitka, in the west of North America, is 55°.6 in July, and 32°.0 in January; whereas at York Factory on Hudson Bay, in the same latitude, the July temperature is 56°.0, and the January —12°.8, thus giving a difference of only 23°.6 between the summer and winter temperature on the coast of the Pacific, but of 68°.8 in the interior of the continent.

205. Fig. 18, giving the *July temperature of the British Islands*, shows that the same law takes effect even over comparatively narrow tracts of land. The temperature of the east and the interior exceeds that of the west; and Ireland may be observed to widen the distance between the isothermals—that is, to increase the summer temperature in the parts of Great Britain lying to the east of it.

206. It is this which makes the most important distinction amongst climates, both as respects animal and vegetable life. On

man especially the effect is great. The severity of the strain of severe climates on his system is shown by the rapidly increasing death-rate according as the difference between the July and the January temperatures is increased. Thus the mortality is 8 per cent greater in England than in Scotland, the climate of the latter country being more equable or insular in its character; and it is proved that on advancing into the continent of Europe, the more extreme the climate becomes, so much the more is the death-rate increased.

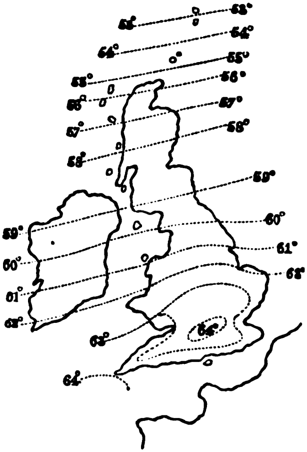

Fig. 18.

207. While the temperature of each place on the earth's surface is undergoing more or less change from day to day, rising in summer and falling in winter, it might have been supposed that the temperature of the earth itself, considered as a whole, would remain constant, from day to day, throughout the year, since the quantity of solar heat poured into it is the same from day to day. Such, however, is not the case; for from July to December, when the sun is south of the equator, a large amount of solar heat passes into the latent state owing to the extensive evaporation from southern oceans, and is conveyed by the winds into the northern hemisphere. But from January to June, when the sun is north of the equator, the evaporation being much less, owing to the larger proportion of land in the northern hemisphere, less heat passes into the insensible state in this way. From this it follows that the earth itself has an annual march of temperature, reaching the maximum at the time of midsummer, and the minimum in the middle of winter of the northern hemisphere. Sufficient materials have not yet been collected for determining with accuracy the annual range of the earth's temperature. Professor Dové has, however, attempted an approximate solution of the problem, of which the following is the result:—

	N. Hemisphere.	S. Hemisphere.	Whole Earth.
Temperature for July,	70°.9	53°.6	62°.3
Do. for January,	48°.9	59°.5	54°.2

From this investigation the temperature of the whole earth, as shown by the thermometer, would appear to be 8°.1 warmer in July than in January.

208. *Decrease of Mean Temperature with the Height.*—The decrease of temperature with the height is perceptibly felt on ascending mountains, and is still more evident in the snow-clad summits which may be seen even in the tropics. For this decrease several reasons may be assigned. In rising from the surface of the earth, we recede from a warm body and approach nearer the cold regions of space. Since comparatively little of the sun's heat is absorbed in passing through the atmosphere, but the greater part reaches the surface of the earth, it is evident that the lower strata of the air, in contact with the earth, will be most heated by the sun's rays, and the upper strata least. But suppose that the same amount of absolute heat(latent and sensible combined) was in the atmosphere at all heights; then since the air in the higher regions of the atmosphere is subjected to less pressure, it occupies a greater space, or the particles are further apart. Now to maintain the aërial particles at a greater distance from each other, more heat will be required to pass into the latent state, and hence the temperature of the higher regions of the atmosphere will be colder. Again, since at elevated situations the atmosphere of invisible vapour intervening between them and space is much less than at lower levels, such situations are less protected from the chilling effects of terrestrial radiation. On the other hand, during calm summer weather, when solar radiation is greatest, the temperature generally rises as high in many situations 1000 feet in elevation as it does at places adjacent, but near the level of the sea. As a practical illustration of this, it may be stated that peaches and apricots ripen in Strathdon, Aberdeenshire, at about 1000 feet above the sea, whereas all along the west coast to the extreme south of Scotland, the heat received from the sun is not sufficient to ripen these fruits.

209. In illustration of this subject, Glaisher has made observations in his balloon ascents, the general results of which he thus summarises: "Within the first 1000 feet the average space passed through for 1° was 223 feet with a cloudy sky, and 162 feet with a clear sky. At 10,000 feet the space passed through for 1° was 455 feet for the former, and 417 feet for the latter; and above 20,000 feet the space with both states of the sky was 1000 feet nearly for a decline of 1°."* These rates of decrease refer to the temperature of the atmosphere at different heights above the ground, which probably are altogether different from the rates of decrease for places on the earth's surface at these heights

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* Travels in the Air, p. 85.

above the level of the sea—this being the phase of the problem of which meteorologists most generally require to attempt a solution in constructing isothermal charts, and in many other physical inquiries. Thus the rate at which the mean temperature falls with the height is a very variable quantity—varying with the latitude, the situation, the dampness or dryness of the air, calm or windy weather, and conspicuously with the season of the year and the hour of the day. Accordingly, much diversity of opinion exists regarding the rate of decrease to be allowed in reducing temperature observations to sea-level. One degree Fahrenheit to every 300 feet is the rate of decrease generally adopted. But the law, through its variations, requires yet to be stated.

CHAPTER VII.

RELATION OF TEMPERATURE TO ATMOSPHERIC PRESSURE.

210. THE relation which subsists between the temperature of a portion of the earth's surface and the atmospheric pressure at that place as compared with the atmospheric pressure of neighbouring regions at the same time is all-important, especially in its bearings on many questions affecting the practical business of life. The relation is a simple one, and admits of clear illustration.

211. *Example* 1. During the severe frost which prevailed in Great Britain from the 1st to the 21st of January 1867, the following were the mean pressures, reduced to 32° and sea-level, at different places from Iceland to the English Channel for these three weeks:—

	Inches.
Reykjavik, Iceland,	30.262
Thorshavn, Farö,	29.941
Inverness,	29.758
Edinburgh,	29.692
Jersey,	29.604

The wind during the time blew from N., N.E., and E. on ten days more than the average of the month; in other words, the air flowed from the region of high towards that of low pressure in the manner previously described. The immediate cause of the singularly low temperature which prevailed is seen at once, it being plain that Great Britain was then in the stream of a powerful northerly current flowing over Western Europe. In Orkney the temperature of the month was 6°.9 below the average, whilst on the Solway Firth it was only 4°.2; on the Moray Firth it was 8°.4, but on the Firth of Forth it was only 4°.6 below the average, and at Jersey 3°. Hence places in the north suffered a greater depression of temperature than places farther south.

212. *Example* 2. During the mild weather of February 1867 the following were the mean pressures :—

	Inches.
Stykkisholm, Iceland, ...	29.320
Thorshavn, Farö, ...	29.521
Sandwick, Orkney, ...	29.655
Dundee, ...	29.818
Silloth, ...	29.903
Bournemouth, ...	30.129
Jersey, ...	30.166

Along with this distribution of the pressure there prevailed over this part of Europe a remarkably strong equatorial current, the winds being almost wholly S., S.W., and W., thus bringing over Great Britain the warmth of southern latitudes. The mean temperature of Scotland for the month rose 4° above the average, being absolutely the highest mean temperature for February recorded. The greatest excess of temperature, 4°.7, occurred in the south, and the least, 2°.6, in the extreme north of Scotland. The mildness of the month was remarkable from its being immediately preceded by the almost unprecedentedly cold weather of January, and immediately followed by equally severe weather in March.

213. *Example* 3. For April 1867 the following were the mean pressures :—

	Inches.
Stykkisholm, Iceland, ...	29.657
Thorshavn, Farö, ...	29.522
North Unst, Shetland, ...	29.521
Sandwick, Orkney, ...	29.520
Dundee, ...	29.588
Silloth, ...	29.640
Jersey, ...	29.937

Here it will be observed that there was not, as in the previous examples, a regular decrease of atmospheric pressure all the way from south to north, or *vice versa*, but that the lowest mean pressure occurred over a somewhat broad area, extending from Orkney to Farö, south and north of which the pressure rose. With this arrangement of the pressure, winds in Iceland and Farö were almost wholly N.E. and E. ; but, on the other hand, in the south of Scotland they were as decidedly S.W. and W. In consequence of which, in the north the temperature was below the average, to the extent of 5° in Iceland and 2° at Farö ; but in the south the temperature was above the average, being 2°.6 at Jersey and 1°.8 in the south of Scotland, from which it diminished northward to 0°.7 in Orkney. Over the region of low pressure a good deal more rain fell than fell to the north and to the south of it. It is often under such conditions as this that long-continued rains occur—viz., in an area of low pressure having a higher pressure on each side of it; on the northern side the rain is cold and the weather raw, and on the southern side the weather is close and warm.

214. *Examples* 4 *and* 5.—*The fine weather of November* 1867, *and the warm weather of September* 1865.—During these two months the pressures were as under:—

	November 1867. Inches.	September 1865. Inches.
Stykkisholm, Iceland,	29.914	29.464
Thorshavn, Farö,	30.100	...
Kirkwall, Orkney,	30.099	30.006
Stornoway, Lewis,	30.088	30.035
Dunrobin, Sutherlandshire,	30.202	30.038
Aberdeen,	30.203	30.131
Cairndow, Head of Loch Fyne,	30.250	30.123
Smeaton, Haddingtonshire,	30.279	30.176
Auchendrane House, Ayrshire,	30.297	30.171
Jersey,	30.278	30.240

It will be seen that during November 1867, which may be regarded as one of the finest Novembers on record, atmospheric pressure over the British Islands was unusually high, and varied little from The Channel to Iceland, but that such variation as was, showed a gradual increase on proceeding southwards. Hence the motion of the atmosphere from south to north kept up the temperature; and frost, which might have been expected at the season with the still atmosphere which prevailed at the time, rarely occurred—its occurrence being checked by the amount of vapour in the air brought by the southerly current. If this state of things had occurred in summer, when the sun's heat is great, we should have experienced a tract of the finest summer weather accompanied by great heat. This is what took place during September 1865. On the fortnight ending the 16th, during which the barometric relations were most completely fulfilled, the mean temperature rose above the average 5°.3 in Orkney, 8°.5 at Belfast, 7°.3 at Aberdeen, 8° at Manchester, 8°.6 at Yarmouth, 6°.9 at Brussels, and 10°.3 at Paris.

215. An important and vital distinction must be carefully noted. When high pressures, with little variation, prevail over the British Islands, the temperatures which accompany them are determined by this circumstance—viz., if the pressure increases, however little, towards the south, so as to appear to issue from or have its origin in that quarter, the temperature will be relatively high; but if, on the other hand, the pressure increases as we go northwards, then the temperature will be low. Thus, if during November 1867 the order of the pressures had been reversed—

that is, if instead of becoming lower in advancing northward they had been higher—severe frosts would no doubt have been the result.

216. It is the general relation of its atmospheric pressure to that of surrounding regions which gives to the climate of Great Britain its distinctive features. These general relations during January and July may be seen by examining Plates I. and II., from which the south-westerly direction of the winds which prevail in these months is the necessary consequence, as well as the peculiar distribution of the temperature as figured on the small charts on pages 71 and 75. In addition to the examples already adduced, another may be added which places in a remarkably clear light the connection between these two important meteorological elements.

217. *Example* 6.—*The Great Frost of December* 1860.—This memorable frost, unquestionably the severest that has occurred in Scotland during at least the present century, may be considered as having commenced with a heavy fall of snow on the 18th, and to have continued till the 26th. I have laid down the isobaric curves for Europe and Western Asia for each day. The general result is shown by a chart, fig. 19, representing the average pressure during these nine days. The mean direction of the wind

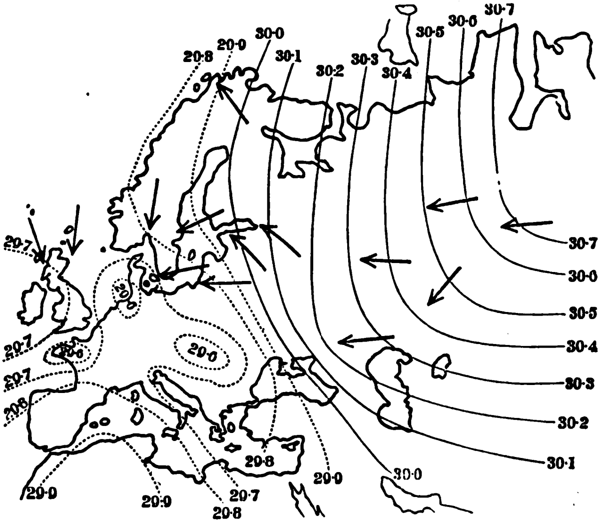


Fig. 19.

during the time is shown by arrows. Compare this chart of the pressure with Plate I., representing the mean pressure for January, which is nearly that of the period of the year when this great frost occurred. It is seen that from the 18th to the 26th December 1860, the isobaric lines did not lie as usual from W.S.W. to E.N.E., and show a gradual diminution of pressure from the south of Europe to Iceland, but that they indicated an enormously high pressure in Western Asia, which extended, in a modified degree, into Northern and Eastern Europe, while at the same time pressure was low over the rest of Europe and in the north of Africa. Now it was by the enormous drawing force which the widespread low pressure over Europe called into play, that the cold, dry, heavy air of Russia and Siberia was drawn over Great Britain and other parts of the Continent. The arrows show a continuous stream of this air flowing from Tobolsk westward through Russia, crossing the Scandinavian peninsula, and descending over Scotland as a northerly wind. At the same time the surface of Scotland was under a thick covering of snow; and the differences of pressure being at the same time comparatively small, light winds and calms prevailed. This desiccated air permitted terrestrial radiation to proceed almost unchecked; the thick covering of snow, which is a bad conductor of heat, arrested the descent of the cold downward into the soil, and the calm state of the atmosphere to a great extent prevented its diffusion upwards through the air. Hence almost all the cold of radiation necessarily accumulated on the surface of the earth; and as the coldest air is the densest and the heaviest, the frost was severest in low-lying localities. On Christmas night the exposed thermometer fell at Carstairs, Lanarkshire, to —20°; the protected thermometer at Castle Newe, in Aberdeenshire, to —12°; and the mean temperature of the whole of the eastern slope of Scotland fell to 5°.5, being about 27° below the average. On the 24th the highest temperature at Paisley was only 3°.5, and the lowest —5°.0, thus giving —0°.8 as the mean temperature of the day. When the causes conspiring to bring about frosts so intense as that of Christmas 1860 are kept in mind—viz., an extraordinary distribution of pressure similar to that exhibited in fig. 18, causing a stream of desiccated air to pass over Great Britain; the surface of the ground covered with snow; and the atmosphere calm, or nearly so—it is easy to see why great frosts so rarely occur in the British Islands.

218. The importance of these investigations is immensely enhanced when we consider the intimate relation which subsists between the march of temperature and the death-rate. This

great cold increased the death-rate to a fearful extent; indeed, more deaths were occasioned by it than when cholera or any other pestilence stalks over the land. With a more extended field for daily weather-telegrams, the notification of the approach and continuance of weather so disastrous to the weak might be shown to be possible; and if so, the physician could then take the necessary precautions to secure for such as require it an artificial atmosphere of warmer and moister air, and thus extend the sphere of his usefulness in assuaging suffering and prolonging life.

219. INTERRUPTIONS OF TEMPERATURE.—It is well known that in no year does the temperature regularly increase till it reaches the maximum in July, and thence fall without interruption to the minimum in January. It might be supposed, however, that if the mean temperature of each day of the year was deduced from a series of observations extending over many years, a close approximation, if not an absolute agreement, with such a regular increase and diminution would be arrived at. The results of all observations hitherto made are unanimous in telling that such is not the case; but that, on the contrary, there are certain periods, more or less well defined, when the temperature, instead of rising, remains stationary, or retrogrades—instead of falling, stops in its downward course, or rises—and at other times falls, or rises for a few days at an accelerated rate. These interruptions illustrate the connection between the pressure and temperature of the atmosphere.

220. Some of these periods are to a certain extent publicly recognised, and have a place among the weather apophthegms current in different countries, thus evidencing the degree to which they obtrude themselves on public attention. One of the best marked of these periods occurs from about the 11th to the 14th of April, or about the beginning of April, Old Style. This is the cold weather commonly known as the BORROWING DAYS in Scotland. There are several rhymes descriptive of it, of which the oldest is evidently the following:—

"March borrows frae April
Three days, and they are ill:
The first o' them is wun' an' weet;
The second it is snaw and sleet;
The third o' them is a peel-a-bane,
And freezes the wee bird's neb tae stane."

This is a capital description, giving by a few simple but bold touches the principal features of one of the bitter "norlan' blasts" or storms of the spring equinox; and it is all the more accurate inasmuch as these interruptions of temperature are more or less connected with storms. A period of cold weather also occurs in the middle of May. This cold is very extensively distributed, as is shown not only by its appearance in meteorological records, but also from its prominent position among the "weather saws" of every country in Europe.

221. In Scotland the following interruptions occur from year to year, with rare exceptions, in the annual march of the temperature :—

Six cold periods.

1. 7th to 10th February.
2. 11th to 14th April.
3. 9th to 14th May.
4. 29th June to 4th July.
5. 6th to 11th August.
6. 6th to 12th November.

Three warm periods.

1. 12th to 15th July.
2. 12th to 15th August.
3. 3d to 9th December.

222. These interruptions are wholly determined and regulated by the wind. Nothing could present this in a clearer light than the winds which prevail during the November and December periods. During the cold period of November, winds from the N.E., N., and N.W. are in the proportion of 35 per cent, while winds from the S.E., S., and S.W. are 29 per cent. On the other hand, during the mild period of December, winds from the S.E., S., and S.W. are in the proportion of 69 per cent, while the winds from the N.E., N., and N.W. are only 5 per cent.

223. But since the wind is only an effect resulting from differences between the atmospheric pressure in Scotland and that of neighbouring regions, the atmospheric pressure might be expected to explain the interruptions of temperature. It was found on examination to hold universally during the cold periods that pressure is higher to the north of Scotland and lower to the south, thus drawing a northerly or easterly current over Scotland, thereby depressing the temperature ; and during the warm periods that pressure is higher in Scotland than in places to the north, thus drawing over the country the warm stream of the equatorial current. Thus the unusually cold or warm periods which occur with considerable regularity at certain times of the year depend on the distribution of the pressure at the time. The prevalence of particular distributions of the mass of the earth's atmosphere over this portion of the earth's surface at stated seasons is a valuable fact in meteorology, and the more so from the light it seems to cast on the periodicity of weather-changes.

224. The commencement of each of these anomalous periods is subject to variation from year to year ; during the past fifty years some of them appeared every year between the dates specified,

and none failed to make their appearance on more than five of the years. Being also of short duration, seldom exceeding six days, and most frequently limited to three or four days, they are sudden and striking—thus differing in character from other well-known anomalies of longer duration. An examination of the isobaric curves during the time of the interruptions will, by accurately defining the region over which they spread, doubtless lead to a better knowledge of their causes.

225. From these principles it is plain that the climate of Scotland is determined by the relations which most commonly exist between its atmospheric pressure and that of surrounding regions; and since the same principles are applicable to the whole atmosphere, it follows that mean monthly isobaric charts furnish the key to the climates of all parts of the globe in the different seasons of the year. For the direction of prevailing winds thus becomes known, and these are warm or cold, and dry or wet, as may be determined by the regions from which they blow.

CHAPTER VIII.

THE MOISTURE OF THE ATMOSPHERE.

226. *The Two Atmospheres of Air and Vapour.*—The gaseous envelope which surrounds the earth may be considered as composed of two distinct atmospheres—an atmosphere of dry air and an atmosphere of vapour. The dry air (oxygen and nitrogen) is always a gas, and its quantity constant from year to year; but the vapour of water does not always remain in the gaseous state, and the quantity present in the atmosphere is, by the processes of evaporation and condensation, varying every instant.

227. According to the strength of the force of cohesion which draws the particles of matter together, as compared with the repulsive energy of heat which drives them asunder, so is the body solid, liquid, or gaseous. In solids and liquids the cohesive force is in excess, whilst in gases it is absent. If a little water be poured into a vessel it will only rise to a certain level, and leave the rest of the vessel unoccupied. On the contrary, gases and vapours completely fill the vessels in which they are, showing that there is a mutual repulsion among their particles. Since, then, the particles constantly tend to recede from each other, they exert an outward pressure on the sides of the vessel, and the amount of this pressure is proportioned to the repulsive force, or to the elasticity of the gas.

228. Since a gas completely fills the vessel which contains it, it follows that its volume is determined by the pressure to which it is subjected. The law of the compression of gases was discovered by Boyle and Marriotte, and is generally known as Marriotte's Law. It is as follows: At the same temperature, the volume occupied by the same gaseous mass is in inverse ratio to the pressure which it supports. Consequently the density and tension of a gas are proportioned to the pressure—that is, air under a pressure equal to that of two atmospheres will only occupy half the bulk it occupied when under the pressure of one atmosphere;

under the pressure of three atmospheres, one-third of that bulk, &c. At the pressure of 770 atmospheres, air would become as dense as water. By doubling the pressure we double the elasticity.

229. This law is true for air at all pressures and temperatures which have hitherto been tried; but not for the vapour of water, either as respects pressure or temperature. With small pressures the vapour of water follows the law; but with great pressures the space occupied is less than would have been if the law had been observed, because part of the vapour passes into the liquid state.

230. Since it is the repulsive energy of heat which keeps the particles of bodies asunder, an increase of temperature will add to the elasticity of gases, and a decrease of temperature diminish it. Conversely, if part of the pressure exerted on a given quantity of gas be removed, the gas will increase in bulk and fall in temperature; but if the pressure be increased, the volume of gas will be less, and its temperature higher. Since the pressure is diminished as air ascends, and increased as it descends, in the atmosphere, currents of air become colder as they ascend and warmer as they descend. This law applies to air at all temperatures, but it does not apply to the vapour of water.

231. There is another property of gases and vapours by which they are distinguished from liquids. If mercury, water, and oil be poured into a vessel, they will settle according to their densities,—mercury on the bottom, oil on the top, and water between the two; and they will remain in these relative positions without exhibiting any tendency to mix together. But if gases of different densities be put into the same vessel, they will not arrange themselves according to their densities, but will ultimately be diffused through each other in the most intimate manner. Each gas tends to diffuse itself as in a vacuum—the effect of the presence of other gases being only to diminish the rate of expansion, and thus retard their mutual diffusion. This equal intermixture occurs with all gases and vapours which do not act chemically on each other, and when once such a mixture is effected it remains permanent and uniform. Of this, common air, which is a mixture of oxygen and nitrogen, is an example. As regards the atmosphere, the law is, that vapour diffuses itself through the dry air, the presence of the air having only the effect of retarding the rate of its diffusion.

232. If the vapour of water remained permanently in the atmosphere—that is, were not liable to be withdrawn from it by being condensed into rain-drops—the mixture would be as complete and uniform as that of the oxygen and nitrogen. But the equi-

librium of the vapour atmosphere is being constantly disturbed by every instance of condensation, by the ceaseless process of evaporation, and by every change of temperature. From these considerations, and from the circumstance that dry air greatly obstructs the free diffusion of the vapour, it follows that the law of the independent pressure of the vapour and of the dry air of the atmosphere does not absolutely hold good ; but that from the constant effort of the vapour to attain to a state of equilibrium there is a continual tendency to approach this state. Since the equal diffusion of the dry air and the vapour is, owing to these disturbing causes, never reached, the observations of the hygrometer only indicate local humidity. Hence they should never be regarded as anything more than approximations to the quantity of vapour in the atmosphere over the place of observation. It should, however, be added, that though in particular cases the amount of vapour indicated by the hygrometer may be wide of the mark, yet, in long averages, a close approximation is obtained, except in confined localities which are exceptionally damp or exceptionally dry.

233. Vapour is continually passing into the air from the surface of water and other moist surfaces at all temperatures by *evaporation* (Lat. *e*, off; and *văpor*, vapour). Evaporation also takes place from the surface of snow and ice. Since the vapour is supplied only from the surface of the water, the extent of surface in contact with the air determines the amount and rate of evaporation. By the increase of temperature the elastic force of the vapour in the atmosphere is increased, and with it the rate of evaporation. The atmosphere can contain only a certain amount of vapour, according to the temperature ; hence, when it already has in suspension its full complement, or when it is saturated with moisture, evaporation ceases. Conversely, evaporation would be greatest where the air is perfectly dry or free from vapour. Since currents of air remove the saturated air and substitute drier air to the evaporating surface, evaporation is much more rapid in windy than in calm weather. Though the quantity of vapour required to saturate a given space is the same, whether that space be occupied with air or be a vacuum, yet the time occupied in completing the saturation increases with the pressure on the surface of the fluid. When water evaporates into a vacuum, the maximum density of the vapour is acquired at once ; but when it evaporates into air, it is not acquired till some time has elapsed. And since every addition to the vapour increases the pressure, the rate of the evaporation is under these circumstances continually diminishing.

234. *Evapometer.*—The instrument for measuring the quantity of water which the atmosphere takes up from the surface of water in the form of vapour in a given time, is called an *Evapometer* (Lat. *e*, off, *văpor*, vapour; and Gr. *metron*, a measure). In its simplest form it consists of an evaporating dish, about 5 inches in diameter, with an overflow-pipe a little below the surface fitting into a bottle, and furnished with a wire-work cover. The amount of evaporation is ascertained by filling the dish to the point of overflowing, which is, let us suppose, 3 inches of water. An ordinary rain-gauge goes along with it for the purpose of ascertaining the amount of rain which may fall. In making an observation the water remaining in the dish is measured, together with any that may be in the receiving-bottle, and also the depth of rain fallen. Add the rainfall to the 3 inches, then add the water remaining in the dish to that contained in the bottle; and the difference of the two sums is the amount evaporated.

235. The *Atmometer* (Gr. *atmos*, vapour, and *metron*, a measure), fig. 20, is of a very simple construction, and possesses some practical value. It consists of a long glass tube graduated into inches, having attached to the bottom a hollow ball of porous earthenware similar to that used in water-bottles. In using it, water is poured in at the top till it rises to the zero point of the scale. The outside of the porous ball being always covered with dew, the more rapid the evaporation, the more quickly will the water fall in the tube.

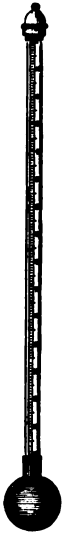


Fig. 20.

236. *Loss of Heat by Evaporation.*—One of the most obvious consequences of evaporation is the loss of heat. During the conversion of a liquid into the gaseous form, a large quantity of heat disappears. Since this heat becomes imperceptible to the senses, or to the thermometer, as long as the gaseous state is retained, the heat is said to become *latent* (Lat. *lăteo*, I lie hid). The heat which thus appears to be lost is not destroyed, but may be made evident by bringing back the vapour to its original liquid state. In the gaseous state the force of the heat is expended in keeping the particles of vapour further apart than in the liquid state, and hence the thermometer is not affected by it. The change of water into vapour by evaporation being thus productive of cold, and the conversion of vapour into water by condensation productive of heat, a few consequences follow. The ocean loses more heat from evaporation than the land, because the quantity evaporated from its surface is much greater. Again, since

more rain falls on land than on sea, especially in hilly and mountainous countries, the temperature of the air over the land will be still further raised by the latent heat thus given out. It is for this among other reasons that the mean temperature of the northern hemisphere is higher than that of the southern hemisphere.

237. *Effect of Drainage on the Temperature of the Soil.*—Theory should lead us to expect that the temperature of drained land would be higher than that of undrained land, because being drier, less heat is lost by evaporation. From observations made to test this point, the following results have been arrived at: 1. The mean annual temperature of arable land is raised nearly a degree (0°.8) by drainage. 2. The temperature of hill pasture is also raised by drainage, but not to the same extent (0°.4). 3. During sudden falls of temperature and during protracted cold weather, such as when the soil is under a covering of snow, the cold passes more quickly and completely through undrained than through drained land. 4. When the temperature of the air is higher than that of the soil, drained land receives more benefit from the higher temperature than undrained land, less of its heat being lost by evaporation. 5. Since, when rain or sleet falls, the superfluous moisture soon flows away from drained land, drainage tends to maintain in the soil a comparatively equable temperature; whereas undrained land is liable to considerable fluctuation, for when soaked with warm rain-water its temperature is temporarily raised, and when soaked with melted snow it is temporarily lowered. 6. The temperature of drained land is in summer occasionally raised above undrained land 3°, often 2°, and still more frequently 1°.5; and hence the beneficial effects of drainage are sometimes as great as if the land had been transported 100 or 150 miles southwards.

238. In 1847 Professor James Elliot made a number of experiments which throw some light on this question. He showed that peat-moss absorbs more than twice its own weight of water, dry clay nearly its own weight, dry earth or garden mould more than half its own weight, and dry sand little more than a third of its own weight. With equal times of drying under the same circumstances, peat-moss lost $\frac{2}{5}$ of all the water it contained, clay and earth each more than $\frac{3}{4}$, and sand more than $\frac{9}{10}$. Evaporation was greater from the surface of loose earth than from the surface of water, till the earth became so far dry as to be of a light colour. Evaporation from saturated moss was excessive during the first day, being far more than from the surface of water; but on the second day the water began to evaporate more, and on the third day very much more, than the moss, although the moss was still wet 10 inches below the surface.

239. Six years ago, D. Milne Home of Wedderburn made the following experiment: Two boxes of the same size were taken and filled, one with sandy loam, and the other with strong clay. Each was suspended at the end of a balance, and so adjusted that the one box was exactly equal in weight to the other. An equal quantity of water was poured into each box. Before a week had elapsed, the box with the sandy loam rose above the level of the other box, showing that more water had evaporated from it than from the strong clay; and during that time the temperature of the sandy loam was almost always lower than that of the clay.

240. From these experiments it may be concluded that in all cases the amount evaporated from wet substances, and the consequent decrease of temperature, are proportioned to the number of evaporating points, or to the whole extent of the evaporating surfaces in contact with the air; this explains why evaporation is greater from wet moss and grass than from wet soils, and greater from wet soils than from a surface of water. But as evaporation proceeds and the substances begin to dry, the rate of evaporation is modified by the facility with which the water is drawn by capillary attraction from the interior of the substances to their evaporating surfaces. Thus dry sand parts with its moisture quicker than common mould, common mould quicker than clay, and clay quicker than peat-moss. In respect of evaporation, drainage affects the temperature of the soil in two ways: (1) By keeping the soil dryer, and so diminishing the evaporation, a higher temperature is maintained. (2) Since a dry soil is more friable than a wet soil, and therefore presents more evaporating points, it is probable that on soils bare or nearly bare of vegetation, and freely exposed to the influence of the weather, drainage lowers the temperature for some time after rain, or so long as the evaporation exceeds that of undrained land. When the soil is covered with vegetation, this peculiarity can only obtain to a very limited degree. The conversion of a swamp or a low-lying damp piece of ground into a lake will add materially to the dryness and amenity of the climate of the surrounding district; and the rainier the locality the greater will be the advantage gained.

241. *The Hygrometry of the Atmosphere.*—At all temperatures, even the lowest, moisture exists in the atmosphere in an invisible state, so that the air is never absolutely dry. Intervals occur between the particles of air which are partially filled with the vapour that is constantly rising from the earth. This property is termed the capacity of the air for moisture, and when the intervals between the particles contain as much vapour as can be maintained in the gaseous state, the air is said to be saturated.

242. An increase of temperature, by expanding the air and thus separating the particles farther from each other, increases the capacity of the air for moisture. On the other hand, a fall of temperature, by drawing the particles closer together, diminishes the capacity. But the capacity of the air for moisture increases at a more rapid rate than the temperature. Thus, air can contain at 32° the 160th part of its own weight, at 59° the 80th part, and at 86° the 40th part; the law being that for every increase of 27° the capacity is doubled.

243. *Hygrometer.*—The instrument for ascertaining the amount of vapour in the atmosphere is called a *hygrometer* (Gr. *hygros*, wet; and *metron*, a measure). There is a great variety of hygrometers, differing both in form and in principle of construction. Some are formed of substances which, by readily absorbing moisture from the air, and as readily parting with it, change in form and size, and thus give some indication of the amount of vapour present in the air. Of these the most noteworthy is the hair hygrometer of Saussure, which, when the air is damp, absorbs moisture and becomes shorter, and when the air is dry, returns to its original length. The *conservatory hygrometer* (fig. 21), constructed by Richard Adie, belongs to this class. The pointer is made of two pieces of wood glued together, so that increasing dampness twists it to the right, and increasing dryness to the left. Though of no scientific value, it may be turned to good account in the sick-room or in conservatories.

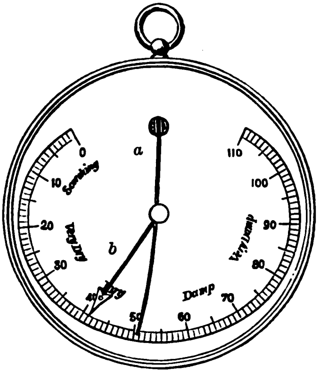


Fig. 21.

244. It is this property of substances to be changed in bulk by absorbing moisture from the atmosphere, or by parting with it, which explains a large number of popular prognostics of the weather, especially such of them as refer to the feelings and conduct of animals, the opening and closing of flowers, and the lengthening and shortening of strings, cordage, and other materials.

245. Hygrometers constructed on the *principle of absorption* are faulty, not only because they are irregular in their action, but also because in the course of time they undergo great changes.

The most accurate hygrometers are those constructed on the *principles of condensation, or of evaporation.* A familiar illustration of the principle of condensation is the forming of dew on a tumbler filled with cold water on being brought into a warm room. This dew is caused by the deposition of moisture from the air, which, in contact with the cold surface of the glass, is cooled below the point of saturation. The temperature of the glass at the moment dew begins to form on its surface is termed the *dew-point,* which corresponds with the point of saturation of the air.

246. Daniell's and Regnault's hygrometers are constructed on the principle of this simple phenomenon, having only superadded to them certain contrivances for quickly reducing the temperature to any point that may be desired, and for observing the temperature at which dew begins to form with precision. Daniell's hygrometer (fig. 22) consists of a glass tube bent at right angles at two points, with a bulb at each extremity. One of the bulbs is nearly filled with ether, into which the ball of a delicate thermometer is plunged. The other bulb is covered with muslin; this being wetted with a few drops of ether, evaporation of the ether takes place, which quickly cools the bulb, and thus condenses the vapour of the ether which is within it. In consequence of this, evaporation goes on rapidly from the ether inside the other bulb; and the temperature of this ether and the bulb which contains it being thereby reduced, *a ring of dew begins to be formed outside the bulb.* At this instant the thermometer inside is read, and the reading gives the dew-point of the air at the time; and the temperature of the air is given by the thermometer, which is freely exposed to the air on the upright stand. This is the simplest and cheapest of the two hygrometers, but Regnault's requires less time in making the observations. Owing to the trouble and expense attending the use of all hygrometers which give the dew-point directly by condensation, another hygrometer has come into general use by which the dew-point may be determined indirectly by evaporation—viz., the *dry-and-wet-bulb thermometers.*

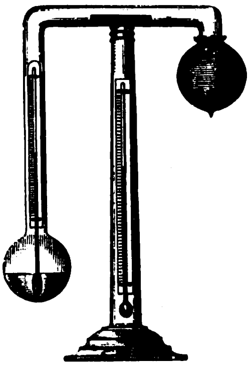


Fig. 22.

247. This hygrometer (fig. 23) consists of two ordinary mer-

curial thermometers. The dry-bulb is a common thermometer, designed to show the temperature of the air. The wet-bulb is also a common thermometer, having its bulb covered with a piece of thin muslin, from which pass a few threads of darning cotton or narrow strip of muslin into a small vessel containing rain-water. Water rises by capillary attraction from the vessel to the muslin, thus keeping it constantly wet. When the air is dry, evaporation proceeds rapidly from the muslin, and on account of the heat lost by evaporation the wet-bulb indicates a lower temperature than the dry-bulb. When the air is damp, evaporation is slower, and the difference between the two thermometers becomes smaller; and when the air is completely saturated evaporation ceases, and the two thermometers indicate the same temperature.

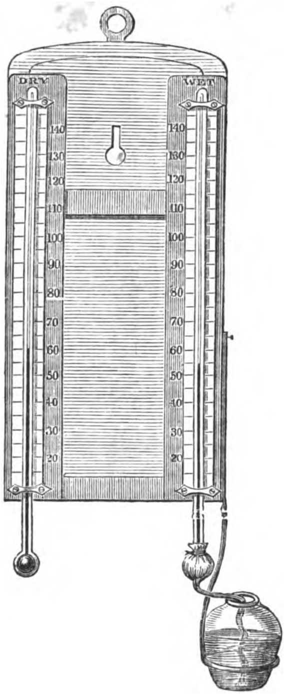


Fig. 23.

248. Some precaution is required in taking the observations when the temperature of the air is below 32°. In such cases, if the wet-bulb reads higher than the dry-bulb, the observation should not be recorded, the instrument being for the time not in proper working order. If the water on the muslin be frozen, the readings are quite good, since evaporation takes place from ice as well as from water. But if the muslin be dry, it must first be wetted and then allowed to freeze before the observation is taken. A useful rule to observe in frosty weather is, to immerse the bulb and conducting-thread in water after every observation, by which sufficient ice will still be adhering to the muslin at the time of the next observation. When the temperature of the air rises above 32°, the wet-bulb must be plunged into warm water to melt any ice that may remain on it, after which it must be allowed sufficient time to cool before being observed.

249. To keep this instrument in working order one or two

points require to be attended to. Both thermometers must be exactly the same; for if one is filled with mercury and the other with spirit, or if they contain different quantities of the same fluid, the readings will in either case be vitiated. All starch or foreign matter should be washed out of the muslin and cotton. The water used should be pure; for if lime be dissolved in it, the muslin will soon be coated with a calcareous incrustation. Rain or distilled water should be used. The muslin ought to be changed when covered with dust or other impurities; and care should be taken not to touch the muslin with the fingers, otherwise it will get slightly greased, and capillary attraction be interfered with. The bulbs of the two thermometers should be made to project 1½ or 2 inches below the scales. The thermometers should also be a little apart from each other, and the glass vessel be, as in the figure, removed as far as possible from the dry-bulb.

250. Since the mean of the temperatures observed at 9 A.M. and 9 P.M. is nearly the mean temperature of the day, these are the hours to be preferred for observing the hygrometer. An additional observation at 3 P.M., when the temperature is near the maximum, is recommended, as showing the greatest dryness of the air during the day. By these two observations, *the temperature of the air*, as shown by the dry-bulb, and *the temperature of evaporation*, as shown by the wet-bulb, the following may be either determined, or approximated to, by means of tables constructed for the purpose: (1) The dew-point; (2) the elastic force of vapour, or the amount of the barometric pressure due to the vapour present in the atmosphere; (3) the quantity of vapour in a cubic foot of air; (4) the additional vapour required to saturate a cubic foot of air; (5) the relative humidity; and (6) the weight of a cubic foot of air at the pressure prevailing when the observation is made.

251. The formula of reduction, as deduced from Dr Apjohn's investigations, is as follows: Let F be the elastic force of saturated vapour at the dew-point, f the elastic force at the temperature of evaporation (the wet-bulb), d the difference between the dry and wet bulb, and h the barometric pressure, then

$$F = f - \frac{d}{88} \times \frac{h}{30}$$

when the reading of the wet-bulb is above 32°; and

$$F = f - \frac{d}{96} \times \frac{h}{30}$$

when the wet-bulb is below 32°. M. Regnault has determined by carefully-conducted experiments the value of the elastic force of vapour; the results are given in Table VI. From this table, f is found; and d and h being obtained by observation, F is calculated. *The dew-point* is found from F by using Table VII. reversely, and finding the temperature opposite the *elastic force* calculated. To take an example:—Suppose the dry-bulb to read 50° and the wet 45°, and the barometer 29 inches, then f=.299 inch (from Table VI.); $d=50°-45°=5°$; and h=29 inches. Hence

$$F = .299 - \frac{5}{88} \times \frac{29}{30} = .244.$$

And from Table VI. we find the temperature opposite .244 to be 39°.7, which is therefore the temperature of the dew-point when the dry-bulb is 50° and the wet-bulb 45°. To obviate such laborious calculations Mr Glaisher has elaborated a series of factors from the combination of simultaneous observations of the dry and wet bulb thermometers with Daniell's hygrometers. These factors are given in Table VII. We shall find the dew-point of the above example by them. The factor opposite the dry-bulb 50° is 2.06, and the difference between the two thermometers is 5°, therefore

$$2.06 \times 5 = 10.3,$$

and hence the dew-point=50°–10°.3, or 39°.7, as before.

252. *Relative Humidity.*—In calculating the relative humidity, saturation is assumed to be 100, and perfectly dry air 0. The relative humidity is found by dividing the elastic force of vapour corresponding to the temperature of the dew-point by the elastic force corresponding to the temperature of the air, and multiplying the quotient by 100. Thus elastic force at 39°.7 is .244, and at 50° .361; dividing and multiplying by 100, we find the relative humidity to be 68 when the dry-bulb is 50° and the wet-bulb 45°. Valuable and copious tables for facilitating the processes of finding the dew-point, humidity, and other elements specified above, have been published by Mr Glaisher. These tables are indispensable to every meteorologist.

253. *Dew-point.*—The ascertaining of the dew-point is of great practical importance, particularly to horticulturists, since it indicates the point near which the descent of the temperature of the air during the night will be arrested. For when the air has been cooled down by radiation to this point, dew is deposited and latent heat given out. The amount of heat thus set free being great, the temperature of the air is immediately raised. But as the cooling by radiation proceeds, the air again falls to, or slightly under, the dew-point; dew is now again deposited, heat liberated,

and the temperature raised. The same process continues to be repeated, and thus the temperature of the air in contact with plants and other radiating surfaces may be considered as gently oscillating about the dew-point. For if it rises higher, the loss of heat by radiation speedily lowers it, and if it falls lower by ever so little, the liberation of heat as the vapour is condensed into dew as speedily raises it. Thus, then, the dew-point determines the minimum temperature of the night.

254. This suggests an important practical use of the hygrometer. If the dew-point be ascertained, the approach of low temperatures or of frost may be foreseen and provided against. Thus, suppose on a fine clear spring day, towards evening, that the dry-bulb was 50° and the wet 40°; the dew-point at the time is therefore 29°.4. Frost on the ground may then be predicted with certainty, and no time ought to be lost in protecting such tender plants as may be exposed in the open air. If, on the other hand, with a sky quite as clear, the dry-bulb was 50° and the wet 47°; the dew-point being in this case 43°.8, no frost need be apprehended. The raising or depressing of the dew-point during the night by a change of wind, is the only circumstance that can happen to interfere with predictions founded on the hygrometer.

255. *Elastic Force of Vapour.*—In an atmosphere of pure steam, its force at the earth's surface is the pressure it exerts; and in an atmosphere of vapour and air perfectly mixed, the elastic force of each at the surface of the earth is the pressure of each. The elastic force of aqueous vapour would be the pressure of the whole vapour in the atmosphere over the place of observation. It is expressed in inches of mercury of the barometric column. Thus, suppose the total barometric pressure to be 30.000 inches, and the elastic force of vapour .450 inch, the weight of the dry air, or air proper, would be represented by 29.550 inches of mercury, and the weight of the vapour by .450 inch. The elastic force may be regarded as representing the absolute quantity of vapour suspended in the atmosphere subject to the modification stated in par. 232. It may also be termed the absolute humidity of the atmosphere. It is greatest within the tropics, and diminishes towards the poles. It is greater in the atmosphere over the ocean, and decreases as we advance inland. It is greater in summer than in winter, and greater at mid-day than in the morning. It also diminishes with the height, but the average rate at which it diminishes is not known. The balloon ascents of Mr Glaisher and other aeronauts have thrown some light on the question. But the number of ascents are too few to warrant the drawing of general conclusions as to the mean rate of the decrease. The chief point

established is, that in particular instances the decrease is generally very far from uniform. Different strata are superimposed on each other, differing widely as regards dryness and dampness, and the transition from the one to the other is frequently sharp and sudden.

256. *Relative Humidity.*—This must not be confounded with absolute humidity. Suppose the temperature of the air to be 40° and quite saturated with vapour, and then to be suddenly raised to 50° without any addition being made to its vapour, its absolute humidity would in each case be the same; but in the former case it would in popular language be said to be very damp, and in the latter case very dry. This palpable difference is expressed by the term *relative humidity*, or more briefly the *humidity of the air*. Thus, in the language of meteorologists, humidity of the air means the degree of its approach to complete saturation. When the humidity is 100, the air is completely saturated. If the humidity, when the temperature is about the average of the day, be 73, the air to an inhabitant of Great Britain would feel very dry, 73 being about the lowest mean humidity that occurs in Scotland during May, the driest month. This low humidity is, however, greatly exceeded when the east winds of spring happen to acquire their greatest virulence and dryness.

257. In the ocean, at a distance from the land, the humidity is great, and during the night generally approaches 100. In the interior of continents it is less, especially in sandy deserts, which allow the rain-water speedily to sink, thus drying the surface, and in rocky countries, which are never wetted more than on the surface. Thus at Djeddah, in Arabia, on 12th March 1866, the humidity was as low as 11. The humidity is greatest during the night, when the temperature is at the minimum; it is also great in the morning, when the sun's rays have evaporated the dew, and the vapour has not yet had time to find its way up into the air; and it is least during the greatest heat of the day and for some time thereafter, or before the temperature has begun perceptibly to fall. Between the vapour present in the air and the temperature of the air there is a vital and all-important connection.

258. *Diathermancy of the Air.*—As substances are said to be transparent when they permit the rays of light to pass through them unimpeded, so bodies are said to be diathermanous (Gr. *dia*, through, and *thermē*, heat) when the rays of heat which fall on them pass freely through them, or when the rays of heat are not absorbed. Bodies possess perfect diathermancy when they allow all the rays of heat to pass through them. Thus perfectly dry air,

or air altogether free from aqueous vapour, allows heat to pass through it without being sensibly warmed thereby. But it is otherwise with the vapour of water or with a mixture of vapour and air as these exist in the atmosphere, which obstruct the free passage of the heat of solar and terrestrial radiation. This is undoubtedly one of the most important conservative functions of the moisture of the atmosphere. For if the moisture was drained out of it, and its diathermancy thereby rendered complete, the sun's rays would burn up everything by their intolerable fierceness, and during night the escape of heat by radiation to the cold stellar spaces would be so swift and the cold so intense, that the whole living creation would be blighted by its withering touch. The earth would in truth

> "Feel by turns the bitter change
> Of fierce extremes, extremes by change more fierce,
> From beds of raging fire to starve in ice."

It is the imperfect diathermancy of a moist though clear atmosphere, together with its high dew-point, which prevents the temperature of the air from falling to so low a point during the night as happens when the atmosphere is clear and dry.

259. Observations show that when the quantity of vapour in the air is great, the escape of heat by radiation is obstructed, and the temperature falls little during the night ; but when the quantity of vapour is small, radiation is less impeded, and the temperature rapidly falls ; and on the other hand, when the quantity of vapour is great, the temperature rises slowly, even although the sky be perfectly clear and the sun shining brightly; but when the quantity of vapour is small, the sun's rays have a freer access to the earth, and the temperature rapidly rises. The temperature is hottest during the day, when the air is driest, and evaporation consequently greatest. Since the extent to which the temperature falls during dry nights owing to the evaporation is comparatively small, the cause of night cold is radiation.

260. In mountainous countries, where, on account of their height, little aqueous vapour is interposed between them and the regions of space, radiation, both solar and terrestrial, is least obstructed, and consequently the alternations of heat and cold are very great. It is this which explains the scorching heat that surprises the Alpine tourist while travelling over fields of snow under a blazing noonday sun. And it is the same cause, the small amount of vapour in the air, that explains the intense heat experienced in the direct rays of the sun in the polar regions, where Captain Scoresby observed it to melt the pitch on the side of the

ship exposed to the sun, while ice was rapidly forming on the other side. It has been proved that the power of solar radiation in the atmosphere increases from the equator to the poles, and from below upwards—a result quite in accordance with these remarks on the vapour of the atmosphere.

261. The above considerations explain in part the nervous derangement and general unhealthiness produced by the east wind in spring; for as the air is then very dry, the part of the person exposed to the sun's rays is greatly heated as compared with the part in shadow, and this strain on the physical frame few constitutions except the most robust can bear without positive discomfort. On the other hand, exposure to the sun's rays in the tropics is, on account of the thick screen of vapour above, not attended with the intense heat which might have been expected. Nothing is more common than for natives of the West Indies and other warm moist climates to complain of the, to them, intolerable heat of the sun in our British climate in spring and early summer.

CHAPTER IX.

MISTS, FOGS, AND CLOUDS.

262. MISTS and fogs are visible vapours floating in the air near the surface of the earth. They are produced in various ways—by the mixing of cold air with air that is warm and moist, or generally by whatever tends to lower the temperature of the air below the dew-point. During a calm clear night, when the air over a level country has been cooled by radiation, and dew is begun to be deposited, the air in contact with the ground is lowered to the dew-point, and becomes colder than the air above it. Since in these circumstances there is nothing to disturb the equilibrium and give rise to currents of air, and there being no cause in operation which can reduce the temperature much below the point of saturation, the air within a few feet of the surface remains free from mist or fog. But if the ground slopes, the cold air, being heavier, necessarily flows down and fills the lower grounds; and since it is colder than the saturated air which it meets with in its course, it reduces its temperature below the point of saturation, and thus produces mist, or *radiation fog*, as it is sometimes termed. When a lake, river, or marsh fills up the valley, the air, being thereby saturated, often gives rise to denser fogs; but when the low grounds are sandy or dry, mist is less frequently produced.

263. When an ocean-current meets a shoal in its course, the cold water of the lower depths is brought to the surface; and in all cases where its temperature is lower than the dew-point of the air, fogs are formed over the shoal. This is well known to sailors, and the knowledge of it is often of great use in apprising them of their approach to land. For a similar reason icebergs are frequently enveloped in fogs. Analogous to the above is the mist which is sometimes seen to rise from rivers the temperature of which is lower than that of the air. The waters of the Swiss rivers which issue from the cold glaciers having a temperature

considerably lower than that of the air, cool the air in contact with them below the point of saturation, and mist is thereby produced. Similarly such rivers as the Mississippi, which flow directly into warmer latitudes, and are therefore colder than the air above them, are often covered with mist or fog.

264. When rivers are much warmer than the air, they give rise to fogs, because the rapid evaporation from the warm water pours more vapour into the atmosphere than it can hold suspended in an invisible state, and consequently the surplus vapour is condensed into mist by the colder air through which it rises. Thus deep lakes, and rivers flowing out of them, are in winter generally much warmer than the air, and hence when the air is cold and its humidity great they are covered with fogs. When Sir Humphry Davy descended the Danube in 1818, he observed that mist was always formed during the night when the temperature of the air on shore was from 3° to 6° lower than that of the stream; but when the sun rose, and the temperatures were brought to an equality, the mist rapidly disappeared. The densest fogs occur during the cold months in large towns built on rivers—the causes which produce fogs being then at the maximum.

265. In all these cases fogs are very locally distributed, being confined to the basin of the river or lake where they are formed, and do not extend far up into the atmosphere. There are, however, other fogs that spread over large districts, which are due to different causes. Fogs often accompany the breaking up of frosts in winter. When the humid south-west wind has begun to prevail, and is now advancing over the earth's surface as a "light air," it is chilled by contact with the cold ground, and its abundant vapour thereby condensed into a widespread mist.

266. Mountains are frequently covered with mist. Since the temperature of the air falls with the height, it follows that as warm air is driven up the slopes of the mountain by the wind, it becomes gradually colder, and its capacity for moisture is diminished until condensation takes place, and the mountain is swathed with mist. Owing to the peculiarity of their temperature (par. 132), forests have a marked effect on mists as well as on the rainfall of mountainous regions. Mists often appear sooner on the parts of hills covered with trees than elsewhere. This happens especially when the mist begins to form after mid-day, because then the temperature of the trees is lower than that of the grassy slopes of the hills. Mists also sometimes linger longer over forests, probably on account of the increased cold arising from the large extent of evaporating surface presented by their leaves when drenched with mist. During his residence at the Cape of Good

Hope, Sir John Herschel observed a remarkable illustration of the influence of trees in condensing the vapour of the atmosphere. On the side of Table Mountain, from which the wind blew, the clouds spread out and descended very low, frequently without any rain falling, while on the opposite side they covered the mountain in dense masses of vapour. When walking beneath tall fir-trees at the time these clouds were closely overhead, he was subjected to a heavy shower of rain; but on going out from beneath the trees the rain ceased. The explanation he gave of the phenomenon was, that the clouds were condensed into rain on the cool tops of the trees. And doubtless the innumerable fine leaves of the fir-trees, adding largely to the surfaces of evaporation, increased the cold, and thus condensed the vapours into a more copious shower.

267. Extensive fogs also prevail where great differences occur in the temperature of neighbouring regions. Thus promontories running out into the sea are frequently covered with mist; the reason is, that land being generally warmer than the sea in summer and colder in winter, the difference of temperature is sufficient to give rise to mists with the veerings of the wind landward or seaward. The mists and fogs which frequently prevail on the coast are similarly explained. They generally occur in the morning and evening, seldom advance far inland, and usually accompany fine weather.

268. The British Islands, being bounded by the warm waters of the Atlantic on the one side, and separated from the Continent on the other only by narrow belts of sea, are subject to fogs during winter. For the same reason dense thick fogs are prevalent in Norway, Newfoundland, along the coast of Peru, and South Africa, and in the polar regions. The Gulf Stream is notorious for dense and long-continued fogs, which seriously obstruct the navigation of that part of the Atlantic, particularly at its northern limit, where it meets the arctic current. The high temperature of the stream, which is often from 16° to 18°, and on rare occasions 30°, higher than that part of the sea past which it flows, accounts for the denseness and persistency of these fogs.

269. Occasionally the summit of a hill or an isolated peak is wrapped in mist or cloud, while elsewhere the atmosphere is clear; and though a breeze be blowing over the hill, yet

> "Overhead
> The light cloud smoulders on the summer crag,"

apparently motionless and unchanged. This phenomenon is easily explained. The temperature at the top is below the dew-point of the atmospheric current. Hence when the air rises to this region its moisture is condensed into cloud, which is borne forward over the top of the hill and down the other side, acquiring heat as it descends till it is again dissolved and disappears. Meanwhile its place is constantly supplied by fresh condensations which take place as the current, rising to the height of the cloud, falls below the temperature of saturation. Thus, though the cloud on the top of the hill appears to remain motionless and unchanged, the watery particles of which it is composed are continually undergoing renewal.

270. There is another sort of fog of occasional occurrence, differing from any of the foregoing in several important particulars, which, from its relation to storms, is of great importance in meteorology. It would appear to originate from the juxtaposition of two currents, one cold and dry and the other warm and humid. When such currents flow, roughly speaking, side by side, fog frequently fills up the comparatively calm space intervening between them. It may be supposed to result from the mixing together of the two currents, the cold current condensing the vapour of the moist current. It sometimes stretches several hundred miles in the form of a long narrow strip. At other times, and more usually, it is a precursor of storms which succeed fine dry weather, during which the wind has been chiefly from a dry quarter, such as the north-east. The south-west wind is seen to prevail in the upper regions of the atmosphere by the direction in which the thin cirrus cloud is blown, some time before it is felt on the surface of the earth. During this interval the moist current overlaps the cold current, and the fog which prevails is due to the mixing of the two. In discussing storms, fogs constitute one of the most important elements which call for consideration, and they supply valuable help towards the foretelling of storms.

Clouds.

271. Clouds are visible vapours floating in the air at some height above the ground, thus differing from mists and fogs, which float near the surface. Both arise from the same causes. During the warmest part of the day, when evaporation is greatest, warm moist air-currents are constantly ascending from the earth. As they rise in continuous succession, the moist air is pushed high up into the atmosphere, and losing heat by expansion, a point is at length reached when it can no longer retain in solution the moisture with which it is charged; hence condensation takes place, and a cloud is formed which increases in bulk as long as the air continues to ascend. But as the day declines, and

evaporation is checked, the ascending current ceases, and the temperature falling from the earth's surface upwards, the lower stratum of air contracts, and consequently the whole mass of air begins to descend, and the clouds are then dissolved by the warmth they acquire in falling to lower levels.

272. The balloon ascents of Mr Glaisher and other aeronauts, as well as observations of the clouds, show us that the whole atmosphere, to a great height, is constantly traversed by many aerial currents superimposed on each other, and flowing in different, frequently in opposite, directions. Masses of air of different temperatures thus frequently combine together; and since the several portions when mingled cannot hold in suspension the same quantity of vapour that each could retain before they were united, the excess is condensed and appears as cloud.

273. But again, when a dry and heavy wind begins to set in, or take the place of a moist and light wind, it generally does so by edging itself beneath the moist wind and forcing it wedgewise into the upper regions of the atmosphere, where condensation rapidly follows, and dense black clouds, often heavily charged with rain, are formed. This is a frequent cause of cloud and rain in Great Britain, when cold easterly winds thrust high up into the air the rain-bringing south-west wind, thus causing it to darken the sky and pour down its surplus moisture in torrents of rain. Currents of air driven up the sloping sides of hills and mountains by the winds, have been already referred to as a frequent cause of the formation of clouds.

274. How are clouds suspended in the air? The example of a cloud appearing to rest on the top of a hill though a strong wind be blowing at the time (par. 269) suggests an explanation; the cloud itself may appear stationary or suspended, but the particles of which it is composed are undergoing constant renewal. The particles of visible vapour forming a cloud may be supposed to be upheld by the force of the ascending current at the top of which they are formed; but when that current ceases to rise, or when they become separated from it, they begin to fall through the air by their own weight till they melt away and are dissolved in the higher temperature into which they fall. Hence, as Espy has reasoned, every cloud is either a forming cloud or a dissolving cloud. While it is connected with an ascending current, it increases in size, is dense at the top, and well defined in its outlines; but when the ascending current ceases the cloud diminishes in size and density.

275. When a cloud overspreads the sky, its lower surface is for the most part horizontal, or more generally it seems, as it were, a

rough impression taken from the contour of the earth's surface beneath it. This arises from the high temperature of the air below the cloud, which is sufficient to dissolve the particles as they descend into a lower stratum of the atmosphere. On ascending through this lower stratum of cloud, the temperature is found frequently to rise, and the air to be quite clear of clouds for a considerable thickness. Higher up a second stratum of clouds succeeds, and again another clear space, and so on, cloud and clear sky following each other several times in succession. These phenomena arise from the different currents which are encountered, superimposed over each other and differing in temperature and humidity.

276. *Height of Clouds.*—Kaemtz has collected the results arrived at by many observers, and deduced the heights between which clouds range as from 1300 to 21,320 feet. This extreme height is, however, much too small, as has been proved by balloon ascents. Thus Gay-Lussac, in September 1804, when at the height of 23,000 feet, saw clouds floating apparently at a great height above him; and Glaisher has also made the same observation. It is probable that the cirrus cloud is often ten miles above the earth.

277. Since clouds are subject to certain distinct modifications from the same causes which produce other atmospheric phenomena, the face of the sky may be regarded as indicating the operation of these causes, just as the face of man indicates his mental and physical states. The ancient meteorologist was content with discerning the face of the sky in predicting the coming weather. It is to the sky chiefly that the weatherwise sailor and the farmer look in foretelling the weather; and their predictions are frequently more correct than those which are made solely from the indications of the barometer and other meteorological instruments. The best system of weather-prediction comprises both methods. Considering, therefore, the importance of clouds, a nomenclature specifying their different modifications becomes necessary, in order that the experience of one observer may be communicated to others. The classification all but universally adopted is that published by Luke Howard in 1803.

278. By this nomenclature clouds are divided into seven kinds; three being simple—the *cirrus* (Lat. *cirrus*, a curl), the *cumulus* (Lat. *cŭmŭlus*, a heap), and the *stratus* (Lat. *strātus*, spread or laid); and four intermediate or compound—the *cirro-cumulus*, the *cirro-stratus*, the *cumulo-stratus*, and the *cumulo-cirro-stratus* or *nimbus* (Lat. *nimbus*, a black rain-cloud).

279. *Cirrus Cloud.*—This cloud consists of parallel, wavy, or

diverging fibres which may increase in any or in all directions. Of all clouds it has the least density, the greatest elevation, and the greatest variety of extent and direction, or figure. It is the cloud first seen after serene weather, appearing as slender filaments stretching like white lines pencilled across the blue sky, and thence propagated in one or more directions, laterally, or upward, or downward. Sometimes the thin lines of cloud are arranged parallel to each other, the lines lying in the northern hemisphere from north to south, or from south-west to north-east; sometimes they diverge from each other in the form of the tail of a horse; whilst at other times they cross each other in different ways like rich delicate lace-work. It is probable that the fine particles of which this cloud is composed are minute crystals of ice or snow-flakes. The duration of the cirrus varies from a few minutes to many hours. It remains for a short time when formed in the lower parts of the atmosphere and near other clouds, and longest when it appears alone in the sky, and at a great height.

280. The cirrus, though apparently motionless, is closely connected with the movements of the great atmospheric currents. It is this intimate connection which has long caused it to be considered as a most valuable prognostic of stormy weather, and as such it deserves more attention than has hitherto been given to it. Small groups of regularly formed and arranged cirrus scattered over the sky often accompany *fair* weather with light breezes; these do not indicate the approach of a storm for some time at least. Horizontal sheets of this cloud which fall quickly and pass into the cirro-stratus cloud indicate, in an unmistakable manner, continued *wet* weather. When streaks of cirrus run quite across the sky in the direction in which a light wind happens to blow, the wind will probably soon blow hard, but it will continue in the same direction; in other words, the variable winds and fitful gusts which accompany storms are not likely to be experienced. When the fine threads of the cirrus appear blown or brushed backward at one end as if by a wind prevailing in these elevated regions, the wind on the surface will ultimately veer round to that point. If the direction indicated be from the south-west, whence the storms of Europe come, wind and rain may be expected; and it matters not how fair and settled-like the weather appear at the time, a storm more or less severe is advancing, and may be looked for within 30 or 48 hours. But if, instead of this, innumerable groups and streaks of cirrus cover the sky, crossing each other in all directions, and presenting the appearance of skeins of yarn inextricably tangled together, we may be sure that a second storm will shortly follow the one already past.

281. *Cumulus.*—This name is applied to convex or conical heaps of clouds increasing upwards from a horizontal base. They are usually of a very dense structure; are formed in the lower regions of the atmosphere; and are carried along in the current next the earth. The cumulus has been well called the *cloud of the day*, being caused by ascending currents of warm air which rise from the heated ground. Its beginning is the little cloud not bigger than a man's hand, as the nucleus round which it increases. The lower surface remains roughly horizontal, while the upper rises into towering heaps, which may continue comparatively small, or swell into a size far exceeding that of mountains. Saussure attributes their conical shape to the way in which they are formed. When one fluid is poured through another it makes its way in curved lines; thus ink poured into water is diffused through it like clouds. The steam from an engine poured into the air diffuses itself as a cloud; and in like manner the vapour poured upward into the air by the heated currents as they ascend is diffused, and, being condensed, forms the cumulus. When they are of moderate height and size, of a well-defined curved outline, and appear only during the heat of the day, they indicate a continuance of fair weather. But when they increase with great rapidity, sink down into the lower parts of the atmosphere, and do not disappear towards evening, *rain* may be expected. If loose fleecy patches of cloud begin to appear thrown out from their surfaces, rain is near at hand.

282. *Stratus.*—The stratus is a widely-extended, continuous sheet of cloud, increasing from below upwards. It is properly, and as its name implies, a continuous layer of cloud. It is, besides, the lowest sort of cloud, its lower surface commonly resting on the earth. The stratus may be called the *cloud of night*, since it generally forms about sunset, grows denser during the night, and disappears about sunrise. It is caused by the vapours which rise during the day, but towards evening fall to the earth with a falling temperature; and since during night the cooling of the air begins on the ground and thence proceeds upwards, the stratus first appears like a thin mist floating near the surface of the earth; it thence increases from below upwards as successive layers of the air are reduced below the point of saturation. It includes all those mists, already described, which in the calm evening of a warm summer day form in the bottom of valleys and over low-lying grounds, and then spread upwards over the surrounding country like an inundation. When the sun has risen and commenced to shine on the upper surface of the stratus cloud, it begins to be agitated and to heave up in different places into the rounded

forms of the cumulus, while at the same time the whole of its lower surface gradually rises from the ground. As the heat increases it continues to ascend, becomes broken up into detached masses, and soon disappears. These appearances indicate a continuance of the finest and serenest weather.

283. *Cirro-cumulus.*—This cloud is composed of well-defined, small, roundish masses, lying near each other, and quite separated by intervals of sky. It is formed from the cirrus cloud by the fibres breaking, as it were, and collapsing into small roundish masses, thus destroying the texture but retaining the arrangement of that cloud. The change takes place either over the whole cloud at once, or it begins at one extremity and proceeds slowly to the other; and while the change takes place it generally descends to a lower position in the atmosphere. This very beautiful cloud is commonly known as a "*mackerel sky*"; it occurs frequently in summer, and is attendant on dry and warm weather. It is also sometimes seen between showers, its graceful form and slow easy motion presenting a striking contrast to the dark, heavy rain-clouds below, which drift hurriedly across the sky. In this case, however, the cirro-cumulus will be found wanting in the settled aspect which it wears in fine weather.

284. *Cirro-stratus.*—The cirro-stratus partakes partly of the characteristics of the cirrus and stratus. It consists of horizontal or slightly-inclined masses thinned towards a part of the circumference, bent downwards or undulated, and either separate or in groups. Their form and relative position sometimes resemble shoals of fishes. In distinguishing this cloud, attention must be paid, not so much to the form, which is very variable, but to the structure, which is dense in the middle and thin towards the edges. The cirro-stratus is markedly a precursor of storms; and from its greater or less abundance and permanence, it gives some indication of the time when the storm may be expected. It may generally be seen between storms, occasionally with the cirro-cumulus, and, from what then takes place, important information may be learned regarding the continuance or non-continuance of the stormy weather then prevailing. For if the cirro-cumulus give way or pass into the cirro-stratus, thus leaving it, as it were, in possession of the field, more wind and rain may be confidently expected; but if the cirro-stratus yield, and the cirro-cumulus prevail, the storm is past, and fair weather may be looked for.

285. Since the cirro-stratus possesses great extent and continuity of substance, with little perpendicular depth, it is the cloud which most frequently and completely fulfils the conditions

requisite for exhibiting *Parhelia* (Gr. *para*, about or near, and *hēlios*, the sun) or mock-suns, *Paraselenæ* (Gr. *para*, about or near, and *sēlēnē*, the moon) or mock-moons, *Coronæ*, and *Solar* and *Lunar Halos*.

286. *Cumulo-stratus*.—This cloud is formed by the cirro-stratus blending with the cumulus, either among its piled-up heaps, or spreading underneath its base as a horizontal layer of vapour. It sometimes appears indistinctly in the intervals of showers. The *distinct* cumulo-stratus is formed when the cumulus becomes surrounded with small fleecy clouds just before rain begins to fall, and also on the approach of thunderstorms.

287. *Cumulo-cirro-stratus, or Nimbus.*—This is the well-known *rain-cloud*, consisting of a cloud, or system of clouds, from which rain is falling. The rain-cloud often has its origin in the cumulo-stratus, which increases till it overspreads the sky, and becomes black or bluish-black in colour; but this colour soon changing to grey, the nimbus is formed, and rain begins to fall. Its name, cumulo-cirro-stratus, suggests more accurately the manner of the formation of the rain-cloud. At a considerable height a sheet of cirro-stratus cloud is spread out, under which cumulus clouds drift from windward; these rapidly increasing unite at all points, forming one continuous grey mass, from which rain falls. It is evident that the whole body of air under the upper sheet of cloud into which the clouds drift must be all but completely saturated. The breaking-up of the lower grey mass indicates that the rain will soon cease. When a rain-cloud is seen approaching at a distance, cirri appear to shoot out from its top in all directions; and it has been observed that the more copious the rainfall the greater is the number of the cirri thrown out from the cloud.

288. *Observing Clouds*.—In observing clouds, the class to which they belong, the direction in which they are carried both in the lower and upper regions of the atmosphere, and the proportion of the sky covered with them, should be noted. In estimating the amount, that portion of the sky from the horizon half-way to the zenith should not be taken into account, because, the clouds being there foreshortened, the estimate formed would be too great. The scale generally adopted in this country is 0 to 10; 0 indicating a clear sky, 5 a sky half covered, and 10 the sky wholly obscured.

289. The mean amount of cloud in the west of Scotland is 7.2 in winter, 6.4 in spring, 6.5 in summer, and 6.8 in autumn; and in the east and interior of the country the amounts are 6.0, 5.8, 6.0, and 6.1. In Shetland the amount of cloud is greater, three-fourths of the sky being the average space covered with cloud. The months most free of clouds are May and June, owing to the rising

temperature and the dry winds which then prevail. The cloudiest month is December, when the temperature is rapidly falling, and the south-west wind attains its greatest frequency.

290. *Velocity of Clouds.*—The rate of the motion of the clouds is greater than is commonly supposed, and very much greater than the velocity of the wind at the earth's surface. From observations accurately made on the passage of the shadows of clouds across a landscape on a breezy day, it has been ascertained that a velocity at the rate of 70 miles an hour occurs with an apparent leisurely motion of the clouds, and that a velocity of 110 miles an hour occurs when the motion is not at all striking. It cannot be doubted that the motions of the upper currents of the atmosphere far transcend the limits usually assigned to them.

CHAPTER X.

RAIN, SNOW, AND HAIL.

291. WHATEVER tends to lower the temperature of the air is a cause of rain. Various causes may conspire to effect this, but it is chiefly brought about by the ascent of air into the higher regions of the atmosphere. Moist air-currents are forced up into the higher parts of the atmosphere by colder, drier, and therefore heavier, wind-currents getting beneath them, and thus wedgewise thrusting them upwards; and the same result is accomplished by ranges of mountains opposing their masses to the onward horizontal course of the winds, so that the air is forced up their slopes and cooled, and its vapour is condensed into showers of rain or snow. Moist air-currents are also forced into the higher regions of the atmosphere over the area of least pressure at the centre of storms. The temperature of the air is lowered, and the amount of the rainfall increased, by those winds which convey the air to higher latitudes. The meeting and mixing of winds of different temperatures, being the theory of rain propounded by Hutton, is doubtless a cause of rain, since the several portions, when combined into one, are incapable of holding in suspension the same quantity of vapour that each could hold separately. The rainfall is also increased if the prevailing winds arrive immediately from the sea, and are therefore moist; but diminished if they have previously passed over large tracts of land, particularly mountain-ranges, and are therefore dry. Since the quantity of rain is evidently much modified by the temperature of the earth's surface over which the rain-producing winds blow, it follows that sandy deserts, by allowing solar and nocturnal radiation to take immediate effect in raising or depressing the temperature, and forests, by delaying, if not in many cases counteracting, the effects of radiation, have each a peculiar influence on the rainfall.

292. The rain-cloud has been already generally described in

paragraph 287; but the more specific conditions under which rain is precipitated are thus stated by M. E. Renou: 1. Two layers of clouds at least; an upper layer, the cirrus, which, being at a great height, is composed of minute ice-particles at a very low temperature, probably not higher than —40°; and a lower layer, the cumulus, or cumulo-stratus, which has its density increased and its temperature diminished by the descent of the ice-crystals of the cirrus. 2. The temperature of the air at the earth's surface as high as possible. 3. The atmospheric pressure notably lower than in surrounding regions. 4. Regular horizontal currents of air allowing the atmosphere to remain a sufficiently long time in a state of unstable equilibrium. 5. A rapid movement of the air tending to re-establish the equilibrium of temperature and pressure, by mixing together the different layers of the atmosphere.

293. Rain sometimes falls from a cloudless sky, and is then called *Serein.* Sir J. C. Ross thus describes a case which occurred near Trinidad, South Atlantic, on the 25th December 1839: "It was a beautiful clear night, not a cloud to be seen in any part of the heavens, yet we had a light shower of more than an hour's continuance. The temperature of the dew-point was 72°, and that of the air 74°." Many similar cases have been recorded.

294. The instrument for ascertaining the quantity of rain which falls is called a *Rain-gauge.* Rain-gauges are of various constructions. The simplest consists of a metallic cylinder, from the bottom of which a glass tube, *b c*, divided into inches and parts of an inch, issues, as in fig. 24. It is provided with a funnel inserted within at the top to prevent evaporation, and the rain-water is emptied out by a stop-cock, *d*, at the bottom, or, what is still simpler, by a hole, *a*, fig. 25, pierced in the funnel at the top. As this form of gauge is objectionable from the frequent breaking of the glass tube in time of frost, a float is used instead, which is raised by the water, and a scale is attached to it projecting above the gauge, by which the quantity of rain is measured. This is the

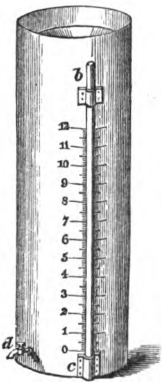


Fig. 24.

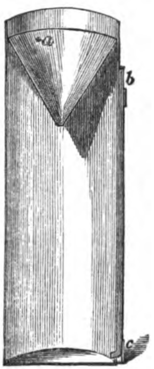


Fig. 25.

gauge, fig. 26, commonly known as Fleming's gauge, which is used extensively in Scotland. Another gauge is frequently used, consisting of a receiving-vessel, and a glass measure of much smaller diameter, which admits of as nice graduation as may be desired. A good specimen of this class is the gauge recommended by G. J. Symons, London, fig. 27, in which *b* is the vessel which receives the rain, and *c* the graduated vessel which measures the amount. There being often great difficulty or trouble experienced in replacing the glass measure when it chances to get broken, the late G. V. Jagga Rew, a wealthy zemindar of Vizagapatam, proposed a gauge (fig. 28) in the form of a funnel, having a diameter of 4.697 inches, on a receiving area of 17.33 square inches. Now, since a fluid ounce contains 1.733 cubic inches of water, it follows that for every fluid ounce collected by this gauge the tenth of an inch of rain has fallen. The measure can of course be graduated to any degree of nicety; and it may easily be reproduced if required. It is also the cheapest rain-gauge, costing only 7s. 6d. when made of copper, and 4s. 6d. when made of tin. Self-registering rain-gauges have been invented by Osler, Crosley, and P. Stevenson; but, being too expensive for general use, they need not be described here.

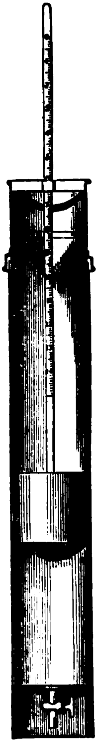


Fig. 26.

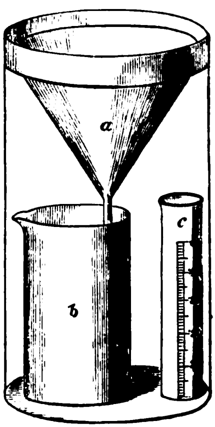


Fig. 27.

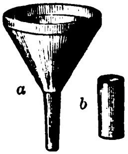


Fig. 28.

295. So far as size is concerned, no difference exceeding one or two per cent exists between the indications of gauges whose apertures have areas from 12 to 452 square inches. Gauges 1 inch or 2 inches in diameter register too little. It may therefore be concluded, that gauges from 3 inches diameter and upwards are all nearly equally good for rain observations, and that expensive gauges of large diameters have no practical advantage over cheaper sorts.

296. A most important point in the position of the rain-gauge is

its height above the ground. Professor Phillips found the rainfall at York for twelve months during the year 1833-34 to be 14.96 inches at 213 feet from the ground; 19.85 inches at 44 feet; and 25.71 inches on the ground. An extensive series of observations has also been conducted by Colonel Ward, with the view of ascertaining the quantity of rain collected at different heights from the ground. The following is the relative rainfall at different times for the four years 1864-67: On a level with the ground, 1.07 inch; at a height of 2 inches, 1.05; 6 inches, 1.01; 1 foot, 1.00; 2 feet, .99; 3 feet, .98; 5 feet, .96; 10 feet, .95; and 20 feet, .94. Observations at Castleton give at 1 foot 1.00 inch; at 5 feet, .96; and for 20 feet, .90. R. Chrimes's observations at Rotherham during 1866-67 give the following amounts: At 1 foot, 1.00 inch; 5 feet, .94; 10 feet, .91; 15 feet, .90; 20 feet, .89; and 25 feet, .88. The remarkable fact here indicated, that different quantities of rain are collected at different heights, the quantity being greater at the lower levels, has been always confirmed whenever the experiment has been tried. No perfectly satisfactory account has yet been given of this singular phenomenon.

297. Rain is the most capricious of all atmospheric phenomena, both as regards frequency and the amount which falls in a given time. It rarely or never falls in certain places, which are on that account named the rainless regions of the globe: the coast of Peru, in South America; the great valley of the rivers Columbia and Colorado, in North America; the Sahara, in Africa, and the desert of Gobi, in Asia, are examples: whilst, on the other hand, in such places as Chiloe and Patagonia, it rains almost every day.

298. The quantities of rain which have been recorded as having fallen at one time in some places are truly enormous. In Great Britain, if an inch falls in a day, it is considered a very heavy rain. But in many parts of the Highlands of Scotland, 3 inches not unfrequently fall in one day. On the 5th December 1863, 5.2 inches fell at Drishaig, near Ben Cruachan, in Argyleshire, where also two days afterwards 7.12 inches fell in 30 hours. At Seathwaite, in Cumberland, 6.62 inches fell on 27th November 1848; and this enormous fall in one day has been nearly reached six times since that date. But it is in lower latitudes that the heaviest single showers have been recorded. The following are a few of the most remarkable: At Joyeuse, in France, 31.17 inches in 22 hours; at Genoa, 30 inches in 24 hours; at Gibraltar, 33 inches in 26 hours; on the hills above Bombay, 24 inches in one night; and on the Khasia Hills, north-west of Calcutta, 30 inches on each of five successive days.

299. *Rainy Days.*—Rainy days are more numerous in high than

in low latitudes. Thus, in the northern hemisphere, from 12° to 43° latitude, the number of rainy days in the year is, on an average, 78; from 43° to 46° latitude, 103; from 46° to 50° latitude, 134; and from 50° to 60° latitude, 161. Considerable discrepancy exists among observations as to the number of rainy days, owing to the want of a generally received definition of what constitutes a *rainy day*. The fall of .01 or $\frac{1}{100}$ inch of rain, as suggested by Mr Symons, is now very generally adopted.

300. *Rainfall within the Tropics.*—At places within the tropics where the trade-winds blow regularly and steadily, the rainfall is small, because, as these winds travel from higher to lower latitudes, their temperature is increasing, and they are therefore rather in the condition of taking up moisture than of parting with it. Where, however, the trade-winds are forced up the slopes of mountain-ranges lying in their course, as on the east of Hindostan, or the north of South America, they bring rain in copious showers.

301. *The Region of Calms* is a broad intertropical belt about 5° in breadth, marked by a low atmospheric pressure, towards which the north-east and south-east trades blow. This is the region of constant rains. Here the sun almost invariably rises in a clear sky; but about mid-day clouds gather, and in a short time the whole face of the sky is densely covered with black clouds, which pour down prodigious quantities of rain. Towards evening the clouds disappear, the sun sets in a clear sky, and the nights are serene and fine. The reason of this daily succession of phenomena in the belt of calms is, that there the air, being greatly heated by the vertical rays of the sun, ascends, drawing with it the whole mass of vapour the trade-winds have brought with them, and which has been largely added to by the rapid evaporation from the belt of calms; this vapour is condensed as it rises to the line of junction of the lower and upper trades. The discharge is in some cases so copious that fresh water has been collected from the surface of the sea. As evening sets in, the surface of the earth and the superincumbent air being cooled, the ascending currents cease and the cooled air descends; the clouds are thus dissolved, and the sky continues clear till the returning heat of the following day brings round a recurrence of the same phenomena. It will be observed that the daily rains of the belt of calms are to some extent analogous in their origin and causes to the formation of the cumulus cloud of temperate climates. Since the region of calms which determines the rainy season within the tropics moves northward or southward with the sun's declination, carrying the trade-winds with it on each side, it follows that there will be only one rainy and one dry season in the year at its ex-

treme northern and southern limits; but at all intermediate places there will be two rainy and two dry seasons, these being at the equator equally distant from each other.

302. Over a great part of the tropics disturbing influences draw the trade-winds out of their normal (Lat. *norma*, a rule) course, and sometimes, as in the case of the monsoons, give rise to winds which blow from the opposite point of the compass. These winds determine the rainfall of India, and but for them the eastern districts of Hindostan would be constantly deluged with rain, and the western districts constantly dry and arid. As it is, each part of India has its dry and wet seasons, summer being the wet season of the west and interior as far as the Himalaya, and winter the wet season of the east, and especially the south-east. Thus the rainfall at Mahabuleshwar, in the Western Ghauts, in the four months from June to September, is 242 inches, while during the other eight months it is only 12 inches. At Benares for the same time the quantities are 46 inches and 7 inches. On the other hand, in the east, at Madras, the rainfall for the three months, October, November, and December, is 30 inches, and for the other nine months 19 inches.

303. So far as known, the heaviest annual rainfall at any place on the globe is 600 inches, on the Khasia Hills, about 500 inches of which fall in seven months, during the south-west monsoons. This astonishing quantity is due to the abruptness of these hills facing the Bay of Bengal, from which they are separated by only 200 miles of low swamps and marshes. Hence the southerly winds not only arrive heavily laden with the vapour they have licked up from the Indian Ocean, but, receiving further accessions of moisture in passing over the 200 miles of swamp, they are, so to speak, ready to burst in torrents, even before they are suddenly raised, by the hills they encounter, into the cooler regions of the atmosphere. At 20 miles farther inland the annual amount is reduced to 200 inches; at 30 miles to 100 inches; north, at Gowahatty, in Assam, it is only 80 inches. In the north-west of the Bay of Bengal, at Cuttack, it is only 50 inches; while in the north-east, in Arracan, being more in the course of the south-west monsoon, the rainfall is swelled to 200 inches. In the following annual amounts the effect of the hills is strikingly shown: At Madras, 48 inches, but Seringapatam only 24 inches; at Bombay, 76 inches; among the West Ghauts, at Uttra-Mullay, 263 inches; and at Mahabuleshwar, 254 inches; while at Poonah, more inland, it is only 22 inches. In Mauritius, for the four years ending 1865, the average rainfall at Gros Cailloux was 30 inches; whereas at Cluny, only about 16 miles distant, it amounted to

146 inches. In regard to the above, Mr Meldrum remarks: "At Cluny, in the vicinity of mountains and forests, in the south-east part of the island, and exposed to the trade-wind as it arrives from the sea, the rainfall in almost any month is from four to six times greater than at Gros Cailloux on the north-west coast, where neither mountain nor forest exists, and where the air arrives partly deprived of its moisture."

304. The following are a few of the more interesting annual rainfalls in the tropics: Singapore, 97 inches; Canton, 78 inches; Somerset, Cape York, 87 inches; Akyab, 104 inches; Colombo, 74 inches; St Benoit, Isle of Bourbon, 166 inches; Sierra Leone, 89 inches; Christiansborg, 23 inches; St Helena, 5 inches; Ascension, 9 inches; Caraccas, 155 inches; Pernambuco, 106 inches; Rio Janeiro, 45 inches; Georgetown, 75 inches; Barbadoes, 72 inches; St Domingo, 107 inches; Bahamas, 56 inches; Vera Cruz, 183 inches; Ceara, 60 inches; Doldrums of the Atlantic, 225 inches; Maranhao, 280 inches. In many places in the interior of continents, and places situated a little to the leeward of mountain-ranges, considered with reference to the prevailing winds within the tropics, the rainfall is small, being not greater than what occurs in temperate countries.

305. *Rainfall in Europe.*—The periodicity of the rainfall disappears as we recede from the tropics, and the times of the year during which it falls are different, the greatest quantity falling within the tropics in summer, whereas in temperate regions the greatest quantity generally falls in winter. In respect of the rainfall, Europe may be divided into two distinct regions—Western Europe, extending in a modified degree into the interior of the continent; and the countries bordering on the Mediterranean.

306. A vast ocean on the one hand, a great continent on the other, and a predominance of westerly winds, are the determining circumstances in the distribution of the rainfall over Western Europe. Since westerly and southerly winds prevail from the south of Europe northwards, it follows that the western parts, especially where mountain-ranges stretch north and south, are rainy districts. Hence the wettest regions are the west of Great Britain, Ireland, Norway, and of France, Spain, and Portugal. At the Stye, in the lake district of England, being, so far as known, the wettest spot in Great Britain, 38.9 inches fell in January 1831: at Drishaig, near Ben Cruachan, 33.2 inches; and at Portree, 32.4 inches in December 1863; and in the same month from 23 to 30 inches at many places in the Scottish Highlands.

307. In the west of Great Britain and Ireland, in the immediate neighbourhood of high hills, the average rainfall is from 80 to

150 inches, and in some years it is higher: thus, at Seathwaite, in Cumberland, it was 183½ inches in 1861; at the Stye, 224½ inches in 1866; and at Upper Glencroe, Argyleshire, 166½ inches in 1868. At Bergen, in Norway, the rainfall is 72 inches; in the Peninsula, at Coimbra, 118 inches; at Oviedo, 74 inches; and at St Jago, 73 inches. In France, it is 51 inches at Nantes, and 49 at Bayonne. At places at some distance from hills, and in more inland situations, the annual fall is much diminished. Thus, in the west of Great Britain, away from hills, it is from 30 to 45 inches; while in the east of the island it is only from 20 to 28 inches. In the west of Norway, it is 45 inches at Alesund; 35 inches at Christiansund; 20 inches at Tromso; but in Christiana it is only 21 inches. In Sweden, east of the Scandinavian Mountains, the annual fall nowhere exceeds 22 inches; at Piteă and Jockmock it is only 15 inches, and at Kalmar only 13 inches. At Goteborg it is as high as 35 inches. In France the average is 30 inches, and in the plains of Germany and Russia, 20 inches and under. But in the interior of Europe, in mountainous districts, it rises much above these amounts; thus at the Brocken it is 59 inches, and at St Maria, in the Alps, 104 inches.

308. An important distinction between the mode of distribution of the rainfall in the west of Europe and at more inland places, is that the greater part of the annual quantity of the west falls in winter, whilst in the interior the amount in summer is greater than in winter. Thus, comparing the summer with the three winter months, the amounts are 6 and 3½ inches at Carlstadt, Sweden; 6½ and 3 inches at St Petersburg; and 7½ and 1½ inches at Kursk. This peculiarity is also shown by the east and west sides of Great Britain. It is probably owing to the more westerly direction of the winds in summer, by which the vapours of the Atlantic are conveyed more directly into the heart of the continent; and doubtless also to the clouds being much lower in winter, by which they are arrested and drained of their moisture by the less elevated hills, thus leaving little to be deposited eastward—whereas in summer, the clouds, being high, pass above and discharge their moisture in the interior.

309. It will be shown further on that the greater proportion of the rain which falls during storms falls in the front part of the atmospheric depression which accompanies the storm—that is, as respects Great Britain, with easterly, southerly, and south-westerly winds. Hence, in those districts where the greater part of the rainfall of the year is made up of the rain which falls during storms, or on the eastern slope of the island, it might be expected that the greater part of the annual rainfall is brought by easterly

and not by westerly winds. The Rev. Alexander Beverly, Aberdeen, has examined the rainfall for the different winds at that place for the two years 1864 and 1865, from which it appears that as much rain falls with N.E. as falls with S.W. winds; and that while 12.74 inches fell with S.W., W., N.W., and N. winds, as much as 17.85 inches, or nearly a half more, fell with N.E., E., S.E., and S. winds. This large rainfall, which is deposited by easterly winds, is originally brought by the south-west wind, which, prevailing first in the higher regions of the atmosphere, saturates the air with the vapour which it brings from the ocean; or the easterly winds (N.E., E., S.E.) which deposit the rain, are part of the same moist current drawn back by and towards the low atmospheric pressure which at the time is advancing from the west.

310. The peculiarity of the rainfall of the basin of the Mediterranean and seas adjoining depends on (1) its proximity to the burning sands of Africa, (2) a predominance of northerly winds resulting chiefly from that position, and (3) the Pyrenees and Spanish sierras to the west, on which the south-west winds precipitate their rains before arriving on the north shores of the Mediterranean. In the valley of the Rhone, four times more rain falls in autumn than in summer; and south of the Alps, six times more rain falls with north-east than with south-west winds, being the reverse of what takes place in the west of Great Britain. In Italy the quantity of rain diminishes as we approach the south, because south winds become wetter, and north winds drier as they proceed on their course. At Pisa, the annual rainfall is 49 inches; at Rome, 39 inches; at Naples, 33 inches; at Palermo, 23 inches; and in Malta, 20 inches. Along the Syrian and North African coasts it rarely rains in summer, but frequently in winter. The annual amounts are—at Jerusalem, 19 inches; Beyrout, 20 inches; Larnaka, Cyprus, 13 inches; La Calle, 36 inches; Constantine, 27 inches; Algiers, 31 inches; and Oran, 19 inches.

311. The rainfall on the shores of the Caspian Sea is very remarkable. At Astracan the annual amount is 4½ inches; at Baku, 10 inches; at Derbent, 16 inches; at Lencoran, 51 inches; and at Astrabad, 18 inches;—thus showing a very rapid rate of increase in advancing to the south-west of the sea. In the valley of the Rhone, the annual fall ranges from 20 inches on the coast to 63 inches at St Rambert, the average being 30 inches. This is also the average of the valley of the Po; but on ascending the long slopes northward to the Alps, it rises, as at Tolmezzo, to 96 inches.

312. *Rainfall of America.*—The rainfall in the west of the American continent is distributed similarly to that of Europe—

the quantity being chiefly dependent on the physical configuration of the surface over which the prevailing winds blow. In North America the yearly amount increases as we proceed northward: thus, at San Francisco it is 21 inches; at Fort Reading, 29 inches; at Fort Oxford, 72 inches; at Fort Vancouver, 47 inches; at Astoria, 86 inches; at Steilacoom (Wash. Ter.), 54 inches; and at Sitka, in the north-west of America, 90 inches. To the south, at San Diego, the annual rainfall is only 8 inches, and at Fort Yuma, 3 inches.

313. But in the United States the manner of the distribution of the rainfall differs greatly from that of Europe. The United States are chiefly dependent for their rain, not on the Pacific Ocean, but on the Gulf of Mexico. The high range of the Rocky Mountains plays an important part in the rainfall. With reference to the rainfall of America, Blodget remarks: "For much the larger area of the United States, and for all portions east of the Rocky Mountains, the distinguishing feature of the distribution of the rainfall *is its symmetry and uniformity* in amount over large areas. The quantity has rarely or never any positive relation to the configuration of the surface, which would identify it with Europe and the North Pacific coasts; and in contrast with these it has a diminished quantity at the greater altitudes generally, and the largest amounts in the districts near the sea-level. It also differs from these districts, and from large land areas generally, in having a larger amount in the interior than on the coast, for the same latitude, at least as far north as lat. 42°." The rainiest districts are Florida, the low flats of the Mississippi, then along the course of its valley, then in Iowa, that remarkable depression at the head of the river; and the least quantities on the Alleghanies, especially their higher parts, and the high grounds of the Missouri district. The following figures give the annual amounts in inches at different places: In Florida—Pensacola, 57; Fort Brook, 55; and Fort Pierce, 63: in Alabama—Monrosville, 66; and Mobile, 64: in Mississippi—Natchez, 58; and Jackson, 53: in Louisiana—Rapides, 63; and New Orleans, 52: in Tennessee—Nashville, 53: in Georgia—Savannah, 48: in Iowa—Fort Madison, 50. At Athens, in Georgia, south of the Alleghanies, the amount is 36; at Alexandria, in Virginia, also 36; and at Jefferson, in Missouri, 38. In the Northern States the quantity diminishes at most places to between 27 and 45 inches, and the mode of its distribution becomes assimilated to that of Europe.

314. There is very great diversity in the rainfall of *Australia.* At Somerset, at the north-east point, the annual rainfall is 87 inches; Brisbane, 47 inches; Sydney, 49 inches; Melbourne, 28

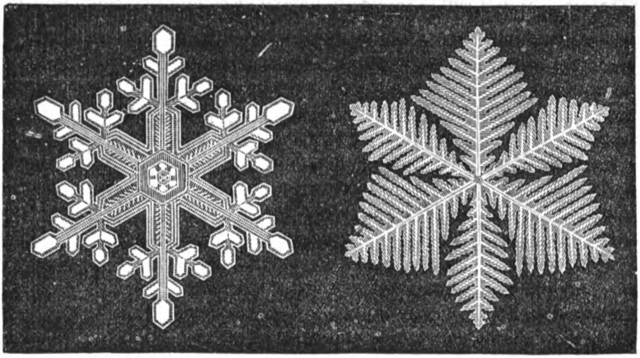
inches; Adelaide, 20 inches; and Freemantle, 31 inches. At Deniliquin, on the Murray River, only 12 inches fall annually. The rainfall of this continent is extremely fluctuating from year to year. In *Tasmania* the annual amounts vary from 59 inches in King's Island to 21 inches in Goose Island—at Hobart Town the average is 27 inches, which is probably the average of the open districts on the east side of the island; on the west much more rain falls. In *New Zealand* the differences are still greater. At Hokitika, in the west, 120 inches fall annually, and at Bealey 118 inches; whereas at Christchurch, on the opposite side of the island, the average is only 25 inches. At Southland the annual fall is 44 inches; Dunedin, 34 inches; Nelson, 58 inches; Wellington, 50 inches; Tranaki, 56 inches; Auckland, 49 inches; and Mongonui, 54 inches. In *South Africa* very great differences prevail, the annual amounts being 40 inches at Wynberg, 32 inches at Pietermaritzburg, 30 inches at Simon's Town, 27 inches at Somerset West, 23 inches at Cape Town, 19 inches at Alwali North, 14 inches at Graff Reinet, 12 inches at Worcester, 10 inches at Concordia, and 8 inches at Keerom, Namaqualand; and at all these places the annual rainfall is subject to great fluctuation. In the south of South America, the annual amounts are, 48 inches at Buenos Ayres, 22 inches at Punta Arenas near Cape Horn, 109 inches at Valdivia, and 102 inches at Puerto Montt; but at Santiago de Chili it is only 17 inches.

Snow.

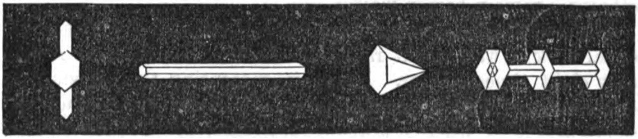
315. *Snow* is the frozen moisture which falls from the clouds when the temperature is 32° or lower. The particles of which snow is composed are crystals, which are usually in the form of six-pointed stars. About 1000 different kinds of snow-crystals have been already observed, many of which have been figured and described by Scoresby, Glaisher, Lowe, and others. These numerous forms have been reduced by Scoresby to the following five principal varieties: 1. Thin plates — the most numerous

Figs. 29 30 31 32 33

class—comprising several hundred forms of the rarest and most exquisite beauty (figs. 29 to 35). 2. A spherical nucleus or plane figure, studded with needle-shaped crystals (fig. 36). 3. Six or more rarely three-sided prismatic crystals (fig. 37). 4. Pyramids of six sides (fig. 38). 5. Prismatic crystals, having at the ends and middle thin plates perpendicular to their length (fig. 39). The forms of the crystals of the same fall of snow are generally similar to each other. Snow-flakes vary from an inch to 0.07 inch in diameter, the largest being observed when the temperature is near 32°, and the smallest at very low temperatures.



Figs. 34 35



Figs. 36 37 38 39

316. The limit of the fall of snow at any time of the year coincides nearly with 30° N. lat., which includes almost the whole of Europe. On traversing the Atlantic this line rises to lat. 45°, but on nearing the American continent it descends to near Charleston in lat. 33°; it rises in the west of America to lat. 47°, and again falls to lat. 40° in the Pacific. It corresponds nearly with the winter isothermal of 52° (Plate IV.), since in places where the mean winter temperature is no higher than 52°, the air may be expected to fall during the coldest months occasionally to 32° or lower. Snow is unknown at Gibraltar; at Paris it falls 12 days on an average annually, and at St Petersburg, 170 days.

317. The *white colour* of snow is caused by the combination of the different prismatic rays which issue from the minute snow-crystals. When the crystals are looked at separately, some appear red, others green, purple, and, in short, all the colours of the spectrum, as these are seen in crystal gasaliers; but when a mass of snow is looked at, the different colours blend into homogeneous white. Pounded glass and foam may be referred to as other illustrations of the prismatic colours blending together and forming the white light from which they had been originally produced. It may be added that the air contained in the crystals intensifies the whiteness of the snow. *Red snow* and *green snow* have been occasionally met with in the arctic regions and in other parts of the world. These colours are due to the presence of microscopic organisms, called *Protococcus nivalis*, about $\frac{1}{1000}$ inch in diameter, which grow and flourish in the region of eternal snow.

318. The uses of snow are very important; thus, from its loose texture, and from its containing about ten times its bulk of air, snow is a very bad conductor of heat; and thus is an admirable covering for the earth in preserving it from the effects of its own radiation. It not unfrequently happens, in times of great cold, that the soil is 40° warmer than the surface of the overlying snow. The flooding of rivers from the melting of the snow on mountains in spring and summer, carries fertility into regions which would otherwise remain barren wastes.

319. Snow is generally from 10 to 12 times lighter than an equal bulk of water; but rare cases have occurred where it was only eight times lighter. Hence in measuring the snowfall, in order to add it to the rainfall, a common rule is to measure the depth at a place where it is about the average depth of the district, and take one-tenth as the equivalent of the rainfall. Thus, if the average depth of snow fallen be 5 inches, this would equal 0.5 inch, or half an inch, of rain; if 12 inches of snow, it would be 1.20 inches of rain, &c. This, however, is only a rude way of comparing the snow with the rainfall, being liable to considerable error owing to the varying compactness of the snow. It may be accurately measured by thrusting the open end of a cylindrical tin vessel down through the snow to the ground, and melting the snow which it brings up. The depth of the water or melted snow is considered as the rainfall.

320. Sleet appears to be formed from snow-flakes falling through a stratum of moist air at a temperature of 32°, or higher. The great size of the flakes is caused by the snow particles uniting by regelation as they come against each other; and they are no doubt

further enlarged by the condensation of vapour on their surfaces as they float down through the moist air. Sleet falls chiefly in winter and in spring.

321. *Snow-Line.*—The snow-line marks the height below which all the snow that falls annually melts during summer; above this imaginary line lies the region of perpetual snow. No general rule can be laid down for the height of this line, owing to the many causes by which it is determined. These are, (1) the exposure of the slope of the mountain to the sun's rays, and hence, other things being equal, it is higher on the south than on the north side of mountains; (2) the situation with respect to the rain-bringing winds; (3) the steepness of the slope; and (4) the dryness or wetness of the district. Hence the snow-line can only be ascertained from observation. The following are the observed heights in feet, in different parts of the globe:—

HEIGHT OF THE SNOW-LINE ABOVE THE SEA.

	N. Lat.	Height.
Spitzbergen,	78°	0
Sulitelma, Sweden,	67° 5′	3,835
Kamtchatka,	59° 30′	5,249
Unalaschta, W. America,	56° 30′	3,510
Altai,	50°	7,034
Alps,	46°	8,885
Caucasus,	43°	11,063
Pyrenees,	42° 45′	8,950
Rocky Mountains,	43°	12,467
North Himalaya,	29°	19,560
South Himalaya,	28°	15,500
Mountains of Abyssinia,	13°	14,065
Purace,	2° 24′	15,381
	S. Lat.	**Height.**
Nevados of Quito,	0	15,820
Arequipa, Bolivia,	16°	17,717
Paachata, Bolivia,	18°	20,079
Portillo, Chili,	33°	14,713
Cordilleras, Chili,	42° 30′	6,010
Magellan Strait,	53° 30′	3,707

322. It will be observed from this table, that, speaking generally, the snow-line from lat. 0° to 20° sinks only a very little; from 20° to 70° it continues to fall equally; but from 70° to 78° it falls with great rapidity. To this general rule there are, however, several noteworthy exceptions. Thus, it is about 4000 feet higher on the north than on the south side of the Himalayas, owing (1) to the greater depth of snow which falls on the south

side; (2) to the greater dryness of the climate of Thibet, which increases the evaporation from the surface of the snow and the heating power of the sun to melt snow at these great heights; and (3) to the rocks and soil of the north being in a great measure destitute of vegetation, and therefore capable of absorbing more heat than the regions south of the Himalayas, which are covered with vegetation.

323. It is higher in the centre of continents than near the coasts, because the rainfall is less, and the heat greater; thus, while in the Caucasus it is 11,063 feet, it is only 8950 in the Pyrenees, both places being nearly in the same latitude. Similarly, it is higher on the east than on the west side of continents, as is strikingly shown by Kamtchatka, 5249 feet, and Unalaschta, 3510 feet, situated respectively on the west and east coasts of the North Pacific.

324. South of the equator it rises very considerably from lat. 0° to 18°, and more so on the west than on the east slopes of the Cordilleras, owing to the small quantity of rain and snow which fall on the west side of these mountains. It is as high in S. lat. 33° as in N. lat. 19°; but south of this parallel it rapidly sinks, owing to the heavy rains precipitated by the north-west winds which there prevail; so that in the south of Chili it is 6000 feet lower than at the same distance from the equator among the Rocky Mountains of North America, and 3000 feet lower than in Western Europe. The mean temperature of the snow-line varies greatly from the equator to the poles, being at some places 35°, and at others as low as 20°. In the Swiss Alps it is about 25°, and in Norway about 23°.

Hail.

325. The hard pieces of ice which fall in showers are called *hail.* Hail is very different from snow, both in its formation and in the circumstances attending its precipitation. Hailstones are generally of a conical or of a round shape, and when cut across are found to be composed of alternate layers of clear and opaque ice, enveloping a white snowy nucleus. Less frequently they are composed of crystals radiating from the centre outwards (figs. 40 and 41). The interior generally contains several nuclei, in which cases the hailstones appear to be a conglomeration of several hailstones, as in fig. 42, which represents one that fell at Bonn on 7th May 1822; the surface is rough, and in the case of the larger hailstones often bristling with small icicles.

326. Hailstones vary much in size, some being as small as the smallest shot, while others are several inches in diameter. In August 1813, hailstones the size of eggs fell upon the British army in the Pass of Maya in the Pyrenees; the storm lasted twenty minutes, and was not accompanied with thunder or lightning. On 4th June 1814, hail, from 13 to 15 inches in diameter, fell in Ohio. In the Orkney Islands, on the 24th July 1818, during thunder, a very remarkable shower of hail took place; the stones were as large as a goose's egg, and mixed with large masses of ice. In June 1835, hail fully three inches in circumference fell near Edinburgh from a dense cloud during a thunderstorm. On 8th May 1832, an immense mass of aggregated hailstones fell in Hungary, measuring about a yard in length, and nearly two feet in depth. A mass nearly twenty feet in circumference, of an angular shape, and composed of lozenge-shaped pieces congealed together, is said to have fallen in Ross-shire, in August 1849. Masses of this sort are probably formed by regelation after the hailstones have fallen, by which their surfaces are made to adhere together when rolled over each other by the wind. A hailstone (fig. 43) described by Captain Delcrosse as having fallen at Baconnière in July 1819, was 15 inches in circumference, and had a beautifully-radiated structure, showing it to be a single hailstone. On the 8th August 1857, Professor Tyndall saw hail fall among the Alps in the form of perfect spheres of ice, just as if the rain-drops had solidified in their descent.

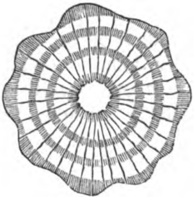


Fig. 40.

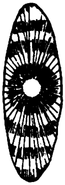


Fig. 41.

Fig. 42.

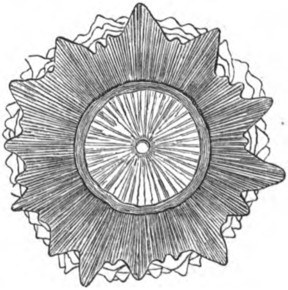


Fig. 43.

327. No satisfactory theory of the origin of hail has yet been

proposed which fully explains all the phenomena connected with hailstorms. Hail appears to be formed by a cold current of air forcing its way into a mass of air *much warmer and nearly saturated*, the temperature of the united mass being below the freezing-point. The warm moist air is easily accounted for, since hail generally falls in summer and during the day. The difficulty is to account for the intensely cold current which is sufficient to reduce the warm saturated mass below 32°.

328. In mountainous regions, cold currents from the fields of snow rushing down the sides of the mountains and mixing with the heated air of the valleys are no doubt frequent causes of hail; and we have seen that such places are peculiarly subject to hailstorms. The sudden ascent of moist warm air into the upper regions of the atmosphere, where a cold current prevails at the time, is, in all probability, a common cause of hail. This is confirmed by the circumstances generally attendant on hailstorms—viz., the sultry, close weather which precedes them, the slight but sudden barometric depression, the whirlwinds and ascending currents which accompany them, and the fall in the temperature which follows after the storm has passed.

CHAPTER XI.

WINDS—PREVAILING WINDS.

329. **Wind** is air in motion. The force of the wind is measured by *anemometers,* of which there are different sorts—some measuring the velocity, others the pressure. Of the anemometers which measure the velocity of the wind, the simplest and best is the *Hemispherical-Cup Anemometer* (Gr. *anĕmos,* the wind, and *metron,* a measure), generally called Robinson's Anemometer, fig. 44. It

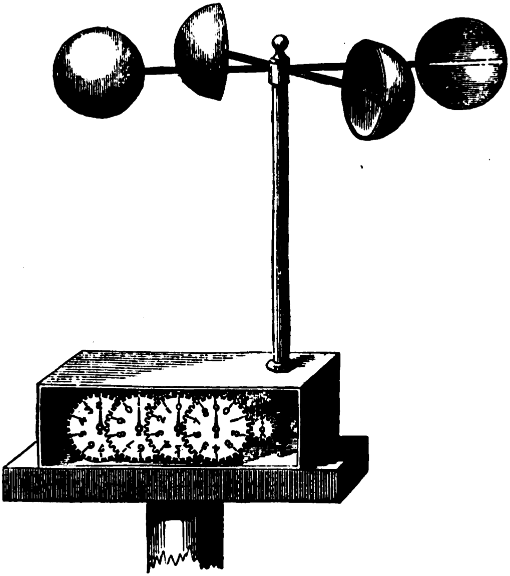


Fig. 44.

consists of four hollow hemispheres or cups screwed on to the ends of two horizontal rods of iron crossing each other at right angles, and supported on a vertical axis which turns freely. When placed in the wind, the cups revolve; and the arms are of such a length that when a mile of wind has passed the anemometer, 500 revolutions are registered by the instrument. The accuracy of its construction may be tested by conveying it rapidly through the air on a perfectly calm day the distance of a mile, and back again the same distance, and noting the number of revolutions made. The number of revolutions is registered by a system of index-wheels set in motion by an endless screw on an upright axis. It is read in the same way as a gas-meter. The number of miles travelled by the wind during a day, an hour, or any other specified time, is found by multiplying the revolutions made in that time by 2, and dividing by 1000. The rate per hour at which the wind blows at any time is found by observing the revolutions made in, say, two minutes; multiply by 30 and 2, or at once by 60, and divide by 1000. Thus, suppose 800 revolutions were made in two minutes, the velocity of the wind would be at the rate of 48 miles an hour.

330. The force of the wind is also ascertained by noting the pressure which it exerts on a plane surface of metal perpendicular to the direction of the wind. The pressure is generally given in pounds avoirdupois on the square foot. The instrument is of simple construction, consisting of a plate a foot square acting on a spiral spring, to which an index showing the degree of pressure is attached. The plate is kept perpendicular to the wind by a vane. This is the principle of Osler's anemometer, which, by means of machinery, leaves a pencilling of the pressure of the wind for every instant. Pressure anemometers are best adapted for measuring the force of sudden squalls and gusts of wind; whilst the Hemispherical-Cup Anemometer best shows the amount of air which passes over a place. Both are required in any complete system of observation of the wind.

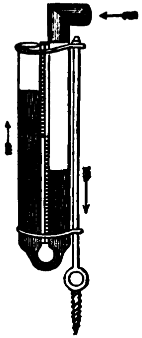


Fig. 45.

331. The pressure is also measured by Lind's wind-gauge, fig. 45, which consists of a tube about half an inch in diameter, in the form of a siphon, one end of it being bent at right angles, so as to face the wind. It turns freely on a vertical axis, and a vane keeps the mouth of it directed to the wind. It is half filled with water, and when the wind blows into the mouth of the instrument, it drives the water up the other

leg, to which a scale showing the pressure is attached. The zero of the scale is the level at which the water stands when the air is calm. It may also be made to register maximum gusts of wind, by filling into the tube a chemical solution which colours bits of prepared paper, placed at different levels on the scale-limb of the instrument.

331. The force of the wind is approximately stated by estimation. The scale generally adopted in this country is 0 to 6, where 0 represents a calm, and 6 a hurricane, or the greatest known force of the wind. Observations by the scale 0 to 6 are converted into pressure in pounds on the square foot by simple squaring. Sailors use the scale of 0 to 12, usually called Beaufort's scale. Observations on this scale may be roughly compared with the preceding scale by dividing by 2. In Sweden, Russia, and some other countries, the scale adopted is 0 to 4.

TABLE OF APPROXIMATE EQUIVALENTS FOR ESTIMATED FORCE OF WIND ON SCALE 0 TO 6.

Scale 0 to 6.	Pressure in pounds per sq. foot.	Velocity in miles per hour.	BEAUFORT SCALE.			
0.0	0.00	0.0	0	Calm.		
0.5	0.25	7.1	1	Light air,	Just sufficient to make steerage-way.	
1.0	1.00	14.1	2	Light breeze,	With which a ship with all sail set would go in smooth water,	1 to 2 knots.
1.5	2.25	21.2	3	Gentle breeze,		3 to 4 ,,
2.0	4.00	28.3	4	Moderate breeze,		5 to 6 ,,
2.5	6.25	35.4	5	Fresh breeze,	In which she could just carry	Royals, &c.
3.0	9.00	42.4	6	Strong breeze,		Single Reefs and T. G. Sails.
3.5	12.25	49.5	7	Moderate gale,		Double Reefs and Jib, &c.
4.0	16.00	56.6	8	Fresh gale,		Triple Reefs, &c.
4.5	20.25	63.6	9	Strong gale,		Close Reefs & Courses.
5.0	25.00	70.7	10	Whole gale,	In which she could just bear close-reefed Main-topsail and reefed Fore-sail.	
5.5	30.25	77.8	11	Storm,	Under Storm Staysails or Trysails.	
6.0	36.00	84.8	12	Hurricane,	Bare Poles.	

In addition to this Wind Table, another (Table VIII.) is given at the end, which shows for the pressure in pounds on the square foot the corresponding velocity in miles per hour.

332. The direction of the wind is indicated by the point of the compass from which it blows. Those in common use are N.,

N.N.E., N.E., E.N.E.,; E., E.S.E., S.E., S.S.E.; S., S.S.W., S.W., W.S.W.; W., W.N.W., N.W., N.N.W. When thirty-two points are given, an additional one is inserted between each two of the above. If greater accuracy be required, the exact point is indicated by degrees; thus W. 41° N. means 41° from W. in the direction of N.

333. All winds may be regarded as directly caused by differences of atmospheric pressure, just as the flowing of rivers is caused by differences of level—the motion of the air and the motion of the water being both referable to gravitation. The wind blows from a region of higher to a region of lower pressure—that is from where there is a surplus to where there is a deficiency of air; and this takes place whether the differences of pressure be measurable by the barometer, as is generally the case, or be not measurable, as in the case of sea-breezes, and sudden squalls and gusts which are of short duration. In the latter case, it is probable that, though the difference of pressure cannot be measured by the ordinary barometer, it might be measured by one of great range, such as King's.

334. So far as we know, differences of atmospheric pressure, and consequently all winds, arise from changes occurring either in the temperature or in the humidity of the air. If two neighbouring regions come from any cause to be of very unequal temperature, the air of the warmer region, being lighter than the other, will ascend and be poured over it from above, while the heavier air of the colder region will flow in below to supply its place. Thus a difference in the temperature of the two districts gives rise to two currents of air—one blowing from the colder to the warmer along the surface of the earth, and the other from the warmer to the colder in the upper regions of the atmosphere. Of this class of winds *Land and Sea Breezes* are the best examples, and they are at the same time the most general as well as the most readily comprehended of the winds. On the sea-coast a breeze sets in from the sea in the morning; at first a mere breathing on the land, it gradually rises to a stiff breeze in the heat of the day, and again sinks to a calm towards evening. Soon after, a breeze springs up from the land and blows strongly seaward during the night, and dies away in the morning, giving place to the sea-breeze as before. These breezes are caused by the land being heated to a much greater degree than the sea during the day, by which the air, resting on it, being also heated, ascends, and the cooler air of the sea-breeze flows in to supply its place. But during night the temperature of the land and the air above it falls below that of the sea, and the air thus becoming heavier and denser flows over the sea as a land-breeze.

335. It is interesting to observe the effect of the rotation of the earth on these breezes when the sea-coast lies east and west. Thus, on the coast of the Gulf of Lyons, the sea-breeze from the S. veers to the S.W., and dies away in the west; while the land-breeze from the N. gradually turns to the N.E., and dies away in the east. On the coast of Algeria opposite, the sea-breeze veers from N. to N.E., and dies away in the east; while the land-breeze veers from S. to S.W., and dies away in the west. Thus in each place the daily course of the winds may be regarded as rotatory, acquiring their greater force when they blow from N. and S., and falling to the minimum at E. and W.

336. Again, if the atmosphere of one region be more highly charged with aqueous vapour than the atmosphere of surrounding regions, the air of the more humid atmosphere being lighter will on that account ascend, while the heavier air of the drier regions will flow in below and take its place. And since part of the vapour will be condensed as it ascends, and heat be thereby disengaged, the equilibrium will be still further disturbed. It is in this way that all the more violent commotions of the atmosphere —gales, storms, tempests, and hurricanes—originate.

Constant, Periodical, and Prevailing Winds (Charts I. and II., *where the Arrows show the prevailing winds*).

337. *The Trade-Winds.*—When the portion of the earth's surface which is heated is a whole zone, or a large part of a zone, as in the case of the tropics, an ascending current will rise from the heated belt, and surface winds from north and south set in towards it to supply the place of the ascending current. This ascending current will rise till it attain a height at which the pressure is less; thence it will flow in either direction towards the poles. Thus surface currents flow from higher latitudes towards the equator, and upper currents from the equator towards the poles. But the directions of these winds are modified by the rotation of the earth on its axis from west to east. In virtue of this rotation, objects on the earth's surface at the equator are carried round towards the east at the rate of about seventeen miles a minute. But on receding from the equator, this velocity is continually diminished; at latitude 60° it is only about eight and a half miles a minute, and at the poles it is nothing. A wind, therefore, blowing along the earth's surface in the direction of the equator, is constantly arriving at places which have a greater velocity than itself. The wind thus lagging behind, these places will come, as

it were, up against it; in other words, an east wind will be the result. Since, then, the wind north of the equator is under the influence of two forces—one drawing it southwards, the other drawing it northwards—it will, by the law of the composition of forces, take an intermediate direction, and blow from north-east to south-west. Similarly, south of the equator, the wind will blow from the south-east to the north-west. From the great service these winds render to navigation on account of their relative steadiness, they are called the *Trade-Winds;* but they do not blow with the uniform constancy which is commonly asserted.

338. It is said that in mid-ocean in the Atlantic, the *north trades* prevail between latitudes 9° and 30°, and in the Pacific, between latitudes 9° and 26°; and the *south trades* in the Atlantic, between latitudes 4° N. and 22° S., and in the Pacific between latitudes 4° N. and 23½° S. These limits are, however, not stationary, but follow the sun, advancing northwards from January to June, and retreating southwards from July to December.

339. *Region of Calms.*—The region of calms is a belt of about 4° or 5° in breadth, stretching across the Atlantic and the Pacific, and generally parallel to the equator. It is marked by a lower atmospheric pressure than what obtains to the north and to the south of it in the regions traversed by the trade-winds. It is also characterised by the daily occurrence of heavy rains, and thunderstorms. The position of the calms varies with the sun, reaching in the Atlantic, its most northern limit, 12° N. lat., in July, and its most southern, 2° N. lat., in January. It is greatly modified by proximity to continents; thus in the Indian Ocean it wholly disappears during the summer monsoon. There are two other regions of calms at the limits of the north and south trades. Except in the Pacific Ocean, those belts of calms are either broken up, so as to appear only in patches, or completely obliterated owing to the disturbing influences arising from the unequal distribution of land and water. Of these circumscribed regions of calms, the most interesting is that marked out by the high pressures in the North Atlantic. It will be seen from the charts that the surface winds blow out of this space in every direction, and it may be remarked that the currents of the sea follow the same course. This is the region of the Sargasso Sea, which is thus characterised not only by its comparatively still waters, but also by an atmosphere characterised by calms or light variable winds. These calms are well known to sailors, and are called the Horse Latitudes. A similar region of calms, but of more limited extent, exists in the South Atlantic.

340. It is established by numerous observations, that while the

surface wind within the tropics is directed towards the region of calms, the prevailing winds of the north temperate zone, and of the south temperate zone, are westerly. The *westing* of these great currents is most probably due to the same cause that gives *easting* to the trade-winds—viz., the rotation of the earth round its axis. For since the equatorial current flowing north into higher latitudes is constantly arriving at regions having a less rotatory velocity than itself, it outstrips them and leaves them behind; in other words, it tends to blow over these places as a west wind.

341. But though the mean direction of the winds has been calculated from long series of observations made at many places in Europe, Asia, and North America, and the general prevalence of westerly winds has been established, yet, owing to the unequal distribution of land and water on the earth's surface, and, as a consequence, the unequal partition of temperature and moisture, and hence of atmospheric pressure during the seasons, this great atmospheric current is in many cases turned out of its normal course; so that the prevailing directions, in different seasons and in different places, differ widely from W. I have examined* the prevailing winds at 115 places in the north temperate zone, at almost every one of which places there are two maximum directions—that is, at nearly every place there are two directions from which winds prevail most frequently, one of these being considerably greater than the other. The following is the result: If the two maximum directions be separately examined, it is seen that the *greater* maximum direction being from any point of the compass from

S.S.W. to W.,	occurs at	47	places.
W.N.W. to N.,	,,	33	,,
N.N.E. to E.,	,,	19	,,
E.S.E. to S.,	,,	16	,,

and the *lesser* maximum direction being from any point from

S.S.W. to W.,	occurs at	20	places.
W.N.W. to N.,	,,	22	,,
N.N.E. to E.,	,,	38	,,
E.S.E. to S.,	,,	32	,,

The reason for this striking result, so different from what has generally been accepted as the theory of the motions of the atmosphere, will appear further on. The relation between atmospheric pressure and prevailing winds being stated, a tolerably correct conception of the prevailing winds in different parts of the earth for the months of the year, may be arrived at.

342. *Winds in the North Atlantic and adjoining Regions in January.*—On examining Plate I., which shows the isobaric

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* Trans. Roy. Soc. Edin., vol. xxv. p. 586.

lines for January, it is seen that atmospheric pressure is low at this season in Iceland, from which it rises as we proceed in a south-west direction towards America, in a south direction over the Atlantic, and in a south-east and east direction over Europe and Asia. What influence has this remarkable depression of atmospheric pressure in determining the prevailing winds over this large and important part of the earth's surface? To assist in answering this question, arrows indicating the prevailing winds at many places over the globe are laid down on the charts. These directions are obtained from good averages, based on observations.

343. At the North American stations there is a decided preponderance of winds from the N.W. At the more northern places the general direction is more northerly, while farther south it is more westerly. In the Atlantic, between Great Britain and America, the direction is nearly S.W.; this is also nearly the direction in France, Belgium, and the south of England. At Dublin, and in the south of Scotland, it is about W.S.W.; at Copenhagen and Archangel, it is S.S.W.; at St Petersburg, Vologda, Tobolsk, and Berezov, it is nearly S.W.; on the west of Norway it is generally S.S.E.; and about Spitzbergen, in the north-west of Iceland, and in Greenland, it is N.E. The relation of these winds to the isobaric lines will be seen at once, and it is this: All the prevailing winds in January over this extensive region are the simple expression of the difference of atmospheric pressure which prevails in different parts of the region. The whole of the atmosphere appears to flow vorticosely, or in an in-moving spiral course, towards the region of low pressure which has its centre about Iceland, and extends eastward over the Arctic Sea, north of Russia.

344. The effect which this distribution of the pressure has on the winter climates of the respective countries in intensifying or in moderating the rigours of winter, might afford materials for an interesting discussion. It is to this low pressure which draws over Great Britain W.S.W. winds from the warm waters of the Atlantic that we owe, almost wholly, our mild, open, but, it must be added, rainy winters. It is the same pressure which gives Russia and Central Europe their severe winters, since, on account of it, slow, steady, air-currents, from the cold regions of Northern Asia, are drawn towards the N.W., N., and N.E. over those parts of Europe. It is this consideration which explains fully the enormous deflection of the isothermal lines seen from Norway eastwards and south-eastwards over the Old Continent (Plate IV.) Finally, the same low pressure draws over British America and the United States by the N.W. wind, the cold, dry currents of the arctic regions. In the State of Maine the mean January tempera-

ture is about 23°, whilst on the coast of England, 10° farther north, it is as high as 40°.

345. There is a similar, though less marked, region of low pressure in the north of the Pacific at this season, towards which the winds all round flow, the prevailing direction being S. at Steilacoom, Oregon; S.W. in west of Vancouver Island; E.S.E. at Sitka; E.N.E. at Fort Confidence, Great Bear Lake; N.E. at Ikogmet, N.W. of America; N.N.E. at Peterpaulshavn, Kamtchatka; and W.N.W. at Chacodate, Japan. From these resulting prevailing winds, the winters of Vancouver and adjoining regions are mild and moist, whereas in the north-east of Asia they are dry and intensely cold.

346. *Winds of Asia in January.*—These are explained by the extraordinarily high pressures which prevail in the interior of the continent, and which gradually diminish on all sides on approaching the coast (Plate I.) The arrows represent the winds flowing out of this region of high pressure. At Calcutta the prevailing winds in winter are N.; at Hong-Kong, E.N.E.; at Manila, N.E.; at Pekin, N.W.; at Chacodate, in Japan, W.N.W.; at Nikolajewsk, on the Amoor, also W.N.W.; in the north of Siberia, at Nijnikolymsk, S.E.; at Ustjansk, S.S.W.; and at Bogoslovsk, Ural Mountains, S.W.; but at places in the interior of Asia the atmosphere is generally calm, and the winds light.

347. Under the influence of this high pressure, by which the winds all blow from the land seaward, the rainfall of Asia during this season is reduced to a minimum, the monthly fall being less than an inch, except in Eastern Hindostan and at a few points in the Eastern Peninsula, where the north-easterly winds come up against hills or high grounds, which condense their moisture into rain. The proximity of this area of high pressure to the area of low pressure in the North Pacific, makes the coast of Kamtchatka one of the most inhospitable regions on the globe.

348. The bearing of this high pressure on the temperature is even more marked than it is on the rainfall. Owing to the excessive dryness of the atmosphere of Central Asia, terrestrial radiation is less obstructed than it is anywhere else on the globe; and consequently, from the heat thus poured into space during this season, the mean temperature of January falls to —41°.4 at Yakutsk, being the lowest mean temperature which is known to occur anywhere on the earth's surface. And since from this region the winds flow away in different directions, bearing low temperatures with them, the mean winter temperature of the continent of Asia, and of Central and Northern Europe, which is under the same physical conditions, is everywhere relatively low. Thus at

Pekin, lat. 39° 54′ N., the mean temperature of January is only 23°.4, whereas in Minorca, lat. 40° N., it is 53°.4.

349. *Winds of North America in January.*—The same remarks are applicable to the North American continent, but in a modified degree, owing to its small extent as compared with the continent of the eastern hemisphere. Atmospheric pressure is highest in the interior of the continent, and the arrows show the winds flowing out from this space in all directions, exactly as in the case of Asia; and hence westerly winds prevail in the east, and northerly winds in the south.

350. *Winds of Australia in January.*—This is the summer season of the south hemisphere, during which the land of Australia is highly heated, and, as a consequence, pressure is diminished in advancing inland. In connection with this low pressure the following are the prevailing winds: N. in Sweer's Island, Gulf of Carpentaria; N.W. at Somerset, Cape York; N.E. by E. at Brisbane; E. at Sydney; S. at Melbourne; S.W. by S. at Adelaide; and S.E. by S. at Freemantle, W. Australia. In other words, the winds flow in upon the interior from every direction all round, vorticosely or in an in-moving spiral course. The prevailing winds of SOUTH AFRICA and SOUTH AMERICA are in all respects similar in their general direction to that of Australia.

351. *Winds of Asia in July.*—At this season the central parts of Asia are highly heated by the summer sun, and atmospheric pressure is in consequence very low, being at least 0.400 inch lower than on the seaboard of the continent. Here, again, there is the same result of the winds flowing in upon the region of least pressure. At Bogoslovsk, in the N.W. of the region, the prevailing winds are northerly; at Jerusalem they are N.W.; at Ooromiah, in Persia, chiefly W.; in Ceylon, W.S.W.; at Calcutta, S.; at Hong-Kong, S.S.E.; at Pekin and New Chwang, S.S.E.; at Nangasaki, S. by W.; at Chacodate, in Japan, nearly S.E.; at Nikolajewsk, E.; at Nijnikolymsk, N.W.; and Ustjansk, E.N.E. Hence the particular course taken by the winds is a flowing in towards the region of least pressure in an in-moving spiral course. From this it follows that over the south and east of Asia the summer direction of the wind is exactly the reverse of the direction which prevails in winter. This characteristic of the winds of Southern Asia constitutes the well-known monsoons.

352. *Winds in North America in July.*—The low pressure in the interior of America at this season, and the behaviour of the winds with respect to it, differ in no respect from what prevails in Asia. In both cases the winds flow round and inwards upon the regions of low pressure.

353. *Winds in North Atlantic in July.*—The remarkable protrusion of high pressures from the southern hemisphere where they are massed at this time of the year, northward into the Atlantic to between 10° and 50° lat. N., has been already referred to. It will be observed that out of this region of high pressure the wind blows in all directions towards and round upon the surrounding regions of low pressure. The prevailing winds over this region are not only interesting in science viewed in connection with the distribution of the pressure, but they are of the greatest importance in determining the best routes to be taken over this great highway of commerce ; and the more so because the ocean-currents are coincident with these prevailing winds.

354. *Winds in Australia in July.*—This being the winter season of the southern hemisphere, pressures are higher in inland places in Australia than near the coast. In connection with this distribution of the atmosphere, winds are S.E. in Sweer's Island; S.E. by E. at Somerset; S.W. by S. at Brisbane; W.N.W. at Sydney ; N. at Melbourne ; N.E. by N. at Adelaide; and between N.W. and N.E. at Freemantle.

355. *Winds in the Antarctic Regions.*—In these regions, or rather to south of about 40° lat. S., mean pressures are low during the whole year, being as low as 29.2 inches at 60° lat. S., and probably still lower on approaching the south pole, as the observations made by Sir James C. Ross and other navigators seem to indicate. The prevailing winds are W.N.W. and N.W. This is the region of the "brave west winds," the "roaring forties" of sailors, which play such an important part in navigation, and which determine that the outward voyage to Australia be round the Cape of Good Hope and thence eastward, and the homeward voyage eastward and round Cape Horn, thus circumnavigating the globe by the double voyage.

356. Thus, so far as the prevailing winds on the earth's surface are concerned, it has been shown that where pressures are high—in other words, where there is a surplus of air—out of such space winds blow in all directions ; and on the other hand, where pressures are low, or where there is a deficiency of air, towards such space winds blow from all directions in an in-moving spiral course. This *outflow* of air from a region of high pressure, and *inflow* upon a region of low pressure, is reducible to a single principle—viz., the principle of gravitation. Given as observed facts the differences of pressure, it might have been predicted, before calculating the averages, what the prevailing winds were. Indeed, so predominating is the influence of gravitation, that it may well be regarded as the sole force immediately concerned in causing the

motions of the atmosphere. If there be any other force or forces which set the winds in motion, their influence must be altogether insignificant as compared with gravitation.

357. From what has been stated it is evident that the wind does not blow directly from the region of high towards that of low pressure, but that in the northern hemisphere the region of lowest pressure is to the left* of the direction towards which the wind blows. This direction of the prevailing winds with reference to the pressure is in exact accordance with BUYS BALLOT'S "LAW OF THE WINDS," which may be thus put: The wind neither blows round the centre of least pressure as circles or as tangents to the concentric isobaric curves, nor does it blow directly towards that centre; but it takes a direction intermediate, approaching, however, more nearly to the direction and course of the circular curves than of the radii to the centre. Or the angle is not a right angle, but from about 60° to 80°.

358. Since, from its utmost importance in practical meteorology, it is impossible to be too familiar with the different forms or application of this LAW, we shall state it in two other forms: (1.) Stand with your back to the wind, and the lowest barometer, or centre of depression, will be to your left in the northern hemisphere, and to your right in the southern hemisphere. This is the guiding principle to sailors, by which they are taught how to steer with reference to storms.

359. (2.) Stand with the high barometer to your right and the low barometer to your left,† and the wind will blow on your back. It is in this form that the problem of the best ocean routes can be worked out from the Isobaric Charts—three of which, January, July, and the year, are given in Plates I., II., and III. The following illustration from the July chart will show the method of doing this: Let a person off the coast of Portugal stand thus with reference to the high pressure in the Atlantic and the low pressure in Africa, he will have a N.N.E. wind, and as he proceeded southward along the coast of Africa the wind would wear more to the eastward. On sailing towards and then through the West Indies towards Florida and the south-eastern States, as the influence of the low pressure in South America and in North America come successively into play in their relations to the high pressure in the Atlantic, the prevailing winds gradually become E., E.S.E., S.E., S., S.S.W., and S.W., and from this point across the Atlantic to England to W.S.W. Similarly the outward and homeward tracks to the Cape of Good Hope and India may be examined.

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* In the southern hemisphere it is to the right of that direction.

† These are reversed in the southern hemisphere.

360. The spaces of low and high pressure may therefore be regarded as the true poles of the winds which prevail on the surface of the earth, towards which, and from which, the great movements of the atmosphere proceed. From the unequal distribution of land and water, it results that the poles of the pressure and movements of the atmosphere are, as in the case of the poles of temperature, very far from being coincident with the north pole. It is this which explains why the prevailing winds at so large a proportion of stations in the northern hemisphere are not in the direction in which truly polar and equatorial currents should blow, as explained in par. 341.

361. The causes which bring about an unequal distribution of the mass of the earth's atmosphere are chiefly two—viz., the temperature primarily, and secondarily the moisture of the atmosphere with reference to the geographical distribution of land and water.

362. Owing to the different relations of land and water to temperature, which have been already pointed out, the summer temperature of continents greatly exceeds that of the ocean in the same latitudes. Hence the abnormally high temperatures which prevail in Asia, Africa, America, and Australia during their respective summers, in consequence of which the air becomes specifically lighter, and ascends as from a furnace in vast columns thousands of miles in diameter. In this way the summer pressure of continents is diminished, the amount of the decrease being greatest in Asia, the largest continent, and least in Australia, the smallest, whilst in America it is intermediate.

363. Air charged with vapour is specifically lighter than when without the vapour—that is, the more vapour any quantity of air has in it, the less is its specific gravity; and further, owing to the condensation of vapour, the cooling effect is much less in ascending currents of saturated air than that which would be experienced in ascending columns of dry air. From these two principles it follows that the presence of vapour in the air, and its condensation, exercise a powerful influence in depressing the barometric column. In truth, the chief disturbing influences at work in the atmosphere are the forces called into play by its aqueous vapour.

364. This influence of the vapour in lowering the pressure is well illustrated by the low pressure of the belt of calms in the tropics towards which the trade-winds blow, laden with the moisture they have taken up on their way, this belt being characterised by a highly-saturated atmosphere and heavy rains. Again, much more vapour is observed in the atmosphere near the Atlantic during the winter months than at places in the same latitudes in the interior of continents. The winter temperature is much

higher where the air abounds in vapour than where it is dry. Hence, owing to the presence of a larger amount of vapour, and to higher temperature, the air resting on the north of the Atlantic and regions adjoining is specifically lighter than in the continents which surround it. There are here the physical conditions of an ascending current; and it is evident that the strength of this current will be kept up, if indeed it be not increased, by the condensation which takes place in it, by which a higher temperature, and consequently a greater specific lightness, are maintained. In accordance with this, it is seen from the charts that an enormous diminution of pressure occurs over this region as compared with the continents. Similar depressions from like causes occur in the Pacific and in antarctic regions. Since dry and cold air is, on the other hand, specifically heavy, it might be expected that in the interior of continents, where temperatures are low and the air is very dry in winter, pressures would be high. Observation shows that the highest pressures occur in Asia and North America at this season. For the same reason, pressures are also highest in Australia, South Africa, and South America in the winter months of the southern hemisphere.

365. It has been shown that the tendency of the prevailing winds on the surface of the earth is to blow round and in upon the space where pressures are low, and out of the space where pressures are high. Now, since in this way vast volumes of air are poured into the space where pressures are low without increasing that pressure, and vast volumes flow out of the space of high pressure without diminishing that pressure, it necessarily follows that the air poured in does not accumulate over this space, but must escape into other regions, and that the air which flows out from the region of high pressure must have its place supplied by fresh accessions from above.

366. It may be inferred that ascending currents will continue to ascend till a height is reached at which the pressure of the air composing the currents equals, or just falls short of, the pressure in surrounding regions at that high level. At this point the air will cease to ascend, and expanding horizontally will begin to flow as an upper current over those regions which offer the least resistance to its course; in other words, it will flow towards those parts whose pressure at that height is least. Over what portions of the earth's surface is the pressure of the air least at great heights? Evidently over those regions where the air is coldest and driest near the surface of the earth; because, being thereby densest, the great mass of the air is condensed or gathered together in the lower beds of the atmosphere, thus leaving less air or a diminished pressure in the upper regions.

367. Thus the extraordinarily high winter pressure in Asia is caused both by the low temperature and great dryness of its atmosphere, and by its proximity to the surrounding low pressures of the Atlantic, Pacific, and the equatorial regions, from which upper currents flow towards the centre of Asia, and compensate for the drain arising from the surface winds which blow out of this region in all directions. In support of this view it may be stated, that whereas in winter the surface winds in India are uniformly from some northerly direction, the mean direction of the wind is E.S.E. at Dodabetta on the Neilgherry Hills. Thus the winds at the surface flow out from the continent, but at Dodabetta, at a height of 8640 feet, they form part of the upper current flowing toward the interior of Asia. In summer, on the other hand, whilst the winds at low levels blow from some southerly point, or towards the interior, they are almost wholly N.W. at Dodabetta; and whilst the surface winds are westerly in Western Asia, the prevailing wind is N.E. at Alexandropol, on an elevated plateau about 5000 feet high, south of Caucasus. Thus the summer winds at Dodabetta and Alexandropol may be regarded as forming part of the upper current which flows out of the interior of Asia.

368. Since in summer the temperature of the air resting on the Atlantic between Africa and North America is much lower than that of the land, the ascending currents which arise from the heated land of Africa, Europe, North and South America, and from the region of calms to the south, will, on reaching the upper regions of the atmosphere, flow over this part of the Atlantic, because, from the lower temperature and greater density of the air in the lower beds, there is less pressure in the upper regions. Since the surface winds are constantly draining away the air poured down upon it by the upper currents, extreme saturation cannot take place, and hence the air is relatively cool and dry. On the same principles the high pressure in the South Atlantic is explained.

369. From these considerations it may be concluded that the winds on the surface of the earth are approximately known from the isobaric lines—the direction being from regions of high to those of low pressure, in accordance with Buys Ballot's "Law of the Winds;" and that the upper currents of the atmosphere may be inferred from the isobaric lines taken reversely, together with the isothermal lines taken directly. In other words, the regions of lowest pressure, by giving the ascending currents, point out the sources or fountains whence the upper currents flow; and the isothermals, by showing where, on account of the low temperature, the greater portion of the air is condensed in the lower beds, and so diminishing the pressure in the upper beds, point out the regions towards and over which these upper currents diffuse themselves.

CHAPTER XII.

WINDS—MONSOONS, LOCAL, AND OTHER WINDS.

370. THE term Monsoon, derived from an Arabic word *mausim*, meaning a set time or season of the year, has been long applied to the prevailing winds in the Indian Ocean, which blow approximately from the S.W. from April to October, and from the N.E., or opposite direction, from October to April. The existence of these periodical winds was made known to the ancient Greeks by the Indian expeditions of Alexander the Great; and by the knowledge thus acquired, Hippalus was emboldened to sail across the open sea to Muzeris, the emporium of Malabar. The word Monsoon is now very generally applied to those winds connected with continents which are strictly seasonal, or which recur regularly with the periodical return of the seasons. They are due immediately to different pressures and temperatures characteristic of continents in summer and in winter, and consequently they have their greatest development round the coast of Asia, owing to the great extent of this continent. The winds of Asia blow inward upon the land during summer, and outward from the land during winter; and hence the direction of the monsoons differ in different regions. Thus in winter and summer respectively, they are N.E. and S.W. at Madras; N.N.W. and S.S.E. at Shanghai; N.W. by W. and S.E. in the north of Japan; W. by N.W. and E. near the mouth of the Amoor; S.E. to S. and N.W. to N.E. in the north of Siberia.

371. Some time in March the monsoon begins to change; but since the heating of the interior of the continent, and consequently the diminution of atmospheric pressure, is not sufficiently great so as to be decidedly felt till the middle of May, it is not till this month that the summer monsoon acquires its full strength, and the heavy rains which accompany it fairly set in. In October the monsoon again changes, when the rain ceases and the dry season begins. These times depending on the sun's course, and conse-

quently varying to some extent with the latitude, are called the *breaking-up of the monsoons*, and are marked by variable winds, intervals of calm, and furious tempests and hurricanes. Compared with the trade-winds, monsoons play a most beneficial and important part in the economy of the globe. Their great speed, and the periodical change in their direction, favour increased facility of commercial intercourse between different countries; but the full advantages they bring with them will be better seen when they are considered in their relations to the rainfall of Southern Asia.

372. The winds of Australia are also monsoonal in their character, but owing to the smaller extent of this continent they are not so strongly marked; they do not blow so steadily from the same point of the compass as in Southern and Eastern Asia—that is, they spread themselves over a larger arc of the compass. Off the coast of Mozambique, the trade-winds are diverted more into E. winds; and even as far as Mauritius this influence is felt, the S.E. trade changing there into E. during the summer months. The S.E. trade of the S. Atlantic is changed into a S.W. monsoon on the coast of the Gulf of Guinea.

373. In North America the winds have a decided monsoon character, which is most strongly marked in the southern, central, and western regions. The following are the directions of the monsoons at different points in winter and summer respectively: N.E. and S.W. at Charleston; N.N.E. and E.S.E. at Key West, south of Florida; N.E. and S.S.E. at New Orleans; N. and S.E. at Goliad; N. and E. at Matamoras, on Rio Grande; N.W. by N. and S. at Fort Leavenworth, Kansas; N.N.W. and S. at Fort Yuma, head of Gulf of California; E.N.E. and W.S.W. at San Diego; and S. and E.N.E. at York Factory, on Hudson Bay. These winds are at once explained by the distribution of the pressure as shown by the isobaric lines of January and July. Similarly, monsoons prevail on the coasts of Brazil, Peru, and other regions which happen to lie at any season between other regions the temperatures of which widely differ from each other.

374. The above are the chief prevailing winds in different parts of the globe where the difference of atmospheric pressure is such as to cause a decided, and on the whole steady, movement of the atmosphere over a large part of the earth's surface, resulting in well-marked prevailing winds. But there are other winds which are influenced by local causes, such as the nature of the ground, whether covered with vegetation or barren; the physical configuration of the surface, whether level or mountainous; and the

vicinity of seas or lakes. Within the tropics these local influences are generally overpowered by the great atmospheric currents which may be regarded as constantly prevailing there. But in temperate regions, owing to the larger and more frequent departures of atmospheric pressure from the average, the winds are often variable, and they are thereby also more under the influence of local causes.

375. It was long ago remarked by Lord Bacon, and by other writers since his time, that the wind more frequently veers with the sun's motion, or passes round the compass in the direction of N., N.E., S.E., S., S.W., W., and N.W., to N. The *veering* is due to the influence of the earth's rotation in changing the direction of the wind, and the *direction* of the veering to the circumstance that nearly the whole of Western Europe lies to the right of the central track of storms and of those lesser atmospheric disturbances which are propagated eastward over this part of the earth's surface. At Bear Island, and in the north-west of Iceland, which lie on the left side of the path of storms, the veering is in the opposite direction—viz., from S.E., E., N.E., N., and N.W.

376. An important characteristic of winds is their quality—being dry or humid, warm or cold, according to their direction, and the nature of the earth's surface over which they have passed. Thus, in the northern hemisphere southerly winds are warm and moist, while northerly winds are cold and dry; and in the southern hemisphere *vice versâ*. In Europe westerly winds are moist, and easterly winds are dry; while in North America north-easterly are cold and humid, and north-westerly winds cold and dry. In certain parts of the earth, circumstances occur at stated seasons intensifying these effects, and causing excessive drought, heavy rains, great cold, or great heat, thus giving rise to the following, among other, well-known winds:—

377. *The East Winds of Great Britain.*—These winds prevail, as is well known, in spring. They are always dry, but in some years, as in May 1866, they reach an almost unprecedented dryness, such low humidities as 44 and 37 having been observed at many places in Scotland at nine in the morning. The deleterious influence of the east wind is shown not only in the discomfort and uneasiness it gives to the less robust amongst us, but also in the largely-increased number of deaths from consumption and brain diseases which it causes. The Isobaric Charts for the spring months exhibit a smaller difference of mean pressure between Great Britain and the north of Europe than during the other months. This smaller difference arises from the more frequent occurrence during these months of higher pressures to the north and north-east, or

lower pressures to the south and south-east, of Great Britain than in Great Britain itself; and it is from the repeated occurrence of these throughout the year that next to S.W. or W.S.W., easterly winds are the most prevalent. Sometimes, and in some years, notably during 1867, high pressures prevail to the north-west of Great Britain, in which case the cold current comes to us, not as an east wind, but as a north, north-west, or even west wind. But it matters not from what direction, or in what disguise, the cold dry current comes to us, its noxious characteristics are the same, and it is nearly as injurious to health and to vegetation as when it comes out of the "horrid east." Thus the cold dry wind which, on the 29th April 1868, blasted and shrivelled up vegetation in Scotland, particularly in the west, where it seemed as if a scorching fire had passed over the country, was from the west.

378. Very great cold often occurs in Russia with S.E. winds, and it is all the more striking and severely felt because it is a strong-blowing wind which brings it. Several of these have been examined, and they are found to occur with very high barometers, such as 30.8 inches in Russia, together with a very low pressure and a great storm passing over the British Islands and Norway, but which does not pass into Russia. These two phenomena are probably intimately connected—the high pressure and dry cold air of Russia being occasioned by an upper current flowing out from the region of the storm, and the S.E. direction being a surface inflow towards the low pressure which accompanies the storm, which is to westward at the time.

379. In the south of Europe north winds in winter are notorious for their violence, dryness, and low temperature. The great differences of the temperature of the Alps, the Mediterranean, and Africa explain them; and when a northerly current from a high atmospheric pressure is descending at the same time over Europe, towards a low pressure in the Mediterranean, the effect is greatly heightened. Of these winds the most notorious is the *Bora*, which, descending from the Julian Alps, sweeps over the Adriatic—the bitterly cold tempestuous wind of that much-vexed sea. It is probably the Euroclydon mentioned in the Acts of the Apostles. The *Mistral* is a steady, violent, and cold north-west wind which blows from France down on the Gulf of Lyons. It is immediately caused by a low atmospheric pressure in the Gulf of Lyons as compared with the pressure to the north, and is most severe when at the same time higher pressures occur from France northwards towards the arctic regions. The great cold which prevailed in the north of Italy and south of France in the beginning of January 1868 arose in this way. While it lasted, atmospheric pressure

was very low in the north of the Mediterranean, 29.450 inches, whence it rapidly rose in advancing northwards to the almost unprecedented height of 30.905 inches in the north of Russia, thus drawing over the northern coasts of the Mediterranean the northerly current in its full strength, which became still colder and drier in crossing the Alps on its southward course. The *Gregale* of Malta is a cold dry N.E. wind, and has an origin similar to the Mistral.

380. The *Nortes*, or "Northers," are dry cold winds which frequently prevail from September to March in the regions bordering on the Gulf of Mexico. They result from the high pressure of the interior of North America during winter, taken in connection with the low pressure to the south; and when they occur in the wake of storms, the qualities which characterise them are intensified. In his 'Climate of America,' R. Russell gives an instance of the temperature falling in Southern Texas, with a "norther," from 81° to 18° in 41 hours, and adds that "such great and sudden changes are rendered still more disagreeable by the 'northers' frequently blowing with extreme violence." The influence of these cold winds on the vegetation of the Southern States is very deleterious. A temperature of 18° with a violent wind is perhaps unknown in Great Britain.

381. The *Pampero* is a wind from S.W., which blows chiefly in the months of July and August across the pampas of South America. It is in some respects analogous to the winds under discussion. But since it blows from the direction of the Andes over the South American continent, it is a dry wind. Its approach is indicated by the appearance of a dark cloud in the south-west, which rapidly overspreads the sky, and is accompanied with thunder and lightning, and dense clouds of dust. Since the air is very dry, and the wind blows with great violence, vegetation is quickly withered up by it. Its duration is usually brief, sometimes lasting only a quarter of an hour, but occasionally it continues for two or three days.

382. *Puna Winds.*—To the east of Arequipa, in Peru, there is a barren table-land high up among the mountains, between the Eastern and Western Cordilleras, called the Puna, which from June to September is swept by cold arid winds. These winds may be considered as part of the outflow from the high pressure in the South Atlantic towards the lower pressures in the Pacific near the equator. The inhabitants, in travelling, find it necessary to protect their faces from the glare and heat of the day, and from the intense cold of the night. The drying qualities of the Puna wind are so excessive, that when a mule happens to die in crossing the plains, it is turned into a mummy in a few days. Thunder

and lightning and whirlwinds, with sudden changes of temperature, are of frequent occurrence. Whilst the general direction of the wind is E. and S.E., many of the heaviest gusts are from S.W., W., and N.W.

383. All these winds, which may be grouped together as dry and cold, occur during the winter half of the year, and, so far as they have been examined, are immediately connected with a space of high pressure out of which they appear to issue, and they blow towards a lower barometer where rain is falling and where the temperature is relatively high. A careful examination of the climates of different countries would no doubt add largely to the number of these winds. In contrast to these, there is a large group of winds peculiar to different regions, characterised by extreme heat and dryness, the more remarkable of which will be briefly described

384. *Simoom* (otherwise written simoun, semoun, samoun, samun), or sambuli, a name derived from the Arabic *samma*, signifying hot, poisonous, or generally whatever is disagreeable or dangerous, is applied to the hot suffocating winds which are peculiar to the sandy deserts of Africa and Western Asia. In Egypt it is called *khamsin* (Arab. fifty), because it generally continues to blow for fifty days, from the end of April to the time of the inundation of the Nile, in June. Owing to the great power of the sun's rays, the extreme dryness of the air, and the small conducting power of sand, thus causing the accumulation of heat on the surface of the land, the superficial layers of sand in the deserts of Africa and Arabia become heated to 200° F. to a depth of several inches. The air resting on this hot sand becomes also highly heated, thus giving rise to ascending currents ; air consequently flows towards these heated places from all sides, and, the different currents meeting, small cyclones or whirling masses of air are formed, which are swept onward by the wind prevailing at the time. Since the temperature, originally high, is still further raised by the heated grains of sand with which the air is loaded, it rapidly increases to a degree almost intolerable. In the shade, it was observed by Burckhardt in 1813 to have risen to 122°; and by the British Embassy to Abyssinia in 1841, to 126°. It is to the parching dryness of this wind, its glowing heat, and its choking dust, and not to any really poisonous qualities inherent in it, that its destructive effects on animal life are to be ascribed. The approach of the simoom is first indicated by a thin haze along the horizon, which rapidly becomes denser, and quickly overspreads the whole sky. Fierce gusts of wind follow, accompanied with clouds of lurid burning sand, which often present the appearance

of huge columns of dust whirling forward. Thus vast mounds of sand are transported from place to place by the terrible energy of the tempest, by which large caravans have been overwhelmed and destroyed. The destruction of Sennacherib's army is supposed to have been caused by the simoom. The simoom generally lasts from six to twenty-four hours, but sometimes for a shorter period.

385. Hot winds from Africa and other arid deserts are felt in neighbouring regions, where they are known under different names. They are subject to important modifications by the nature of the earth's surface over which they pass. The *Sirocco* blows occasionally over Syria, Sicily, South Italy, and other districts. In Sicily it is a hot moist wind, receiving its heat from the Sahara, and acquiring its moisture in its passage northward over the Mediterranean. It is the plague of the Two Sicilies; and while it lasts, a haze obscures the atmosphere; and so great is the fatigue which it occasions, that the streets of Palermo become quite deserted. In Syria it is a hot dry wind, and is of frequent occurrence during the summer months. It sometimes extends to the shores of the Black and Caspian Seas, and to the steppes beyond the Volga, the seat of the dreaded rinderpest, where, by its blighting touch, vegetation is withered and dried up, and thousands of cattle are cut off. It is called the *Samiel* in Turkey, from its reputed poisonous qualities. The sirocco blows most frequently in Algeria in July; in Marocco, to the west, it blows strongly in July, August, and September, where it is called *shume*, or hot wind. The *Solano* of Spain is a south-east wind, extremely hot, and loaded with fine dust. It prevails at certain seasons in the plains of Mancha and Andalusia, particularly at Seville and Cadiz. It produces dizziness, and heats the blood to an unusual degree, causing great uneasiness and irritation; hence the Spanish proverb, "Ask no favour during the Solano." The *Harmattan* of Senegambia and Guinea belongs to the same class of winds. It is a periodical wind blowing from the dry desert of Africa towards the Atlantic, from N. lat. 15° to S. lat. 1°, at intervals from the end of November to the middle of February. It blows with moderate force, is often highly charged with fine particles of dust, and being intensely dry, and no dew falling while it lasts, vegetation soon grows languid and withers.

386. Hot winds, sometimes called the Australian Harmattan, also occur in Australia, lasting from 24 to 36 hours. In Victoria they come from N.W.; in South Australia from N.; in the south-west of Western Australia from N.E., and in the north-west from S.W. and W. They thus occur chiefly in the southern portion of the continent, and all blow from the interior seaward. They are in-

tensely dry; and as their temperature is generally from 90° to 100°, vegetation is quickly parched up by them. Bush-fires are of frequent occurrence; of these the most notable is still remembered as the Black Thursday, which occurred on the 14th February 1847. During its continuance the temperature was observed as high as 114°, part of this high temperature being doubtless due to the heat of the great fire.

387. A hot wind from N.W. occasionally prevails in Natal and South Africa, bringing with it a temperature from 90° to 97°, and a dryness which withers vegetation, and causes the furniture of houses to crack with loud explosion. It is probable that these blasts of hot wind are immediately connected with low pressures accompanying storms which at the time are passing to eastward, south of Africa—these low pressures drawing the hot dry air of the interior southward over Natal. But these and the other hot winds referred to can only be inquired into with reference to the causes which produce them by weather-charts constructed from observations made simultaneously in regions surrounding the localities where the hot winds occur.—(See Whirlwinds, Duststorms.)

388. There are other winds of a stormy character peculiar to different parts of the Mediterranean, such as the *Levanter* in the east. The heating of the Sahara in summer causes a general and continued flow of the cooler air of the Mediterranean to the south, to take the place of the heated air which rises from the sandy desert. These are the *Etesian winds* of Southern Europe.

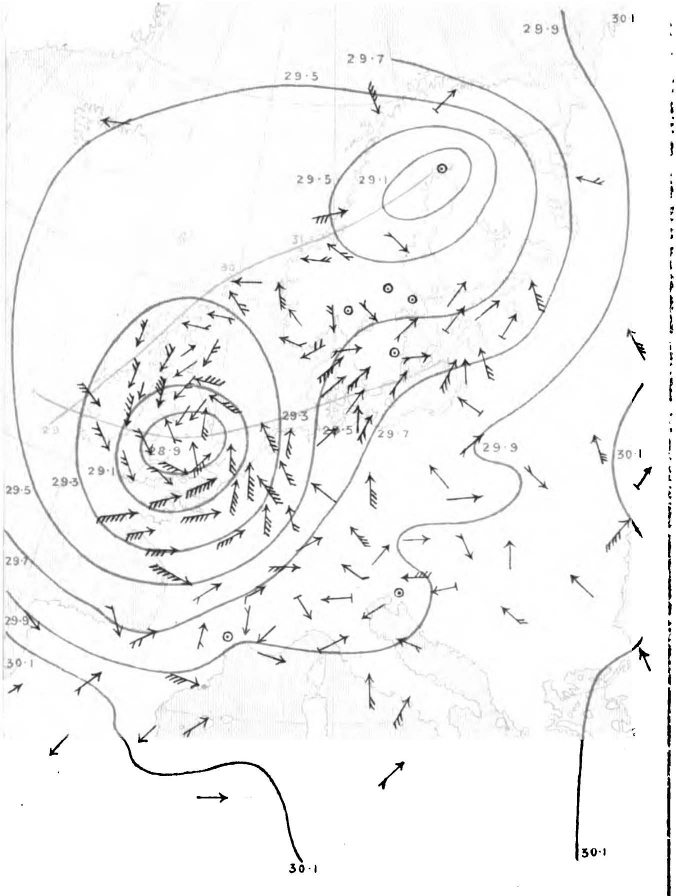
CHAPTER XIII.

STORMS.

389. STORMS are violent commotions of the atmosphere, occurring in all climates, and differing from other atmospheric disturbances in their destructive power and the extent over which they spread. The chief facts of observation regarding storms are best obtained from Synchronous (Gr. *syn*, together, and *chronos*, time) Charts of the Weather over a considerable portion of the globe. Since such charts present the principal elements of the weather at a given instant, they may be regarded as successive photographs of storms in their passage across the earth's surface.

Storms of Europe (Plate VII.)

390. Plate VII. is given as illustrative of the general features of these storms. It is a Synchronous or Synoptic (Gr. *syn*, together, and *optŏmai*, I see) Chart of Europe, showing, from observations made at about one hundred and fifty places, the atmospheric pressure, and the direction and force of the wind at 8 A.M. of the 2d of November 1863, by which are shown the position and character of two storms passing over Europe at the time. The isobaric lines are determined by reducing the observations of the barometer to 32° and correcting them for height, or reducing them to sea-level, and then setting down the pressures thus obtained at each place on the map. From these figures, isobaric lines are drawn for every two tenths of an English inch in the difference of the pressure. They are the red lines of the chart. Hence, where these lines approach near each other, or crowd together, the difference of pressure, or the atmospheric disturbance, was greatest; and least where they are most apart—a distinction of vital importance in relation to the force of the wind. The force of the wind is shown by arrows represented as


30·1
29·9
29·7
29·5
29·5
29·1
31
30
29·3
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29·7
29·9
29
28·9
29·1
29·3
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29·7
29·9
30·1
30·1
30·1

flying with the wind. A plain arrow ⟶ shows that the pressure does not amount to 1 on the scale 0 to 6; ⟶ that the pressure is 1 on the same scale; ⟶ that it equals 2; and so on up to ⟶, which represents 6, a violent storm or hurricane. This arrow ⟼ indicates that the force of the wind is not known; and ⊙ represents a calm.

391. *Form and Extent of Storms.*—The curved isobaric lines on the chart represent the shape storms generally assume. The area of European storms is generally either roughly circular or elliptical, and when elliptical, the major axis of the ellipse seldom exceeds twice the length of the minor axis. Rarely in Europe, and in America, though less rarely in the southern part of the Indian Ocean, the form of storms is more elongated. The outline is occasionally very irregular, but in such cases the storm will generally be found to have parted into two, or more rarely three, centres of low pressure. The irregular shape of the isobaric lines may arise from two storms distinct from each other, though appearing in the chart at the same time, as on Plate VII. The circular or elliptical form of storms, which an examination of some hundreds proves to be their general characteristic, is a most important feature, whether as determining practical rules for the guidance of sailors in storms, or for the foretelling of storms at particular seaports. The extent over which storms spread is very variable, being seldom less than 600 miles in diameter, but oftener two or three times that amount, or even more. Thus the storm in the chart which had at the time its centre near Birmingham, extended in one direction at least as far south as Bordeaux, or 600 miles. Its diameter was therefore about 1200 miles, or about the average extent. Sometimes a region much greater than the whole of Europe appears to be involved in a single storm at one time. The area of storms is by no means constant from day to day, but varies in size, sometimes expanding and sometimes contracting; and it is worthy of remark that, when a storm contracts in area, the central depression gives signs of filling up, and the storm of dying out. Thus the storm which was at Birmingham on the 2d November had, on arriving at Jutland on the following morning, contracted to one-fourth part of its former diameter, and the central depression, instead of 28.9 inches, was only 29.3 inches. Similarly the storm seen in the north of Sweden covered a much wider area while passing over Great Britain. On the other hand, when a storm increases in extent, the central barometric depression becomes deeper, the storm increases in violence, and occasionally is broken up into two, or even three, depressions, which become separate storms, with the wind circling spirally round each.

392. *Direction in which European Storms advance.*—It may be premised that by the direction of the progressive motion of a storm is meant, not the direction of the wind, but the path followed by the central area of disturbance, as shown by the lowest barometric pressures. About half the storms of middle and northern Europe travel from S.W. or W.S.W. towards N.E. or E.N.E., and nineteen out of every twenty, at least, travel towards some point in the quadrant of the compass from the north-east to the south-east. Thus the general direction from which storms come is westerly, understanding by the term any point of the compass from S.W. to N.W. Several storms have advanced on Great Britain from N.W.; still more have come from W.N.W. and W.; but the larger proportion appear to come from W.S.W. and S.W., and advance towards E.N.E. and N.E. These proportions are only conjectural. In Plate VII. the two blue lines represent the track of the centre of each of the storms. Thus the storm which on the morning of the 2d November 1863 was in the north of Sweden, had arrived thither from the west of Ireland and Shetland; its course being thus *from south-west to north-east.* The other storm, the centre of which was at Birmingham on the 2d November, had advanced from the south-west of Ireland; on the two following days it continued its *eastward* course to Denmark and the Baltic Sea, where it died out. The first of these directions, as just stated, is the most general, and the second the next most common. The disastrous storm of November 1854, which inflicted so much damage on the British and French fleets during the Crimean war, travelled towards the south-east, over Great Britain, Austria, and the Black Sea, into Asia.

393. The least common, or rather rarest, direction in which storms travel, is toward some westerly point. The great snow-storm which occurred in Europe in January 1836, and which has been admirably traced and described by Professor Loomis, America, began, as the barometric curves prove, in the north-east of Russia, and thence proceeded south-west to the Swiss Alps, where its westward course would appear to have terminated. A few other storms might be mentioned, particularly during winter and spring, which have advanced from eastern or north-eastern Russia *westward* as far as Norway or Denmark, where generally their western course is arrested; they then retreat on their course and proceed eastward. The dry east winds in the British Islands are very often instances of weather-changes advancing in a westerly direction.

394. But again, storms have been repeatedly observed to remain stationary for several days in succession over the Bay of Biscay; and occasionally, though less frequently, over the Gulfs of Bothnia

and Finland. It should be here noted that both these regions lie to the north-east of extensive mountain-ranges bordering on the Atlantic; hence any system of weather-warnings is incomplete without daily telegrams from these regions, especially the Bay of Biscay, Norway, Sweden, and the north of Russia. A stationary low pressure around Bayonne—which, for example, prevailed for nearly a week during May 1866—influences the direction of the winds in the south of Great Britain by drawing them towards it,—and it may be remarked in passing, that no inconsiderable proportion of the east winds of the south of England occur under these conditions—and a low pressure in the Baltic or Gulf of Bothnia, either stationary or having advanced thither from the east, influences the winds at the seaports of Great Britain by giving to them a W., or rather N.W., direction. It is during the occurrence of such storms in the north of Sweden and Russia that heavy westerly gales occur in Great Britain, blowing from the same point several days in succession. It is only by daily weather-telegrams from the north of Sweden and Russia that warning of such gales can be sent to seamen about to navigate the dangerous waters of the Pentland Firth. And since heavy northerly and easterly gales prevail in North Britain, when a storm from the N.W. passes over the north of Norway and descends on the Baltic, the desirableness of weather-telegrams from the north of Norway, so as to complete a system of storm-warnings for Great Britain, will readily appear.

395. Storms do not always proceed in the same uniform direction from day to day, but occasionally change that direction. Though the change which occurs in the direction of the progressive movement is generally small, as shown by the tracks or blue lines on Plate VII., yet sometimes it is very considerable. Storms are sometimes observed to die out on reaching Russia, and when this happens the barometer at places to the eastward of the storm has been rising, instead of falling as usual in the front of storms, and the sky has remained clear, the air dry, and the temperature low. In passing through Russia storms are frequently of less extent than when passing over western Europe—*a remark of general application to storms in passing from a wet into a dry climate.* The two storms on the chart died out, the one in Finland and the other in the Baltic.

396. *Rate at which Storms travel.*—Figures or dates will be observed on the blue lines, Plate VII., indicating the tracks followed by both storms. These show the position of the centre of the storm on the mornings of the successive days on which they appear on the charts. The dates are, beginning in the west, for the first storm, 29th, 30th October, 1st and 2d November; and

for the second storm, 1st, 2d, 3d, and 4th November. These give a mean rate of about 18 miles an hour, which is nearly the average rate at which storms travel across Europe. Sometimes the rate is only 15 miles an hour; or even, as already stated, in certain situations and under certain circumstances they are stationary; whilst on rare occasions they travel at a rate of 45 miles an hour. Since the distance from the south-west of Ireland to the east of Great Britain is about 450 miles, it follows that even after a storm has appeared on the west of Ireland, the eastern seaports may generally be warned of its approach twenty-four hours before the force of the gale begins to be felt, even though no warning be issued until the storm has actually made its appearance in Ireland.

397. The shortness of the time generally elapsing between the commencement of a storm on the west of Ireland and its arrival even on the eastern ports of Great Britain, points out the inutility of any system of storm-warnings which does not include the receipt, six or eight times a-day, when the state of the weather is such as to require it, of barometric and wind observations made every hour in the extreme west of Ireland; and immediate intimation of the breaking out of a storm, and also of weather seeming to threaten a storm, from the telegraph stations in the west of the British Isles, France, and Spain. For thus only can the appearance of a storm likely to pass over the British Islands be detected in time, followed in its course by the telegraph, and timely warning of its approach sent to different ports; and thus only can security be had that the storm will not outstrip the "Signal" announcing its approach.

398. *General Path of Storms over Europe.*—This point has not yet been properly investigated; but the two blue lines may be regarded as showing not only the two most general directions in which storms travel, but also the average tracks of the routes—the track north of Great Britain being the more common.

399. *Relations of the Temperature and the Dew-point to Storms.*—The temperature increases at places towards which, and over which, the front part of the storm is advancing, and falls at those places over which the front of the storm has already passed. In other words, the temperature rises as the barometer falls, and falls as the barometer rises. Generally the temperature in advance of the storm is above the average, and in the rear of the storm below it; but if it should chance to be considerably above the average of the season in advance of the storm, it may still be above the average when the storm has passed, though lower than it was before it. If the temperature begin soon and markedly to rise after the storm has passed, a second storm may be expected in a

short time. In front of a storm the dew-point is high, in the rear it is low. This state of things is not what is merely due to the high temperature in the one case, and to the low temperature in the other; for, along with the high dew-point there is great humidity, and along with the low dew-point a small humidity. To express this in popular language—before the storm, the air is close and warm (for the season); but after the storm has passed, the air is cold and dry. This excessive humidity in the front of storms, or an excess of moisture in the atmosphere, holds good universally in storms; and to show how this moisture accumulates in the region over which the storm is propagated, would go very far in explaining the storm's origin—of such importance is the vapour of the atmosphere in atmospheric disturbances.

400. *Relations of Rain and Cloud to Storms.*—When the barometer has been falling for some time, clouds begin to overspread the sky, and rain to fall at intervals; and as the central depression approaches, the rain becomes more general, heavy, and continuous. After the centre of the storm has passed, or when the barometer has begun to rise, the rain becomes less heavy, falling rather in showers than continuously; the clouds break up; and fine weather, ushered in with cold breezes, ultimately prevails. The rainfall is generally proportioned to the suddenness and extent of the atmospheric depression at the place where it falls.

Observations of the Wind.

401. *Direction of the Wind.*—Let us first look at the winds in the storm which was passing over the British Islands on the 2d November 1863 (Plate VII.) On that occasion the lowest atmospheric pressure was in the central districts of England, from which it rose to some extent all round. The arrows, representing the winds as observed at the different stations, show that the general direction was as follows: W.S.W. and S.W. in the north, west, and centre of France; S. in north-east of France, in Norfolk, in Belgium, and in Holland; S.E. in north of England and south-west of Norway; E. and N.E. in Scotland and Iceland; N. in west of Scotland, and north and east of Ireland; N.W. and W.N.W. in west of Ireland and south-west of England. Thus the wind blew in all directions round the central patch of low pressure. Again, if the direction of the wind be referred to the region where the pressure was lowest—viz., in the centre of England—it will be seen that it did not blow directly towards this region, but to a point somewhere to the right hand of it. Thus

in France, south of the area of least pressure, the wind was not S. but W.S.W. and S.W.; in Belgium and to the south-east of it, the wind was not S.E. but S.; at Silloth, Solway Firth, to the N.N.W. of it, the wind was not N.N.W. but N.E.; and in the west of Ireland, to the west of it, the wind was not W. but N.W., &c. With regard to the isobaric lines, the wind did not blow round the lines in circles returning on themselves, nor did it blow across them at right angles, holding a straight course towards the region of least pressure, but it took a direction somewhere intermediate between these two directions. This relation is what is known as Buys Ballot's "Law of the Winds," par. 357. It is unquestionably the general direction of the wind in storms, but the angle, while generally from 60° to 80°, is sometimes as small as 45°, especially where the winds become lighter on approaching the central space of least pressure, and on rare and peculiar occasions it exceeds 80° or even 90°. The same general characteristic of the wind is also illustrated by the storm which at the same time prevailed in Lapland and the north of Norway.

402. From this it follows that in these cases the wind blew round the area of low barometer in a circular manner, and in a direction contrary to the motion of the hands of a watch, with, and be this particularly noted, a constant tendency to turn inwards towards the centre of least pressure. It will be observed that the greater the force of the wind was at any place, the more nearly was the direction here indicated approximated to; and that where the direction showed any material departure from the general law, such winds were light, and consequently more under local influences, which tend to turn them out of their course. Hence in these storms the winds circulated round the region of least pressure; or, to state it more accurately, the whole atmospheric system appeared to *flow in upon the* CENTRAL *area of low pressure in an in-moving spiral course.* This peculiarity is common to all European storms, and probably to all storms wherever observed.

403. On the 2d November the pressure over England being much less than in surrounding countries, if the earth had been at rest, it may be assumed that air-currents would have flowed from all directions towards England in straight lines. The earth, however, is not at rest, but revolves from west to east; and as the velocity of rotation diminishes as the latitude increases, it is evident that the current which set out, say from Lyons from S., would, on account of its greater initial velocity, blow, when it arrived at Paris, no longer directly S., but from a point a little the W. of S.; in other words, it would no longer be a south, but a south-west

wind. Again, since the current from the north of Scotland had a less velocity than those parts of the earth's surface on which it advanced, it lagged behind, and consequently, by the time it arrived at Silloth, in the north of England, changed from a N. to a N.E. wind. Similarly the N.W. current changed to a N., the S.W. to a W., &c. The west and east currents, since they continued to blow in the same latitude, would have blown in the same direction, if they had not been disturbed by contiguous currents. Hence in a storm the whole system of winds may be expected to flow in and round upon the centre. As a further confirmation of the correctness of this explanation, it is observed that, when a high barometric pressure covers a limited space, the wind is always observed gently whirling out of this area of high barometer, but in an exactly opposite direction from that assumed when it blows round and in upon an area of low pressure. This, it will be observed, is the same relation that has been already shown to obtain between the mean barometric pressure of neighbouring regions and their prevailing winds; but, in the case of storms, the relation is more strongly marked, inasmuch as the barometric differences are greater, and the whole phenomena are, as it were, condensed into smaller space.

404. *Apparent Exceptions.*—(1.) The influence of local causes in changing the direction of the wind, especially when light or moderate, has been already referred to. Suppose a W. wind to prevail in the west of Scotland, then a S.W. wind would prevail in the upper part of Loch Fyne, Argyleshire, which lies from S.W. to N.E.; in other words, the wind would be diverted from its general course into that of the valley of Loch Fyne. This peculiarity of the wind is well known and acted on by seamen. In inland situations, the influence of hills and valleys in changing the direction of the wind is everywhere recognised. (2.) The irregular outlines of some of the isobaric lines (Plate VII.) suggest that the increase of pressure from the lower to the higher is not in all cases uniform, but that there occasionally occur interruptions in its regular fall or rise over the space covered by the storm. Thus, on the morning of 2d November 1863, small local depressions occurred in the valley of the Clyde; on the coast of the Gulf of Genoa, near Geneva, in the north-east of Austria, and near Odessa in the Black Sea; and in all of these regions corresponding deviations of the wind may be observed. (3.) Since the relations of pressure at great heights over different places may be, nay often are, very different from what obtains near the level of the sea, the direction of the wind at these heights cannot be referred to isobaric lines showing the pressure at the level of the

sea. The value of observations from high stations, as previously stated, consists in the earlier notice they give of the prevalence of the equatorial current and saturation of the atmosphere by means of it, and consequently of coming changes of weather, including the approach of storms.

405. Storms cover a large portion of the earth's surface, and since the part of the earth's atmosphere involved in the storm must be simultaneously moved as one mass by the differences of pressure, it is evident that, as the storm extends over many degrees of latitude, the influence of the earth's rotation must be very considerable. Another force is also, no doubt, brought into play in determining the flow of the winds round and in upon the region of least pressure, resisting the direct flow of the winds towards it, such as we see exemplified in the movements of water let off from a bath of stagnant water, which result in whirling currents flowing round and in upon the centre in an in-moving spiral course. According to this view the rotation of the earth will account for the direction in which storms revolve round their centres of least pressure, and for part of the angle of 60° or 80° of deviation from the centripetal direction of the winds ; whilst the rest of the angle of deviation will be due to the elastic force of the air-currents as they are pressed inward towards the centre, or forced upward into the higher regions of the atmosphere by the greater pressure all round. In this way it is easy to understand, from the unequal distribution of vapour and heat through the air-currents, and their unequal and varying tensions, why the angle of deviation from the drawing force may on rare occasions, and over limited districts, amount to, or even sometimes exceed, 90°.

406. *The Force and Velocity of the Wind.*—It will be observed from Plate VII., that everywhere in Scotland, except in the extreme south, the winds did not exceed in force a moderate breeze (represented on the chart by two feathers on the arrows). Over this space the isobaric lines are far apart; and it will be observed in the other parts of Europe where these lines are far apart, that the wind did not reach the force of a gale. In the south of Scotland, the north of England, and in Ireland, where the isobaric lines 28.9 and 29.1 inches approach close to each other, the wind was strong. Thus gales were at this time blowing at Scarborough, St Abb's Head, Isle of Man, Dublin, and Valencia. The isobaric lines also approach near each other over the south of England, the northern half of France, and in Belgium and Holland ; and it will be seen that over all this region the arrows have from four to six feathers, showing that there the wind was blowing a gale or a tempest (8 to 12 on Beaufort's scale).

407. Near the centres of the isobaric curves which marked the position of the storms in England and in the north of Sweden, calms and light winds prevailed. We thus see that, as the wind comes near the centre of the storm, it gradually abates in force and sinks to a lull or calm. At Christiania, and places adjacent, between the two storms, where the pressure differed little over a considerable space, calms also prevailed. Observations from the east of Russia, including a number further to the east than those of the chart, show that calms and light winds prevailed along the ridge of high barometer, or the region where the barometer was highest, and in receding from which it fell on each side. It may not inaptly be compared with the watershed in physical geography, since from it the wind flows away to places where pressure is less.

408. Since at such times the atmospheric pressure is unusually low, the foul air imprisoned in the mineral of coal-pits escapes more readily into the air, accompanied with a buzzing sound, which miners regard as prognostic of a storm or of heavy rain. Accordingly, it is when the barometer is low that explosions from fire-damp in mines are of most frequent occurrence.

409. *Cause of the Heavy and Frequent Gales in the English Channel.*—During the cold months of the year, when storms are most frequent, the mean atmospheric pressure in Iceland is only about 29.3 inches, while in France and North Germany it exceeds 30 inches. Further, in Iceland, the pressure is often below 29 inches; whereas south of the Channel it seldom falls below 29.5 inches, even when the centres of storms pass over that region. Thus, when the centres of storms are passing over Great Britain, the pressure in France and Germany remains high. It results, therefore, from the position of Great Britain in relation to this distribution of pressure, that north of the centre of storms the wind sometimes scarcely rises to the strength of a gale; but south of the central path of the storm, which generally includes the English Channel, the storm bursts forth in all its fury—that arm of the sea being, as it were, in the aerial rapids of the storm between the high and the low barometer. The stormy character of the Channel has proved one of England's most valuable safeguards, in affording protection from invasion; but more especially in forming a hardy race of sailors, who have proved its best defence.

410. It has been stated that the progressive motion of storms varies from 15 to 30, or even, on rare occasions, 45 miles per hour, which measures the time taken in passing from one place to another. But this gives no indication whatever of the violence of

the storm, which is determined by the velocity of the wind as it blows round and in upon the centre of the storm, combined with the onward movement. In Europe it frequently amounts to 60 or 70 miles an hour continuously for some time. At Liverpool, on the 1st February 1868, there were short intervals between 11.30 A.M. and 12.30 P.M. when the velocity of the wind was at the rate of from 100 to 120 miles an hour. Since all examinations of storms show that where the isobaric lines crowd together the violence of the storm is greatest, and where they are far apart the winds are light or moderate, it may be concluded generally that *the force of the wind at any place is proportioned to the differences of the barometric pressures between which it is for the time situated.* The occurrence of a storm of wind is neither determined by the lowness of the barometer, the opinion vulgarly entertained, nor by the rapidity of the rate at which the barometer rises or falls, which may be to a great extent due to the velocity of the progressive motion of the whole body of the storm, but by the simultaneous occurrence of great differences of pressure between places not far distant from each other.

411. Thomas Stevenson, C.E., has proposed to express the numerical intensities of storms by what he calls the *barometric gradient* (Lat. *grădus*, a step), which is obtained by the simple arithmetic division of the distance between the two places, stated in nautical miles, by the difference of pressure observed simultaneously, stated in inches of mercury. Thus, suppose the distance between two places to be 100 nautical miles, and the readings of the barometer respectively 29.5 and 30.0 inches, the barometric gradient between the two places would be at the rate of 1 inch of mercury to 200 miles. In an examination of several European storms, Mr Stevenson shows that in Great Britain, barometric gradients of 1 inch of mercury to 170 miles have produced atmospheric disturbances sufficient to endanger many of our structures.

412. *Veering of the Wind.*—It follows from the direction of rotation of storms, that at places to the right-hand side of the track of the centre of the storm the wind shifts in the direction from N.E., by E., S., and W., to N.W., and at places on the left-hand side from N.E. by N. to N.W. This is what is observed at some distance from the centre of the storm, or beyond the path taken by the lowest pressures which mark the course of the centre. But at places over which the central calm passes, the wind after the lull changes at once, generally 90° and often 180° in the direction indicated above. Since the centres of most of the storms

pass to the north of the British Islands, the wind most frequently veers from S.E. by S., and S.W. to W.N.W. or N.W.

Storms of America.

413. From the general resemblance of the American storms to those of Europe, it will only be necessary to make one or two general remarks regarding them. The storm which passed over the United States during the 19th, 20th, and 21st December 1836, has been very fully detailed by Professor Loomis in a series of five well-executed synchronous charts. This storm extended from north to south, probably about 3000 miles, forming an oval figure, the length of which was from two to three times its breadth. In every one of the charts the winds are seen circling round the area of least pressure, with a constant tendency to turn inwards towards that area ; in other words, in this feature the storm was precisely similar to the storms of Europe. Comparing the southern limit of the storm on the successive charts together, we see that its progressive march was from south-west to north-east, or nearly so, resembling also in this respect the storms of Europe. The temperature, rainfall, snow, cloud, and clear sky, were perfectly analogous to the storms of Europe.

414. The storm which passed over the United States from the 13th to the 16th March 1859 was nearly circular, or but slightly elliptical, over the region where atmospheric disturbance was greatest; and the diameter of this region of disturbance was about 1000 miles. On the morning of the 16th the ellipses marked out by the isobaric lines were more elongated, with the major axes lying along the line of the coast from Delaware to Newfoundland—that is, nearly from S.W. to N.E. This storm, as marked out by the area of low pressures, has been tracked from Texas on the 13th, through the United States to Newfoundland, across the Atlantic and into Europe as far as St Petersburg, which it reached on the morning of the 23d, having thus taken nearly eleven days to travel about 5300 miles. It thus travelled at the rate of 20 miles an hour, and its track was from W.S.W. to E.N.E. Another storm which occurred immediately after it, travelled over the United States, but died out shortly after reaching the Atlantic; whereas a third storm, occurring at the same time, originated in the Atlantic, and passed nearly N.E. towards the north of Norway. The storms of America take their rise in the great plain which lies immediately to the east of the Rocky Mountains, and thence ad-

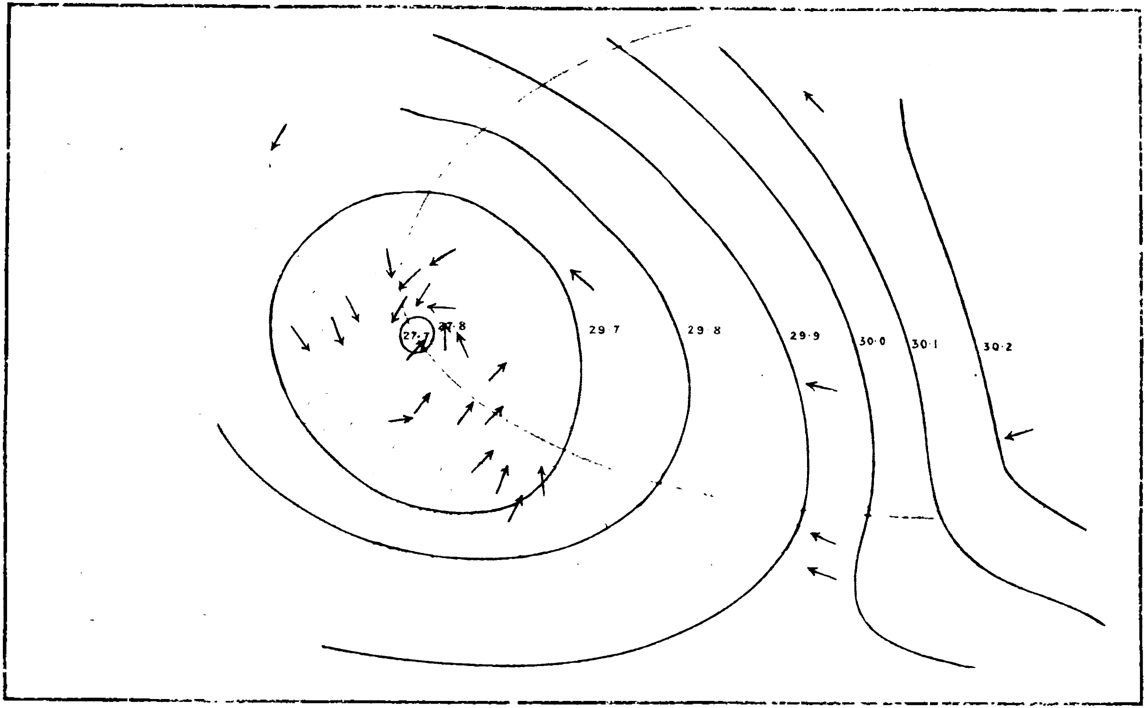
vance, generally in an east-north-easterly direction, across the United States.

415. The most striking difference between American and European storms is in the N.W. winds which accompany them. In America, the barometer rises in the wake of storms more rapidly, the wind veers round more quickly and more uniformly to the N.W., N.N.W., or N., and keeps longer in these directions, and at the same time the temperature falls very much lower than usually happens in Europe. It is well known that in Great Britain a stormy winter is a mild winter. For though the temperature is always higher in the front part of a storm than it is in the rear of it, the difference does not average more than about 10°. The period from the 26th of October to the end of December 1863, was remarkable for the number of storms which occurred—about fourteen well-marked storms have swept over Great Britain in that time. During these months frost scarcely occurred. The uniform mildness of the weather was shown by the circumstance that in the end of December 245 plants were in flower in the open air in the Edinburgh Royal Botanic Gardens, 35 of these being spring flowers; and the strange spectacle was seen of Sweet Peas and Hepaticas blooming together.

Storms or Hurricanes of the Tropics (Plate VIII.)

416. THE BAHAMA HURRICANE OF OCTOBER 1866.—On Plate VIII. are exhibited the isobaric lines and the direction of the winds at different places in the West Indies at 8 P.M. on the 1st October 1866, when the centre of this storm was at Nassau. At this instant the barometer was 27.7 inches at Bahamas, while at a distance of 286 miles it was as high as 29.7 inches; at Bermuda, St Thomas, and Barbadoes, it was at the average height; but to the east, north-east, and north of Barbadoes, it was above the average height of that part of the Atlantic. These figures show such extraordinarily steep barometric gradients as never occur beyond the tropics. In Great Britain the fall of one-tenth of an inch of the barometer in an hour is reckoned a large fall, such as only accompanies great storms; but during this storm, when the barometer was falling most rapidly, it fell at Nassau 0.700 inch in one hour, from 4 to 5 P.M. The fall of the barometer became more rapid as the centre of the storm approached; but at the centre the pressure remained nearly stationary for a time during the lull which there prevailed, and before the barometer began to rise. Since at Nassau the lull at the centre

METEOROLOGICAL CHART OF THE WEST INDIES ON 1ST OCTOBER [illegible] AT 3 P.M.



lasted from 7.20 P.M. to 8.50, it may be inferred, from the rate at which the whole body of the hurricane was carried forward, that the calm at the centre covered an area of at least 23 miles across. This calm may be considered as bounded nearly by the isobaric 27.800 inches, in the centre of which the pressure was only 27.700 inches. Since ordinarily, within the tropics, the barometer rises and falls so little that it may be practically regarded as stationary, such enormous changes of the barometer are the more striking; they are so sudden that the eye, in looking at the mercurial column, can plainly see it falling, and they may be regarded as registering rather than foretelling the different stages in the progress of the storm.

417. *Storm-Wave of the Sea accompanying the Hurricane.*—Owing to the diminished pressure of the air at the centre as compared with what prevailed at the outskirts of the storm, the difference being fully two inches of mercury, the level of the sea at the centre would be raised about three feet, being sustained at that height by the greater pressure all round. This increase of level, when occurring at high tide, and being increased still further by violent winds blowing in upon the centre, quite accounts for the advances made by the sea over the land, especially over low-lying islands, and the heartrending scenes of desolation which it caused. In certain parts of Turk Islands and some other flat islands, those only were saved from drowning who succeeded in climbing up the trees. The great storm which swept over Calcutta on the 5th October 1864, furnishes a notable illustration of the destructive power of the storm-wave occasioned by such low atmospheric pressures. On that occasion the sea, rising ten feet above the highest spring-tides, broke over its usual bounds, and laid the whole level country at the mouth of the Ganges under water, by which 45,000 human beings perished.

418. *Direction of the Wind.*—From the chart, Plate VIII., in which the arrows represent the winds at 8 P.M. of the 1st October, it will be observed that in no case did the winds blow directly to the centre of least pressure in any part of the storm's course, or blow round the area of low pressure in circles returning on themselves; but in every instance they blew in a direction intermediate between these two directions. Thus the storm was rotatory, and it revolved in a direction contrary to the hands of a watch; the winds blowing in upon the centre in spirally in-moving currents of air. In these respects, this hurricane resembled European and American storms.

419. *Probable Track of the Centre of the Storm.*—From observations received, it was clearly seen that the storm began to the

eastward of St Thomas, and thence pursued a W.N.W. course, coming round to Nassau; thence its course was to the N.E., passing 150 miles to the north of Bermuda. Its course thus assumed the form of a parabolic curve, with Nassau near the apex, being the track usually followed by West Indian hurricanes.

420. *Rate of the Onward Course of the Hurricane, and Velocity of the Wind.*—The rate at which the whole body of the storm travelled was slow as compared with European storms, being only fifteen miles, until it had passed the Bahamas and was nearing Bermuda, when it proceeded with the accelerated speed of thirty miles an hour. But this rate gives no idea of the violence of the hurricane, which depends on the speed with which the winds whirl round and in upon the centre. This, doubtless, rose to a steady velocity of from 80 to 100 miles an hour, and for short intervals to 120 or even 130 miles an hour, a velocity which was registered during the Guadaloupe hurricane of September 1865. The long black list of wrecks recorded, bears testimony only too emphatic to the devouring energy of the hurricane.

421. *Veering of the Wind during the Storm.*—At places situated in the south or left-hand side of the storm's track, the veering of the wind was from N.E. by N.,W., S., and E. to N.E.; but on the right-hand side of the storm's track the wind veered from N.E. to E., S., W., and N. to N.E. At St Croix the wind veered from N.E. by W. to S.E, and afterwards to E.N.E., or nearly round the compass; but, as observed on board the ship Mexican, the veerings were only from E. by S. to W., or about half the compass. In the former case the place of observation was much nearer the centre of the storm than in the latter case. Generally, the extent through which the wind veers at any place diminishes in proportion to its distance from the centre of the storm when it passes that place; and at places situated just at the outside of the area swept over by the storm, the veering of the wind is very small.

422. While the vortex of the storm was passing over Nassau, Captain Chatfield remarks that the atmosphere was most oppressive, and *the clouds in the zenith appeared to be revolving rapidly;* there was a little lightning, but no thunder; at 7.30 the clouds in the zenith rose, and the stars appeared, while banks of clouds remained all round the horizon in dense heavy masses. These appearances which occur at the centre or "eye of the storm" are well known to sailors who have encountered tropical storms, and they illustrate well the revolving character of these storms.

423. West Indian hurricanes occur most frequently from July

to October. From Poey's 'Chronological Table of 365 West Indian and North Atlantic Hurricanes, from 1493 to 1855,' we learn that 42 occurred in July, 96 in August, 80 in September, 69 in October, and the remaining 68 were distributed over the other eight months of the year. The tracks of the more important of these storms are laid down in Dr Keith Johnston's 'Physical Atlas.'

Storms of Southern Asia.

424. *Typhoons.*—The name Typhoon (Gr. *typhon*, whirling) is applied to the storms of the northern part of the Indian Ocean and of the Chinese Sea. As regards their form, the sudden barometric changes accompanying them, and the blowing of the winds round in and upon the centre, they entirely resemble the West Indian hurricanes already described. The chief point of difference is in the general direction of their route. The general course of the storms of Hindostan is from a point a little to the west of the Andaman Islands to N.N.W. or towards the mouth of the Ganges, after which they ascend the valley of the Ganges or that of Brahmaputra. The typhoons of the Chinese Sea have their origin in the ocean to the east of China, especially about Formosa, Luzon, and the islands immediately to the south. They thence proceed from E.N.E. to W.S.W.; rarely from E.S.E. to W.N.W.; and scarcely ever from N. to S. or from S. to N. Thus the course generally taken by these typhoons is along the Chinese coast; so that the coast feels the northern side of the storm, while at a distance out at sea the southern side is experienced. They occur from May to October; but it is during July, August, and September that they are most frequent. The season of the typhoons coincides, therefore, with the annual period of the summer moonsoon.

425. STORMS OF THE INDIAN OCEAN SOUTH OF THE EQUATOR.—Through the activity and well-directed efforts of the Meteorological Society of Mauritius, the storms of the Indian Ocean have been submitted to a fuller examination than those of any other ocean on the globe. Thom and others have also investigated these storms. They may be conveniently grouped into two classes—tropical and extratropical storms. The tropical storms occur only from November to May inclusive, or during the winter monsoon. They originate between the parallels of 6° and 14° lats., thence proceed in the direction of W.S.W., and afterwards, though not invariably, their course curves round and turns towards the S. or S.E. The winds blow round a central space,

usually characterised by a calm, and are at the same time drawn in on all sides towards the central calm in an in-moving spiral course. The direction in which the winds move round the centre is from left to right, or with the hands of a watch, being the direction of winds in the storms of the southern hemisphere, as in fig. 46, taken from Thom's 'East Indian Storms,' which represents the *Rodriquez* Hurricane, the isobars and winds being drawn in some degree hypothetically from the logs of sixteen ships which were involved in the hurricane. This is the only circumstance in which the storms of the southern hemisphere essentially differ from those of the northern hemisphere. Both depend on the same cause —viz., the rotation of the earth on its axis in its effect on the winds as they pass from lower to higher latitudes, or *vice versâ*. The diameter of the storm is generally from 1000 to 1500 miles; and the progressive motion is at the rate of 1 to 20 miles an hour —the general rate being from 4 to 7 miles an hour. It lasts from a few hours to ten days, and is accompanied with torrents of rain, and, in its northern half, often with lightning.

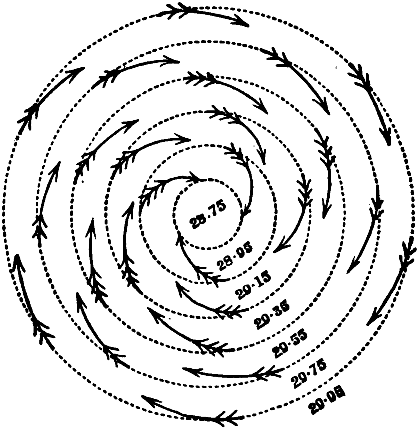


Fig. 46

426. These storms are invariably generated between the N.W. monsoon and the S.E. trade-wind, or they originate in the region of calms which lies between the two trade-winds prevailing in the Indian Ocean from November to May. It is probable that the region of calms at this season does not lie parallel to the equator, but slants from Tamatave in Madagascar, to the west of Samatra.

If the isobaric curves for January, Plate I., be examined, it will be seen that the N.W. monsoon, which prevails in the north-western part of the Indian Ocean, is fed by the region of extraordinarily high pressure which overspreads the Asiatic continent; consequently this current is cold and dry. On the other hand, the S.E. trade arrives at the region of calms heavily charged with vapour, which is condensed into rain in the region of calms between the two trades. As precipitation proceeds, the pressure is diminished, and the N.W. monsoon advances sometimes along its whole front southwards to the tropic of Capricorn, or beyond it. When the vapour has been deposited, the S.E. trade gradually returns, and the N.W. monsoon recedes before it till they regain their normal positions, which they retain till the vapour again accumulates, when a recurrence of the same phenomena takes place. The two winds thus oscillate backwards and forwards at this season; and it is to be specially noted that it is when the monsoon is pressing southward on the S.E. trade that storms occur.

427. The monsoon does not always advance equally along its whole front, but more frequently penetrates into the S E. trade, in which case only one storm is formed. When it penetrates into the trade at different points, two or three, or, on rare occasions, as many as five storms take place at different points, but they do not all last long. In the beginning and end of the season, those storms do not travel farther south than lat. 16°; but during February and March, when they are of most frequent occurrence, they generally proceed as far south as lat. 25°, and sometimes to lat. 32°. Their tracks are usually curves, with the convexity towards the west, and the apices from lat. 14° to 24° according to the season.

428. In applying the knowledge thus acquired regarding these storms to purposes of navigation, Mr Meldrum makes the following remarks: "As the trade-wind in front of a revolving storm often blows in strong gales with a falling barometer over many degrees in longitude, and the direction of the wind, especially at a distance, is far from being at right angles to the bearing of the centre, severe losses have occurred in consequence of vessels, having the wind at S.E., running to the W. or N.W., with the view of crossing the storm's path, under the impression that the centre bore N.E. In place of bearing N.E., when the wind is from S.E., the centre may bear N. or N.N.W., and if the storm be travelling towards the S.W., as is often the case, a vessel steering to the W. or N.W. may be running to her destruction. During a hurricane in February 1860, for example, a number of vessels left the road-

steads of Réunion with the wind at S.E., and running to the N.W. got into the heart of the storm. Several of them were wrecked on the coast of Madagascar, others were never heard of, and of those that returned some had to be abandoned. *The safest course seems to be to lie-to and watch the barometer and wind till the bearing of the centre be known with some certainty.* But perhaps the greatest losses of life and property in the Indian Ocean south of the equator arise from homeward-bound vessels running into revolving storms to the southward of them, by taking supposed advantage of the N.E. winds of a storm, between the parallels of 10° and 16° S., and steering to the S.W. till they get in front of the storm. This is the more to be regretted, inasmuch as all such losses may be easily avoided by lying-to till the barometer rise, and the weather improve, or by proceeding cautiously to the southward. Heavy losses occur annually from inattention to this simple precaution. *In the hurricane season, in those latitudes, with the wind anywhere between north and south, through the west, the weather squally and threatening, and the barometer falling, a vessel should not press too much to the southward. By attention to this rule the storm will be avoided.*"

429. Extratropical Storms occur at all seasons, but are most violent during the winter months, from May to August inclusive, in this respect resembling the extratropical storms of the northern hemisphere. They are generally characterised by the presence of two currents of air, the one from the southward and the other from the northward. Sometimes the two currents exist side by side, the one from the N.E., the other from the S.W., each occupying a belt of 5° to 30° in longitude, and stretching from 30° S. lat. as far south as the observations extend—viz., to lat. 45°. In the space between the two winds, light airs, calms, and a high cross sea, with heavy rain, thunder, and lightning, generally prevail, and there the barometer is lowest. The belt of southerly winds lies, as in the northern hemisphere, to the west of the northerly winds, and the two travel laterally to the eastward, preserving their relative position often for several days. Instead of blowing in parallel belts, however, the winds are often inclined, and sometimes directly opposed, to each other. The barometer stands higher and the thermometer lower in the southern than in the northern gale, being in these respects quite analogous to European and other storms of the northern hemisphere. There cannot be a doubt that the form of by far the majority of these storms is that of elongated ellipses, or trough-like—their length being very much greater than their breadth. On this account the shifts of the wind are generally sudden, from N.E. to S.W., or from N.W. to S.W. The

veering is from N.E. to N., N.W., W., and ending at S.W. or S.E. They last from one to seven days, and travel at the rate of from 4 to 20 miles an hour—their progressive motion being thus generally slower than that of European storms.

430. It occasionally happens from November to May, as the storm proceeds eastward over the southern portion of the Indian Ocean, that the drain, caused by the low pressure which accompanies it, reduces the pressure over the region of the S.E. trades below that of the region of calms to the north of it; in consequence of which the northerly monsoon appears to extend continuously from Central Asia, through the Indian Ocean as far south as the observations extend; and owing to the low pressure of the antarctic regions, it is probable that this northerly current sometimes extends almost to the south pole.

431. There is another class of gales which occur at Mauritius and adjoining regions, in the winter months of June, July, and August, or during those months when atmospheric pressure in Central Asia falls to the annual minimum, and that of the southern hemisphere rises to the annual maximum. During these gales the barometer rises in Mauritius to from 30.200 to 30.400 inches, or nearly an inch higher than the mean summer pressure of Central Asia. In consequence of this difference of pressure, a strong wind sets in from S. to S.S.E., which seldom veers more than a point or two. The barometer oscillates at times during the height of the gale, which is sometimes attended with passing showers, but never with heavy rain, thunder, or lightning. The gale generally commences about 30° S. lat., and advances towards the equator like an extensive wave or billow, the barometer rising at each locality some time before the wind acquires much force. It is preceded by a heavy sea, which occasionally proves dangerous near the equator. It lasts from one to ten days, and blows in fitful gusts usually of from 14 to 45 miles an hour; occasionally, however, it rises to 63 miles an hour—being nearly the velocity reached by one of the ordinary autumn storms experienced in Great Britain.

General Remarks.

432. Since storms are formed of spirally in-moving currents of air, it follows that *the fall of the barometer at the centre is not the effect of centrifugal force.* For if this was the cause of the low barometer, the wind would blow round the centre in circles, subject only to a slight modification from the onward motion of the storm—a state of the winds which has not yet been shown to

occur even in those cases when the storm increases in area and the depression at its centre is deepening. Professor Loomis has shown that any observed velocity of the winds round the centre is altogether inadequate, on the principle of centrifugal force, to bring about the low pressure at the centre. Thus, if the wind blows round a circle 300 miles in diameter at the rate of 70 miles an hour, the centrifugal force would only depress the barometer at the centre a little more than 0.02 inch; whereas in the Bahama hurricane the difference of the pressure at that distance from the centre was 2 inches, or 1000 times greater than that due to centrifugal force, on the supposition that the mean velocity of revolution of the storm, 300 miles in diameter, was 70 miles an hour.

433. *But the spiral rotation, instead of a purely circular rotation, of the winds in storms, changes completely the whole complexion of the question of the theory of storms.* For since it follows from it that enormous quantities of air are constantly being poured all around into the area of the storm, and since, notwithstanding these accessions tending to increase the pressure, observation shows that the pressure is not thereby increased, but on the contrary sometimes diminished, *we are forced to the conclusion that from a large area within and about the centre of the storm a vast ascending current must arise into the upper regions of the atmosphere; and arriving there must flow away over into neighbouring regions.* The physical cause of the ascending currents is to be found in the moist and warm, and therefore light air, which all observation shows to prevail in the front and in the central part of storms. And since most of the rain which accompanies storms falls in those parts of the storm, the barometer will be still further reduced by the removal of the elastic aqueous vapour which is condensed into rain-drops, and by the latent heat set free in the condensation of the vapour. These considerations, taken in connection with what has been advanced in Chap. XI., with reference to the lower and upper currents of the atmosphere in their relation to the lines of equal atmospheric pressure, suggest that the general motions of the atmosphere over the globe and in storms, are due to the same physical causes.

434. An examination of weather-changes over large portions of the surface of the globe from day to day, leaves a deep and lasting conviction on the mind of the essential unity of the earth's atmosphere, and, *a fortiori*, the oneness of comparatively so small a portion as that of Europe, in respect of the intimate relations of its different parts, and their absolute dependence on each other. Waves of temperature are sometimes propagated over that continent, apparently so vast that only a mere fragment of one of

them can be exhibited by the whole continent at one time; and the same remark applies with equal force to the waves of barometric pressure which pass across it. But of the causes of these vast atmospheric changes we are very ignorant. A general prevalence of currents, dry and cold on the one hand, and warm and moist on the other, may be explained; but why on a particular day a cold current descends from the frozen regions, and spreads itself over Europe, and why at another time an equatorial current flows wholly or partially over that continent, the area of observation is too contracted to show. Meteorology is eminently the science of observation and averages; and before those inquiries now raised regarding the general movements of the atmosphere can be satisfactorily and adequately discussed, it is indispensable that the field of observation be extended, so as to embrace nearly the whole of the northern hemisphere.

435. The present state of our knowledge of the science may be thus put: Given in any locality an excess or diminution of atmospheric pressure; an excess or diminution of atmospheric temperature; and an excess or diminution of atmospheric moisture,—we know the atmospheric motions and changes which will take place in restoring the equilibrium thus disturbed, and can to a considerable extent turn this knowledge to account in predicting the weather. But as regards the specific conditions out of which those great atmospheric disturbances take their origin, we know little or nothing; and it is for this all-important knowledge that the field of observation on sea as well as on land must be extended, so that synchronous weather-charts of the northern hemisphere might be constructed, which would supply the information desiderated—viz., trustworthy facts, in place of vague and unsatisfactory theorisings.

CHAPTER XIV.

MISCELLANEOUS.

Atmospheric Electricity.

436. The identity of lightning and electricity was first suspected by Wall in 1708, but it was reserved to Franklin to prove it. In 1749, he suggested, as the mode of proof, the erection of pointed metallic conductors properly insulated. Acting on this suggestion, Dalibard erected near Paris a pointed iron rod, 40 feet in length, and insulated; and on the 10th of May 1752 obtained electrical sparks from it. In June of the same year, Franklin, impatient at the delay in erecting the spire on which to place his pointed conductor, conceived the happy idea of obtaining electricity from the clouds by flying a kite. The kite was flown with a hempen string, to the lower end of which a key was attached; and the whole was insulated by tying a silk ribbon to the key, the other end of the ribbon being attached to a post. On the approach of the thunder-cloud, he raised the kite, and soon the fibres of the hempen string began to erect themselves and repel each other; and at last, when the rain had moistened the string, he had the intense satisfaction of drawing electrical sparks from the key. The experiment was repeated by Romas, during a thunderstorm in France, in June 1753. Instead of a string, he used fine wire (550 feet long), and obtained flashes of electrical fire, 9 or 10 feet long, and an inch in thickness, which were accompanied with a loud report. Thirty of these were obtained in one hour. In August of the same year, Professor Richmann of St Petersburg lost his life when engaged in similar experiments. In observing the electricity of clouds when the tension is great, a metallic ball must be placed near the bar, and be well connected with the ground; and care must be taken to keep at a greater

distance from the bar than the ball, so that if a discharge should take place it will strike the ball and not the observer.

437. *Electrometers* (Gr. *ēlectron*, amber, and *metron*, a measure) are instruments used for indicating the electricity present in the atmosphere. A pole is erected in an open situation on a rising ground, having an insulated pointed metallic wire on the top, to which an insulated wire is attached for conveying the electricity to the electrometer in the place of observation. Fig. 47 represents Bennet's *gold-leaf electrometer*, which consists of a glass jar with a metallic cap, in the centre of which a wooden wedge is inserted. On each side of it a thin strip of gold-leaf, two inches long, is attached, and opposite each, tinfoil is pasted within the jar, rising a little above the lower edge of the gold-leaf, and connected below with the brass stand of the instrument. A pointed wire rests on the cap in connection with the gold-leaf. When this pointed wire receives electricity, the gold-leaves diverge, and by the degree of divergence, measured on a graduated arc, the intensity of the electricity is ascertained. A condenser is used when the electric tension is too feeble to cause the gold-leaves to diverge. In Volta's electrometer, two thin blades of straw are used instead of the gold-leaf; and in Cavallo's, two pith-balls. In Henley's *quadrant electrometer*, fig. 48, a semicircle of ivory is fixed upon a rod rising from a stand, from the centre of which a pith-ball is hung by a piece of slender cane; and the degree of elevation of this ball indicates the quantity of the electricity.

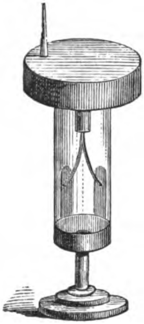


Fig. 47.

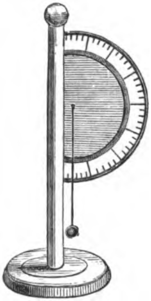


Fig. 48.

438. *Electroscopes* (Gr. *ēlectron*, amber, and *scopeo*, I look at) show whether the electricity is positive or negative. In Bohnenberger's electroscope, a gold-leaf is suspended between the poles of two "dry piles," charged with the opposite electricities; when, therefore, an electric body is brought into contact with the knob, the kind of electricity is known by the gold-leaf being attached to the opposite electricity.

439. It has been found that the atmosphere always contains free electricity, which is almost invariably positive. At Kew Observatory, during the years 1845-6-7, of the 10,500 observations, 10,176 were positive, and only 364 negative. When the sky is cloudless,

the electricity is always positive; but the intensity varies with the height, being greatest in the highest and most isolated situations. Positive electricity is only found at a certain height above the ground. On flat ground it becomes manifest at a height of 5 feet. It is not found in houses, in streets, or under trees. The negative observations almost all occur during heavy rain. When the sky is clouded, the electricity is sometimes positive and sometimes negative, according to the electrified condition of the clouds. In relation to the air the earth's surface is always negative. The electricity of the air increases in intensity with the height. This was shown by an ingenious experiment made at the Great St Bernard, by Becquerel and Breschet. A silk cord, with a fine wire twisted into it, was attached to an electrometer at one end, and an iron arrow tied to the other, and shot from a bow to the height of 250 feet. As the arrow ascended, the thin straws of the electrometer separated more and more, and at last struck against the sides of the jar. The arrow was then shot horizontally, but no increase of the electric tension was observed. This conclusion has been confirmed by flying paper kites, and sending up captive balloons into the air. The electricity of the atmosphere is stronger in winter than in summer, increasing from June to January, and decreasing from January to June. It is subject to a double maximum and minimum each day. Saussure and Schübler have shown that the first maximum occurs from 7 to 8 A.M. in summer, and from 10 A.M. to noon in winter; it then falls slightly to the first minimum between 5 and 6 P.M. in summer, and between 2 and 3 P.M. in winter, or shortly after the period of the maximum temperature; it rises to a second maximum a little after sunset, and then decreases to a second minimum, which occurs about daybreak. The daily march of the electric tension is best marked in clear settled weather.

440. *Sources of Atmospheric Electricity.*—1. *Evaporation.*—Electricity is produced when *impure* water is evaporating, or water in which some degree of chemical decomposition takes place, none whatever being produced by the evaporation of pure water. Vapour rising from water containing a salt or an alkali is charged with positive electricity, while the water retains negative electricity; but when the water contains acid, negative electricity is given off, and positive is left behind. Hence it is supposed that seas, lakes, and rivers are abundant sources of atmospheric electricity, particularly of the positive sort. 2. *Vegetation.*—The vegetable kingdom is also a source of electricity, (1) from the evaporation going on by which water is separated from the sap of the plants, and (2) from the giving off of oxygen

and carbonic acid gas during the night, which is charged with positive electricity. 3. *Combustion.*—During the process of burning, bodies give off positive electricity, and become themselves negatively electrified. This is frequently seen on a grand scale during volcanic eruptions. 4. *Friction.*—Wind, by the friction it produces upon terrestrial objects, the particles of dust, and the watery particles in the vesicular state which it carries with it, contributes to the electricity of the air. Electricity is not generated, if the moisture be in the form of pure vapour.

441. Sir John Herschel has expressed an opinion that, when a great multitude of the ultimate molecules of vapour are condensed by cold into a drop or snow-spangle, however minute, that drop collects and retains on its surface the whole electricity of the molecules from which it is formed. Suppose a number, say 1000, of such globules to coalesce into one, the electric contents, being the sum of those of the elementary globules, will be increased one thousandfold, and, being spread entirely over the surface, will have a tenfold density or tension. This view appears to explain the amount of electricity observed in the lower stratum of air when dew is being deposited, and the highly electrical state of fogs and clouds. It also explains to some extent the annual variation; for since in winter the condensation of vapour is greater and occurs with greater frequency than in summer, the average quantity of electricity, as observed, will be greater in winter than in summer. At this season, also, the south-west winds acquire their greatest frequency. The daily variation is similarly explained. When the sun has risen, and from the increasing temperature evaporation is most active, the first maximum period of electricity occurs; but when the air becoming still warmer is able to hold its vapour in solution, and evaporation has become feebler, the intensity decreases. Again, after sunset, when dew is most copiously deposited, the second maximum period is attained; and lastly, towards sunrise, when little dew is deposited, and evaporation is also small, the second and chief minimum period occurs. The annual and daily variation is further explained by the readier transmission of the electricity of the upper regions of the atmosphere to the earth through strata of moist air than through dry air.

Thunderstorms.

442. Thunderstorms occur most frequently within the tropics, and diminish in frequency towards the poles. They are also more frequent in summer than in winter, though in certain parts of the

globe this is reversed; during day than during night; after midday than before it; and in mountainous countries than in plains. Within the tropics they prevail most in the region of calms and during the rainy season; and least in the trades, in arid deserts, and during the dry season. Before the storm bursts, the air is warm and stifling, and peculiarly so when the storm occurs in winter or during night; and after it has passed, the temperature falls generally to a very marked extent. Thunder and lightning often accompany whirlwinds. During thunderstorms sudden changes from positive to negative electricity, and *vice versâ*, take place.

443. *Lightning.*—Arago has divided lightning into three kinds — viz., zigzag lightning, sheet-lightning, and ball-lightning. When the electric flash darts through the air, it takes the path of least resistance; and since the conducting power of different portions of the atmosphere is unequal, the lightning frequently appears *zigzag*. When branches are given off at different points of its course, the lightning is said to be forked. According to Professor Balfour Stewart, the flash of lightning consists of the various constituents of the air heated up to incandescence; and were the flash analysed by means of the spectroscope, it would, no doubt, reveal the chemical nature of the substances through which the discharge had passed. *Sheet-lightning* is the most common, appearing as a glow of light illuminating the sky. The flashes often follow each other in quick succession, and the thunder which accompanies them is low and at a considerable distance. Analogous to this is *silent lightning*, frequently termed *heat-lightning*, which generally occurs during serene summer evenings, lighting up the sky fitfully for hours, with repeated faint flashes; it is not attended with thunder. It is probable that this kind of lightning is frequently the reflection of the lightning of distant storms from the vapour of the upper regions of the atmosphere, the storms being too far off for the thunder to be heard; but at times it may, according to Professor Loomis, be due to the escape of the electricity of the clouds, in flashes so feeble as to produce no audible sound—such cases occurring in very moist air, which is a tolerable conductor, and offers just sufficient resistance to the passage of the electricity to develop a feeble light. *Ball-lightning* is the least common. It appears as a globular mass, moving slowly or sometimes remaining stationary, and in a short time explodes with violence. It has not yet been satisfactorily explained. Professor Wheatstone has found in one experiment that the duration of the electric spark lasted $\frac{1}{24000}$ of a second.

444. *Thunder* is probably due to the instantaneous expansion

of the air by the heat produced by the lightning along the path of the discharge. The sound emitted by flames is a familiar illustration of a similar phenomenon. Flashes of lightning frequently extend two or three miles in length; and since the thunder is produced at every point along its course nearly at the same instant, the prolonged rolling noise of thunder arises from the different intervals of time it takes the sound to reach the ear. For since sound travels at the rate of 1116 feet per second, it is first heard from the nearest point of the flash, later and later from points more distant, so that the combined effect is a continued peal of thunder. The direction and character of the peal will depend on the length of the flash, and the greater or less obliquity of its course in relation to the observer. Reverberations from clouds and from mountains frequently heighten the effect and prolong the peal. From the rate at which sound travels, if the thunder be not heard till five seconds after the flash, the distance is about a mile. Thunder has not been heard at a greater distance than 14 miles from the flash.

445. Thunderstorms are generally very local. Sometimes, however, they extend over a wide district. On the 11th January 1815, a thunderstorm stretched from Antwerp to Minden, or about 200 miles, and from Bonn to Nimeguen, or nearly 75 miles. When the May monsoon of 1848 burst upon India, it was accompanied with a thunderstorm which covered a district 600 miles from north to south, and 50 miles in breadth. The great proportion of electrical discharges pass into the air, or into other clouds less highly electrified; a very few only take place between the cloud and the earth. The destructive effects of this latter class are well known. By the electric discharge innumerable lives have been destroyed, the strongest trees rent to pieces, heavy bodies displaced, iron and steel magnetised, metals and rocks softened and fused, and combustible substances set on fire. Sir John Herschel mentions a remarkable instance of "a large oak-tree near Alton, Hants, which was rent into ribbons, and every limb of which had been struck off as if by an axe, and had fallen around the tree as by mere privation of support, without lateral projection." He adds: "In producing these effects, the electricity would seem to act immediately by the expansion of vapour generated by its violent heat." When the thunderbolt falls upon sand it occasionally produces *fulgurites* or *fulminary tubes*, which are silicious tubes of various sizes vitrified internally.

446. *Return-Shock.*—This shock sometimes proves fatal to living beings, even at great distances from the place where the electric discharge takes place. It is caused by the inductive action of the

electrified cloud on bodies within the sphere of its influence, by which they become charged with the electricity opposite to that of the cloud. Hence, when the cloud has discharged its electricity into the ground, the induction ceases and a rapid change takes place in bodies from the electrified to the neutral state, thus causing the concussion of the return-shock.

447. *Lightning-Rods.*—The lightning-rod was introduced by Franklin in 1755 as a means of protecting buildings from the destructive effects of electricity. The advantage gained by it consists, not in protecting the building in case of a discharge by allowing a free passage for the electric fluid to escape to the earth, for it is but a poor protection in such a case; but in quietly and gradually keeping up the communication, it tends to maintain the electric equilibrium, and thus prevent the occurrence of a discharge. The best are made of copper not less than three-quarters of an inch thick, and pointed at the upper extremity. They should be of one piece throughout, fastened vertically to the roof of the building, and thence carried down into the ground. The lower extremity should part into two or three branches bent away from the house, and carried sufficiently far into the soil to meet water or permanently moist earth. The conductor should be connected with all metallic surfaces on the roof or other parts of the building, in order to prevent the occurrence of lateral discharges, or discharges from the conductor to these surfaces, which are often destructive.

448. *St Elmo's Fire.*—This meteor is the *Castor and Pollux* of the ancients, and is frequently mentioned in classic writings from the Argonautic expedition downwards. Cæsar notices its appearance after a storm of hail in these words: "Eâdem nocte legionis quintæ cacumina suâ sponte arsêrunt." The finest and most beautiful displays of this most striking phenomenon occur at sea during storms, when it appears as a light resting on the masts. Mr W. Trail of Orkney gives a particular description of it as seen by him there during a storm in 1837. The mast was illuminated, and from the iron spike at the top a flame a foot in length pointed to a dense cloud rapidly advancing from N.N.W. As the cloud, accompanied with thunder and hail, approached, the flame increased, following the course of the cloud, till it reached 3 feet in length, when the cloud was passing overhead; after which it quickly diminished, but continued to point to the cloud as it was borne to the S.S.E. It lasted about four minutes. If in a dark room we bring a needle close to the conductor of an electric machine when charged, a light will be seen to play on the point of the needle caused by the combination of the electricity of the

conductor and that of the needle which is charged by induction with the opposite electricity to that of the conductor. This simple experiment explains St Elmo's fire, which takes place when an electrified cloud approaches near the earth, so that the electricity of the cloud and that of the earth combine, not in flashes of lightning, but more slowly and continuously from different points, which therefore appear to glow with a bright flame.

449. **Hailstorms.**—Hailstorms are modifications of the thunderstorm. Since they occur where the force of thunderstorms is most concentrated, they are of a more local character, and their occurrence and destructiveness would appear to be to a large extent determined by the configuration and vegetable covering of the earth's surface. They seldom occur during the night or during winter; but most frequently in summer, and during the hottest part of the day. They are more common in the neighbourhood of mountains than in plains. Thus the south of France, lying between the Alps and the Pyrenees, suffers much from hailstorms, the vines being often broken and destroyed by their violence. The annual loss from this cause has been estimated at above two millions sterling. So important is a proper knowledge of these and similar storms considered in France, that the services of upwards of 1200 observers have been secured in that country to note the chief features of storms (*orages*).

450. This class of storms are found in France to be invariably bound up, or associated, with barometric depressions, and their general direction is influenced as is that of the wind in the same circumstances. The general direction in which they advanced in 1865 was from S.W. to N.E.; and otherwise on this point they resembled the storms of Europe already described. But when they were confined to the lower parts of the atmosphere they were diverted from their course on coming up against high tablelands and mountain-ranges much in the same way apparently as rivers are when high banks oppose their course, in this respect also resembling the course of the wind. The rate of their progressive motion varied from 12 to 45 miles an hour, thus showing in this respect also a close correspondence with the larger storms of Europe.

451. On the 28th July 1818, a hailstorm of unusual violence passed over Orkney, its course being marked over a district twenty miles in length by one and a half in breadth. It did not last longer at any place than nine minutes, during which 9 inches of ice fell. On the 13th July 1788, a hailstorm passed directly from the south-west of France to Utrecht. It moved in two parallel columns with very great rapidity, traversing the distance in less

than nine hours. The length of the one column was 435 miles, and of the other 497 miles, and the breadth respectively 5 and 10 miles. Between the two tracts there was a space of twelve miles, where no hail, but heavy rain, fell. At each place the storm lasted only a few minutes; and along its course property valued at above a million sterling was destroyed.

Whirlwinds, and Waterspouts or Trombes.

452. Whirlwinds are in several respects very different from the storms already described. They seldom last longer than a minute, sometimes only a few seconds; their breadth varies from 20 to a few hundred yards; their course seldom exceeds 25 miles in length; and while they last the changes of the wind are sudden and violent. The direction of the eddy of the whirlwind, especially when of small diameter, differs from the rotation of the winds in a storm, in that it may take place either way according to the direction of the stronger of the two winds which give rise to it. Thus, suppose a whirlwind produced by the brushing of a

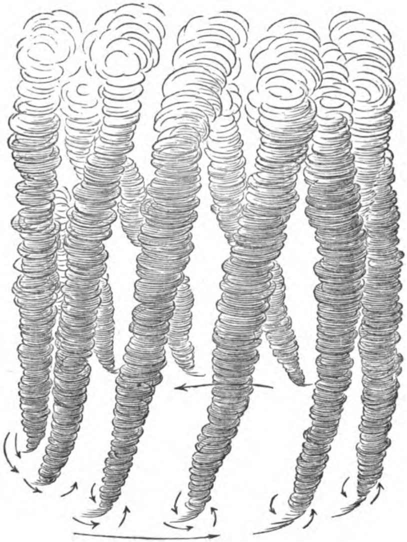


Fig. 49.

north against a south wind, then if the north wind be the stronger, and on the west, the whirl will be in the direction of the hands of a watch, but if the south wind be the stronger the eddy will turn in the opposite direction. Whirlwinds are often originated in the tropics during the hot season; especially in flat sandy deserts, which, becoming unequally heated by the sun, give rise to numerous ascending columns of air. In their contact with each other, these ascending currents give rise to eddies, thus producing whirlwinds which carry up with them clouds of dust. Of this description are the *dust-whirlwinds* of India, which have been described and profusely illustrated by P. F. B. Baddeley. Figs. 49 and 50 represent two of these remarkable phenomena. The large arrows in fig. 49 show the rotation of the whole whirlwind round its axis, while the small arrows show the rotation of each column round its own axis. Fig. 50 shows the general appearance of these dust-whirlwinds viewed at a distance. A dust-storm is occasioned by a number of whirlwind columns moving together over the earth's surface. The storm generally comes on without warning from any direction, and the barometer is said not to be perceptibly affected by it. A low bank of dark cloud is seen in the horizon, which rapidly increases, and before the spectator is aware the storm bursts upon him, wrapping everything in midnight darkness. An enormous quantity of dust is whirled aloft, which is sometimes broken into distinct columns, each whirling on its axis. Violent gusts or squalls succeed each

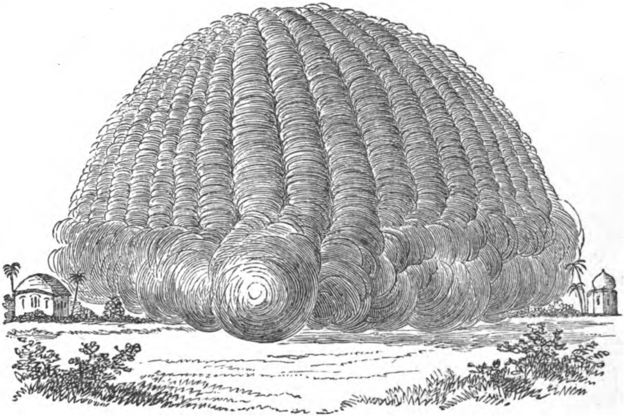


Fig. 50.

other at intervals, which gradually become weaker, and at the close of the storm a fall of rain generally takes place. The air is often highly electrical, arising probably from the friction of the dust-loaded currents against each other. The Simoom may be regarded as in part a whirlwind or a succession of whirlwinds of this description. Sir S. W. Baker thus graphically describes the behaviour of the dust-whirlwinds which occur in Nubia in April, May, and June: "I have frequently seen many such columns at the same time in the boundless desert, all travelling or waltzing in various directions, at the fitful choice of each whirlwind; this vagrancy of character is an undoubted proof to the Arab mind of their independent and diabolical character."

453. *Waterspouts.*—A waterspout (fig. 51) is a whirlwind occurring over the sea or over sheets of fresh water. When fully formed they appear as tall pillars stretching from the sea upward to the clouds, and exhibit the same whirling motion round their axes, and the same progressive movement of the mass, as dust-whirlwinds. As they consist of vortices of wind in rapid motion, the sea is tossed into violent agitation round their bases as they career onwards, the waves being broken up so as to resemble the surface of a glacier, or of water in rapid ebullition. The danger arising

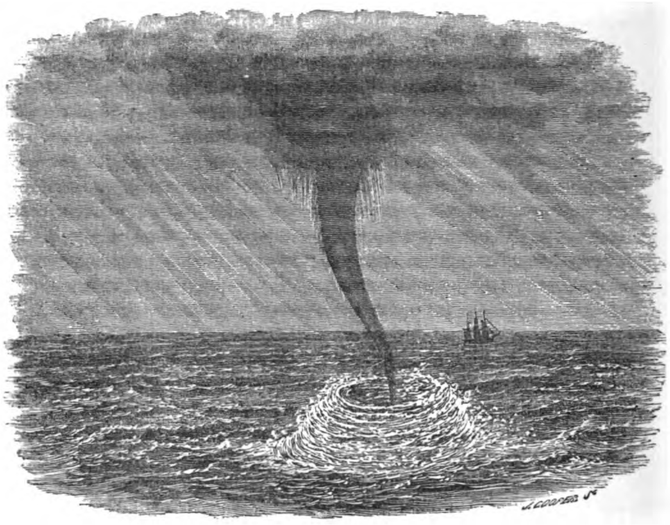


Fig. 51.

from them consists in the enormous velocity of the wind, and the sudden changes in its direction experienced by ships which encounter them. It is a popular fallacy that the water of the sea is sucked up by them, it being only the spray from the broken waves that is carried up the whirling vortex; this is conclusively proved by the fact that the water poured down on the decks of vessels from waterspouts is either wholly fresh or only slightly brackish.

Aurora Borealis and Terrestrial Magnetism.

454. The *aurora borealis* (Lat. *aurōra*, dawn, and *boreālis*, northern) is the luminous appearance in the northern sky, which forms, in most vivid displays, spectacles of great beauty. The aurora is observed also in the neighbourhood of the south pole, and is there called *aurora australis* (Lat. *australis*, southern). From their lively tremulous motions they have been called "the merry dancers." When fully developed, the aurora consists of a dark segment of a hazy or slaty appearance surmounted by an arch of light, at right angles to the magnetic meridian, from which luminous *streamers* quiver and dart towards the magnetic zenith. Careful measurements of several arches show that, except near the horizon, they may be regarded as portions of small circles parallel to the earth's surface. Near the horizon the extremities of the arches sometimes appear to be bent inwards; and Hansteen mentions having twice seen at Christiania the arch in the form of an ellipse almost entire. Several auroral arches are sometimes seen at once. Thus, on one occasion at Bossekop, in Finland, nine arches were visible, separated by dark intervals, and resembling in their arrangement magnificent curtains of light hung behind and below each other, their brilliant folds stretching completely across the sky. Sometimes the streamers appear to unite near the zenith, forming what is called the *corona* of the aurora, towards which the dipping-needle at the time points. The convergence of the rays in this case is only apparent, being merely the effect of perspective.

455. Auroras are very unequally distributed over the earth's surface. Professor Loomis gives the results of a comprehensive examination of auroral observations, and in reference to the geographical distribution remarks that "at Havanna but six have been recorded within a hundred years. As we travel northwards from Cuba, auroras increase in frequency and brilliancy; they rise higher in the heavens, and oftener attain the zenith. If we travel northwards along the meridian of Washington (U.S.), we

find on an average near the parallel of 40° only ten auroras annually. Near the parallel of 42°, the average number is twenty annually; near 45°, it is forty; and near 50°, it is eighty. Between this point and the parallel of 62°, auroras are seen almost in every night, high in the heavens, and as often to the south as to the north. Farther north they are seldom seen except in the south, and from this point they diminish in frequency and brilliancy as we advance towards the pole. Beyond lat. 62°, the number of auroras is reduced to forty annually; beyond lat. 67°, it is reduced to twenty; and near lat. 78°, to ten annually. If we make a like comparison for the meridian of St Petersburg, we shall find a similar result, except that the auroral region is situated farther northward than it is in America—the region of eighty auroras annually being found between the parallels of 66° and 75°. The region of greatest auroral action, averaging at least eighty annually, is a zone of an oval form surrounding the north pole, and whose central line crosses the meridian of Washington in lat. 56°, and that of St Petersburg in lat. 71°. Accordingly, auroras are more frequent in the United States than they are in the same latitudes of Europe. On the parallel of 45° we find in North America an average of forty auroras annually, but in Europe less than ten. The form of this auroral zone does not bear any resemblance to the lines of equal magnetic intensity, but it bears some resemblance to the line of equal magnetic dip. It bears also considerable resemblance to a magnetic parallel, or line everywhere perpendicular to a magnetic meridian; and the coincidence of this result with the uniform position of auroral arches, naturally suggests the idea of a real connection between the two phenomena."

456. The aurora is of great extent, having been sometimes observed simultaneously in Europe and America. From observations made at Hobart Town, and in the United States of America, Professor Loomis thinks it probable that an exhibition of auroral light about one magnetic pole of the earth is uniformly attended by a simultaneous exhibition of auroral light about the opposite magnetic pole. The height varies from about 45 to 500 miles above the earth. From observations made on one which appeared in England during March 1826, Dalton calculated its height at 100 miles. Sir John Herschel determined the height of one which was seen on the 9th March 1861 by himself in Kent, and at the same time by Mr Lowe at Nottingham, to be 83 miles. Of auroras which have been seen near the earth, the one thus described by Captain Parry is the most remarkable: "While Lieutenants Sherer, Ross, and myself were admiring the extreme

beauty of the northern lights, we all simultaneously uttered an exclamation of surprise at seeing a bright ray of aurora shoot suddenly downward from the general mass of light, and between us and the land, which was there distant only 3000 yards. I have no doubt that the ray of light actually passed within that distance of us."

457. As regards frequency, auroras have a daily period which reaches the maximum about midnight. The aurora is not often seen in summer, partly, no doubt, on account of the short nights and the clear skies. There is, however, a double maximum and minimum occurrence in the year, which the following table from Kaemtz and Loomis, giving the number of auroras seen in each month in Europe and America respectively during many years, clearly establishes:—

	Kaemtz.	Loomis.		Kaemtz.	Loomis.		Kaemtz.	Loomis.
Jan.,	229	173	May,	184	191	Sept.,	405	293
Feb.,	307	210	June,	65	179	Oct.,	497	236
Mar.,	440	240	July,	87	244	Nov.,	285	215
April,	312	267	Aug.,	217	238	Dec.,	225	159

In addition to this annual period, there would appear to be a secular period comprising a number of years. Observations appear to indicate a maximum every ten years, and a still larger maximum period recurring every sixty years.

458. The culminating point of the auroral arch being at or near the magnetic meridian, and the centre of the corona in the line of the dipping-needle produced, point out an evident connection between the aurora and terrestrial magnetism. The magnetic needle is also much agitated when the aurora is visible. When the arch is motionless, so is the needle; but as soon as streamers are shot out, its declination changes every moment, and this happens though the aurora does not appear at the place of observation, but is seen near the pole. According to Hansteen, the intensity increases greatly a short time before the appearance of the aurora; but as soon as the aurora begins to be seen, it diminishes in proportion to the brilliancy of the display; and it then returns slowly, generally in twenty-four hours, to its original value. During 1857 and 1858, Captain M'Clintock, when in the arctic regions, observed that the aurora in all cases appeared to come from the surface of open water, and not in any case from the fields of ice,—an observation favouring the idea that it is caused by electrical discharges

between the earth and the air, and that these are interrupted by the fields of non-conducting ice.

459. General Sabine has discovered that magnetic disturbances of the earth are due to the sun, but not to his heat and light; and are invariably accompanied by the aurora and by electric currents in the surface of the earth. Dr Balfour Stewart considers that auroras and earth-currents are to be regarded as secondary currents due to small but rapid changes in the earth's magnetism; and that the body of the earth may be likened to the magnetic core of a Ruhmkorff's machine, the lower strata of the air forming an insulator, while the upper and rarer, and therefore electrically-conducting strata, may be likened to the secondary coil; and the sun perhaps likened to the primary current which produces changes in the magnetic state of the core. If this be so, he adds that the energy of the aurora may come from the sun; but this may be considered doubtful, from our ignorance of the way in which the sun affects terrestrial magnetism. The secular periods of the sun's spots, of the variation of the magnetic needle, and of the frequency of auroras, seem to indicate that these phenomena are regulated not by terrestrial but by astronomical causes.

460. P. Secchi, Director of the observatory of the College, Rome, and M. Marié Davy, Chief of the Meteorological Division in the Imperial Observatory, Paris, have for some time given particular attention to magnetic storms, electric disturbances, and auroras in their relations to weather and the prediction of storms. Marié Davy states that the perturbations of the magnetic needle are joined inseparably with one or more of the three following phenomena: 1. General disturbances of the telegraphic lines due to widespread auroras, which indicate general movements of the atmosphere in high latitudes and over the Atlantic. 2. Disturbing currents of a more local character occurring over the telegraphic lines some time before the storm appears to which they owe their origin, thus lengthening the distance and time at which the approach of the storm may be perceived. 3. Disturbing currents still more restricted accompanying the electric changes which occur when the storm itself is passing.

Ozone.

461. In the year 1848 Schönbein discovered a new chemical principle, to which he gave the name of *ozone* (Gr. *ozo*, I smell), on account of its peculiar smell. Ozone is generally supposed to be oxygen in an allotropic state; that is to say, it is the same

substance as oxygen, but in a different form, and endowed with different properties. The properties by which ozone is distinguished from oxygen are the following: It smells strongly and has the flavour of lobsters; readily discharges the colour from litmus paper, oxidises silver, burns ammonia spontaneously, and converts it into nitric acid; burns phosphoretted hydrogen immediately with emission of light; decomposes iodide of potassium, setting iodine free, and hydrochloric acid, setting chlorine free; and is a powerful oxidising and chlorodising agent. Oxygen may be transformed into ozone by the electric machine; and there can be no doubt that it is constantly being produced by the electricity which is ever present in the atmosphere, and most copiously by lightning during thunderstorms. As the most powerful known disinfectant, it most readily unites with the gases which arise from decaying vegetable and animal matter, and, by depriving them of their noxious qualities, is a great purifier of the air. It is this property which brings it within the province of the meteorologist, and accordingly it has been extensively observed of late years in Great Britain and on the Continent.

462. *Ozonometer* (Gr. *ozo*, I smell, and *metron*, a measure).—The following is the mode of preparing Schönbein's ozone test-papers. Take 200 parts of water, 10 of starch, and 1 of iodide of potassium, and boil together for a few seconds; dip bibulous paper into the solution, and after it is dried, cut it into strips. In observing with it, it is only necessary that a strip be placed in an airy situation, free from wet and the sun's rays. A good position is to attach it to a hook on the inside of the roof of the box for thermometers. After being exposed for twelve hours it is taken off, and dipped in water. The depth of the tint of the paper determines the amount of the ozone, and it is compared with a scale showing the different tints marked according to depth from 0 to 10. The tests generally used are Schönbein's and Moffat's. It is necessary to estimate the force of the wind during the time, since, in a windy day, more ozone is collected, not because there is more in the atmosphere at the time, but because more air has passed over the tests, thus deepening the tint of the paper. Ozone is more abundant on the sea-coast than inland; in the west than in the east of Great Britain; in elevated than in low situations; with south-west than with north-east winds; in the country than in towns; and on the windward than on the leeward side of towns. From the observations made by the observers of the Scottish Meteorological Society, ozone is most abundant from February to June, when the average amount is 6.0, and least from July to January, when the average is 5.7. The maximum, 6.2, is reached

in May, and the minimum, 5.3, in November. Thus the maximum period occurs when evaporation is greatest, and the minimum when the condensation of aqueous vapour is greatest—a result in accordance with the conclusions arrived at by Dr Berigny and M. Houzeau. It thus appears that it is most abundant where electricity is produced; and least so, or entirely wanting, where electricity is in least quantity, and where there is much decaying vegetable and animal matter. But there are great, if not insuperable, difficulties in the way of accurately observing the ozone of the atmosphere; for no simple means have yet been devised of drawing over the test-papers an ascertained quantity of air, the same at all places and times; and of determining whether the colouring of the paper be due to ozone, to nitric or other acid present in the atmosphere.

Optical Phenomena.

463. Though rainbows, halos, and other optical phenomena furnish many most beautiful and surprising spectacles, yet from the very subordinate position they hold among meteorological objects, any description given here will be brief and of a popular character. For a full account of them we must refer to the common treatises on *Optics*, to which department of Natural Philosophy they more immediately belong. *The Rainbow.*—The rainbow generally consists of two arches, the inner or primary bow, and the outer or secondary bow, each composed of the seven prismatic colours, violet, indigo, blue, green, yellow, orange, and red; or rather of the three primary colours, blue, yellow, and red, blended together. In the primary bow the violet colour is on the inner side of the bow, and the red on the outer; but in the secondary bow this arrangement of the colours is reversed. Coloured bows are also sometimes seen in the interior of the primary bow, and more rarely at the exterior of the secondary bow; these are called *supernumerary bows.*

464. As the centre of the circle of which the rainbow is a part is in the continuation of a line drawn from the sun through the eye of the spectator, its position varies with that of the spectator, and its size with the degree of proximity of the sun to the horizon. Thus, if the sun be in the horizon the rainbow will be a semicircle; if higher, less than a semicircle; if about 42° high, the top of the primary bow will be just visible in the horizon; and if at greater heights, no rainbow will be formed on the sky. Rainbows have been sometimes seen from the tops of mountains forming complete circles, when the sun was high and a shower of rain was falling in

the plain below. When the sun is reflected from the surface of still water, *extraordinary bows* are sometimes formed. From the reflected image of the sun being in effect beneath the horizon, such bows are larger than a semicircle. The arrangement of the colours is the same as the primary bow ; and when their summit happens to coincide with that of the secondary bow, a band of white light is formed at the place of union where they blend together.

465. *Lunar Rainbows.*—Rainbows are also produced by the light of the moon falling on rain-drops, exactly in the same way as solar rainbows. They are by no means of rare occurrence. Owing to the feeble light of the moon the bow is generally without colours ; but when the sky is very clear and the moon at the full, the prismatic colours appear, but in subdued splendour.

466. Since rainbows in the morning are always seen in the west, they indicate the advance of the rain-cloud from the west at the time that it is clear and bright in the east ; and since the fall of rain at this time of the day when the temperature should be rising is an additional evidence of increasing moisture, a morning rainbow is regarded as a prognostic of a change to wet stormy weather. On the contrary, the conditions under which a rainbow can appear in the evening are, the passing of the rain-cloud to the east, and a clearing-up in the west at the time of day when the temperature has begun to fall, thus further indicating a change from wet to dry weather. Hence the popular prognostic,—

> " A rainbow in the morning—
> Sailors, take warning ;
> A rainbow at night
> Is the sailor's delight."

467. *Coronas.*—The corona (Gr. *korōnē,* a crown) is an appearance of faintly-coloured rings encircling the moon when seen behind the light fleecy cloud of the cirro-cumulus. When the corona is perfect, the rings form several concentric circles, the blue prismatic colour being nearer the centre than the red. When of large dimensions it is called a *brough* in Scotland, and the ring has then generally a whitish nebulous appearance. The peculiar rings of the corona may be seen by looking at a light through a piece of glass upon which club-moss seed, which is very small, has been dusted ; and the same appearance may be observed by looking at the gas-lamps of the streets through the window of a carriage on which moisture has been condensed. Similar appearances are seen in certain diseases of the eye, when the cornea becomes coated with minute particles of foreign matter. Coronas are only seen when the globules composing the cloud are all or nearly all of equal size ; and the smaller the size of the globules

the greater is the diameter of the corona. Hence the corona is a valuable prognostic ; for when its diameter contracts round the moon, we know that the watery particles composing it are uniting into larger ones, which by-and-by will fall in rain ; whereas if the corona be extending, the particles are growing less, thus indicating increasing dryness, and consequently fair weather. Coronas are also very frequently formed round the sun ; but to see them it is necessary to dim his stronger light, by looking through smoked glass, or at his image reflected from still water.

468. *Glories of light*, sometimes called *anthelia* (Gr. *anti*, opposite, and *hēlios*, the sun), because formed opposite the sun, are sometimes seen when the shadow of an observer is cast on fog ; and the shadow of his head is surrounded with the prismatic circles. On one occasion Scoresby saw four coloured concentric circles around his shadow, and he observed that the phenomenon was always seen in the polar regions whenever sunshine and fog occurred at the same time.

469. *Halos.* — Halos are circles of prismatic colours around the sun (figs. 52, 53, 54, and 55) or moon (figs. 56 and 57), but

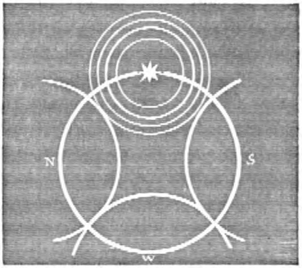


Fig. 52.

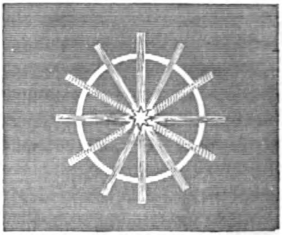


Fig. 53.

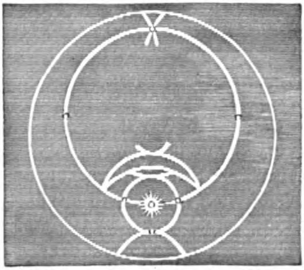


Fig. 54.

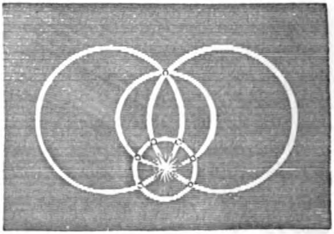


Fig. 55.

they are perfectly distinct from coronas, with which they must not be confounded. Halos are of comparatively rare occurrence; coronas, on the contrary, may be seen every time a light fleecy cloud comes between us and the sun or moon. The structure of halos, as seen from the figures, is often very complicated, circle cutting circle in the most remarkable manner, and with mathematical exactness, the diameters of the circles being generally very large; but the structure of the corona is simple, the circles concentric, the inner one small, varying from 2° to 4°, the diameter of the second circle being double that of the first, and of the third three times. In halos, the red prismatic colour is next the centre; in coronas, the blue. Halos are formed from the refraction and reflection of the rays of light by the minute snow-crystals of the cirrus cloud; while coronas arise from the interference of the rays passing on each side of the globules of vapour.

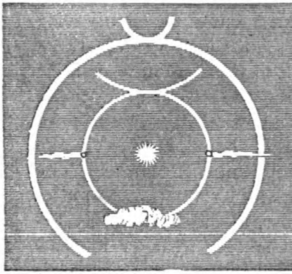


Fig. 56.

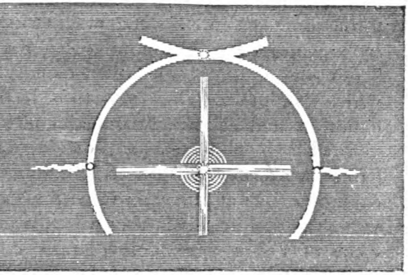


Fig. 57.

470. *Parhelia and Paraselenæ.*—At the points of intersection of the circles of the halo, images of the sun or moon generally appear from the light concentrated at these points, the images of the sun being called *parhelia* (Gr. *para,* about or near, and *hēlios,* the sun) or *mock-suns,* and those of the moon *paraselenæ* (Gr. *para,* about or near, and *selēnē,* the moon), or *mock-moons,* which also exhibit the prismatic colours of the halo.

471. Colours of Clouds.—The gorgeous colours of the clouds at sunset are the accompaniment of cumulus clouds (the cloud of the day during fine weather), while in the act of dissolving as they sink into the lower and warmer parts of the atmosphere; consequently they disappear from the sky shortly after sunset. Such sunsets are therefore universally regarded as prognostics of fine weather. Frequently small thin clouds appear high up in the sky some time before sunrise, but when the sun has risen they disappear. They are probably caused by the sun shining on and

warming the upper layers of the atmosphere before it appears above the horizon ; thus small ascending currents are formed, the vapour of which, as they ascend, is condensed in small clouds of the cirro-cumulus type. Their rounded definite forms show them to be produced in the same manner as the cumulus cloud—viz., by ascending currents forcing their way through colder strata. Their consistence is thin and vapoury, and their colour generally whitish or grey. They may thus be regarded as heralding the cumulus, and as sure prognostics of fine weather. A green or yellowish-green tinted sky, on the other hand, is one of the surest prognostics of rain in summer, and snow in winter. The changing tints of the evening sky after stormy weather, supplies valuable help in forecasting weather ; for, if the yellow tint become of a sickly green, more rain and stormy weather may be expected ; but if it deepen into orange and red, the atmosphere is becoming drier, and fine weather may be expected.

472. Some years ago, Principal Forbes showed that high-pressure steam, while transparent and *in the act of expansion*, readily absorbs the violet, blue, and part of the green rays, thus permitting the yellow, orange, and red to pass ; and he suggested that coloration may be produced in a mixture of air and vapour, when the vapour is in the intermediate state. Dr E. Lommel has shown that successive layers of air charged with visible vapour, act, so to speak, like sieves, and continually separate the transmitted light more and more completely from its more refrangible rays. Hence, in passing through different thicknesses of vapour, the blue rays are first absorbed, then the yellow rays, and finally the red rays. It is in the lower layers of the atmosphere that dust, smoke, watery vesicles, and rain-drops are chiefly suspended. When the sun is high in the heavens, the thickness of the vapour-screen between the sun and the eye is not sufficient to produce any perceptible action on the rays of light, which consequently appear white ; but as the sun descends towards the horizon the thickness of the vapour-screen is greatly increased, and at sunset it is calculated that the light of the sun has to pass through 200 miles of the air in illuminating a cloud a mile above the earth. Hence, as the rays fall more and more obliquely on the clouds, they appear successively yellow, orange, and finally red. The varied colours often seen at sunset are caused by the clouds being at different heights and in different parts of the sky, so that various thicknesses of vapour are interposed between them and the sun. At dawn the clouds first appear red; but as the sun rises higher, the yellow light ceases to be absorbed, and the clouds appear orange, yellow, and finally white.

It is evident that a *high* red dawn may be regarded as prognostic of settled weather, because the redness seen in clouds at a great height while the sun is yet below the horizon may be occasioned by the great thickness of the vapour-screen through which the illuminating rays must pass before reaching the clouds, and not to any excess of vapour in the air itself. But if the clouds be red and *lowering* later in the morning, it may be accepted as a sign of rain, since the thickness traversed by the illuminating rays being now much less, the red colour must arise from an unusual amount of vapour in the vesicular state, and in the state intermediate between the vesicular and the gaseous, when, according to Forbes, the blue rays are absorbed, and the yellow and red pass. It is to the latter of these kinds of red sunrise that the prognostic refers:—

> "The evening grey and the morning red,
> Put on your hat, or you'll wet your head."

Meteors.

473. *Meteors and Shooting-Stars* can scarcely with propriety be included among meteorological phenomena, since the whole of the facts known regarding them lead to their being classed with astronomical bodies. Of late years they have been carefully observed and their movements made the subject of scientific investigation; and attention was forcibly drawn to their consideration by the magnificent star-shower of the night of the 13th–14th November 1866. During a shower of meteors, if the lines of the tracks of the different meteors be projected on the sky, it is found that nearly all meet in one point. This is the vanishing point in the perspective on which their tracks are projected, and points to that region in space over which the meteors are distributed. A number of these vanishing points have been determined. Olmstead first drew attention to this inquiry regarding the distribution in space of meteoric matter, and showed that the great star-shower of November 1833 had its vanishing point in the constellation Leo. Professor Newton, America, has collected the records of the great November showers from the tenth century, from which there is evidence of eleven instances of their occurrence; and these records prove that they recur at regular intervals of thirty-three years and part of a day, the date of their occurrence having been from the 9th to the 14th November. In addition to the annual period in November, meteors also are frequently observed about the 10th of August; and, though not so common,

about 2d January, 20th April, 28th July, 24th October, and 8–13th December. These showers indicate the regions of space through which immense numbers of meteors are moving with planetary velocity; and when the earth in its motion round the sun travels through these spaces, it attracts to it many of these bodies, which, as they enter the atmosphere with a speed of thirty miles a second, are set on fire by the rapidity of their flight, like the arrow shot by Acestes—

> "Chafed by the speed, it fired; and as it flew,
> A trail of following flames ascending drew."

Meteors move in orbits variously inclined to that of the earth. Professor Herschel has particularly studied this class of bodies, and, from twenty well-observed cases, has shown that their weight varied from 30 grains to upwards of 7 lb.

474. Since they become luminous on entering the atmosphere, careful observations made at different places would give an approximate solution to the problem of the height of the atmosphere. From such observations it is supposed that the earth's atmosphere is at least one hundred miles high, and that probably, though in an extremely attenuated form, it reaches to about two hundred miles. The extraordinary quantity of latent heat in air so attenuated, becomes sensible as the air is compressed before the meteor, and thus we have a satisfactory explanation of the speedy ignition of all meteors as they traverse the atmosphere, and the rapid conversion of the smaller ones into thin mist, which in some cases remains floating in the sky for half an hour. Meteors enter the atmosphere bringing with them the temperature of the stellar spaces, which Sir John Herschel supposed to be about —239°; and since their surfaces quickly become highly heated, an explosion soon takes place from the difference of the temperatures. Such explosions, however, do not always take place; thus the meteoric mass which fell at Dhurmsala, in India, on the 14th of July 1861, was first very hot, but as the great cold of the interior of the meteor quickly counteracted the heat produced on its surface by its rapid flight through the air, it soon became so intensely cold that it could not be touched.

CHAPTER XV.

WEATHER, AND STORM-WARNINGS.

475. **Weather** is the condition of the air at any time as regards heat, moisture, wind, rain, cloud, and electricity; and a change of weather implies a change in one or more of these conditions. From the direct bearing which weather-changes have on human interests and pursuits, they have been closely observed from the earliest times, so that their approach might be predicted with some degree of confidence. The strong craving in the public mind for this knowledge is attested by the prognostics current in every language, which, amid much that is shrewd and of practical value, embody more that is vague, and not a little that is absurd. The truth is, no prediction of the weather can be made, at least in the British Islands, for more than three, or perhaps only two days beforehand; and any attempt at a longer prediction is illusory. But though no prediction of the weather weeks or months beforehand can be made with any pretension to trustworthiness, yet guesses or surmises may be formed which are not without value. All prediction based on solar or other astronomical causes, if not misleading, is useless. Investigations appear at present to point to a connection between the positions of the planets on the one hand, and the sun's spots, terrestrial magnetism, and the aurora, on the other hand. Nothing, however, could be inferred from such a connection, even were it conclusively established, that could be turned to account in predicting the weather likely to occur in a particular country within a specified time. The only safe guides we can have in attempting to forecast the weather for some time are averages based on terrestrial observations.

476. Of this class may be mentioned the *interruptions* which occur in the regular march of temperature in the course of the year. Thus, since in Scotland at least, cold weather prevails

some time in the second week of February, April, May, the last week of June, and the first week of August and November; and warm weather in the second week of July and of August, and in the beginning of December, it follows that, when at these times the weather becomes cold or warm, a continuance of such weather may be expected for a few days. These interruptions of temperature are generally either preceded or followed by stormy weather. If, after an unusual prevalence of south-west wind, or the equatorial current, cold north-easterly or easterly winds should set in, it is probable that they will prevail for some time. If the season be winter, frost, and perhaps snow, may be looked for; and if summer, the weather may be expected to become dry, warm, and bracing, particularly if the wind be E. or S.E. But suppose easterly winds have largely predominated in autumn, and south-westerly winds begin to prevail in the end of November or beginning of December, the weather is likely to continue exceptionally mild, with frequent storms of wind and rain, till about Christmas. This period occurs nearly every year, and its beginning is popularly known as St Martin's summer. On the same principle, if easterly winds preponderate largely above the average in spring, the summer is likely to be characterised by south-westerly winds, with much rain and moisture, and little sunshine; but if easterly winds nearly fail in spring, they are likely to prevail in summer, bringing in their train dry, warm, bracing weather, clear skies, and brilliant sunshine.

477. It is an opinion which has been long and popularly entertained, that the changes of the moon have so great an influence on the weather that they may be employed with confidence in prediction. That the moon's changes exercise an influence so strongly marked as to make itself almost immediately felt in bringing about fair or rainy, or settled or stormy weather, an examination of meteorological records, extending over many years, conclusively disproves.

478. The next class of prognostics are of a more certain character, being taken from those indications or appearances which experience has shown to be the precursors of changes of weather; or rather, they are the first indications or beginnings of these changes. The visible form of these crystals, known as the cirrus cloud, has already been referred to, as indicating the approach of storms. But there is one form of it which may be here adverted to, from its connection with the great atmospheric currents of the northern hemisphere. It is thus given in Dr Arthur Mitchell's

'Prognostics': "The farmers in Berwickshire say that a long strip of cloud, sometimes called by them a salmon, sometimes called Noah's ark, when it stretches through the atmosphere in an east-and-west direction, is a sign of stormy weather; but when it stretches in a north-and-south direction, is the sign of dry weather." When the cirrus cloud—the salmon or boat form being merely the effect of perspective—stretches from north to south, or, more accurately, from N.W. to S.E., atmospheric pressure is at the time, at least in regions immediately surrounding Great Britain, at the normal height; and there being thus no disturbance indicated, settled weather may be looked for. But when the cirrus stretches in bands lying east and west, or from S.W. to N.E., there is a great atmospheric disturbance indicated, pointing to a system of low pressure, the characteristic of a storm, somewhere to the west or south-west, from which a column of moist warm air is ascending and flowing as an upper current over Great Britain; and from experience we know that this current will ultimately prevail lower down, saturating the air as it descends, in preparation for the storm which is advancing. Hence, when the cirrus lies from west to east, a storm is imminent.

479. The *south-east* wind is a most valuable weather-prognostic in Great Britain. There are two totally distinct kinds of south-east wind—the one presaging stormy weather, and the other settled fine weather. The characteristics of the former are moisture and warmth, and the sky clear down to the horizon, or streaked with cirrus clouds, and then covered with clouds bringing rain. The wind itself is caused by an in-draught towards the low barometer which accompanies a storm approaching from the west, and it gradually veers to the south and west as the storm advances. The other south-east wind is accompanied with dry weather, a clear sky with haze near the horizon, and a high barometer still rising or stationary. It is the result of a higher atmospheric pressure descending over Russia and Central Europe, does not veer to the south and west, and may be considered as our only really settled fine weather.

480. Quite analogous to the above is the *north-east* wind in its relation to weather-changes. When the centre of a storm passes to the eastward at some distance south of any place, the wind which points to its approach is not a S.E. but a N.E. wind. This is particularly the case when the pressure has been for some time high in the north, which in winter occurs with protracted frosts. Hence one of the surest signs of the breaking up of a severe frost is the setting in of the N.E. wind, if it be accompanied with a falling barometer, and a green or yellowish-green tinted sky; and

it is all the more certain if the sky becomes gradually overcast, and the wind veers from N.E. to N. and N.W. It is accompanied with a fall of snow, which passes into sleet as the wind shifts into the west, and finally into rain. On the other hand, if the north-east wind be accompanied with a clear sky with haze near the horizon, and a high barometer rising or stationary, and if the wind does not increase in strength, and tends to veer rather in the direction of E. and S.E., the weather will remain settled for some time.

Storm-Warnings.

481. It is in tropical and sub-tropical countries that an isolated observer may, with the greatest degree of certainty, predict the approach of gales and hurricanes. In those regions barometric pressure and the other meteorological elements are so constant from day to day, that any deviation, even a little, from the average of the hour and season in respect of pressure, direction and strength of the wind, and the direction and amount of cloud, implies a storm at no great distance. This important practical problem has been worked out with great success by Mr Meldrum at Mauritius. At Port Louis, Mauritius, in July, the mean pressure at 32° and sea-level is 30.274 inches at 9 A.M., from which it falls to 30.186 inches at 3 P.M., it then rises to 30.236 inches at 10 P.M., and again falls to 30.192 at 4 A.M. The mean direction of the wind for the same month is from S.E. to E., generally E.S.E.; and its force about 0.41 lb. to the square foot, subject to an increase or decrease at different times of the day. Suppose now that the barometer was observed to fall after 9 A.M. with a greater rapidity than was due to the usual daily range; or that in the afternoon it did not rise to the second maximum, or that it fell instead of rising; or suppose, in short, any deviation from the observed daily march, then it is certain that there is *somewhere* an atmospherical disturbance, near enough to Mauritius to influence the pressure.

482. The direction in which the disturbance is from Mauritius is readily known from the wind. The distance of the storm may be closely approximated to by observing the rate and amount of fall of the barometer, taken in connection with the observations of the wind and the clouds. The rate and direction of the progressive motion of the storm are known chiefly from the veerings of the wind. Mr Meldrum worked at the solution of this problem for several years, and took a very effective course to test the justness of his conclusions. He laid down the path of the storm from

the Mauritius observations alone; and on afterwards receiving, from captains of vessels who had encountered the storm, a note of the latitudes and longitudes, stated, to their surprise, when and where they had the storm, and the direction and veerings of the wind during its continuance. After sufficient experience had been acquired, a note was sent to the daily newspapers when it was concluded from the Mauritius observations that a storm was abroad, stating its position and probable course from day to day. These notifications were carefully compared with the logs of ships which afterwards touched at the island. No case of failure has occurred since these notices began to be sent to the daily press. This gratifying result is of great value, since it shows what may be done at an isolated station in the ocean, or what may be done in ships at sea.

483. In regions such as Great Britain, an isolated observer cannot, with a like certainty, draw conclusions from his own observations regarding the approach of storms and other weather-changes. But he may almost, if not altogether, attain to the same degree of certainty, if he be assisted by a sufficient staff of observers, well distributed over Western Europe; and be able, when he considers it necessary, to communicate with them through the telegraph. Out of 100 warnings sent to the north coast of France during the winter of 1864-65, 71 were realised, and during that of 1865-66, 76; and out of 100 storms which occurred, 89 were signalled during the first winter, and 94 during the second winter. This result is remarkable, as showing that of the storms which occurred in the north of France during these two winters, warning of the approach of 11 out of every 12 was sent. This leads to the important result that, practically, the approach of every storm which visits Great Britain may be signalled some time before it reaches the different ports, except those in the extreme west.

484. The requisites of a system of storm-warnings are these: 1. A day-and-night watch at Valencia, in the south-west of Ireland; 2. The telegraphing to the office in London notice of storms in the north-west of France and Spain, the west of Ireland, and the west and north of Scotland, immediately on their occurrence; 3. Power to the person intrusted with the issuing of the warnings to use the telegraphic wires at his discretion, so that he may ascertain how the storm advances.

485. It is seen from Plates I. and II. that the highest atmospheric pressures are chiefly distributed over the northern hemisphere in January, and the lowest in July. If the pressure due to the elasticity of the vapour of the atmosphere was deducted from

that of the whole barometric pressure, the pressure of the dry air which remains would present this relation in a much stronger light. The causes by which the dry air should have a minimum pressure in the hottest months of the year have been already referred to.

486. ISOBARIC CHARTS of dry air for the globe, taken in connection with charts representing the whole pressure, may be regarded as the last step to be taken towards attaining a position whence the great movements of the atmosphere over the globe may be observed, and the causes of these movements satisfactorily explained. Whilst the rule is, that the minimum pressure of dry air occurs in the hottest months, there are important exceptions. Thus, in the north of Scotland the pressure of dry air is greater in summer than in winter; at Aberdeen nearly equal; but at Glasgow the pressure of the dry air is greater in winter than in summer, and at Greenwich the difference in favour of winter is still greater. In Iceland the pressure of dry air in summer exceeds that in winter in a still greater degree than in Orkney. At Sitka, in the north-west of North America, the pressure of the dry air is greater in July than in January; whereas to the south, at New Westminster, in British Columbia, the pressure of the dry air is greater in January than in July—thus showing the same peculiarity to prevail in the North Pacific that prevails in the North Atlantic.

487. This low winter pressure is explained by the ascent, and thence flowing away, through the upper currents, of the moist warm air which is poured into these regions from the respective oceans to the south of them; and the outflow is maintained at the high rate necessary to reduce the winter pressure to so marked an extent by the extraordinarily high pressures in Asia, Europe, and North America, by which they are surrounded. As the pressure falls in summer over these continents, the force, arising from the difference of the pressures, which originates and maintains the outflow, is diminished; and consequently, less air being drawn off from the North Pacific and North Atlantic in summer, the pressure is more nearly maintained at a normal height.

488. This question has important bearings on storms, particularly on the storms of Great Britain, which is situated within the southern limits of the region of most anomalous atmospheric pressure, which has its centre in Ireland. As the temperature falls in September and October, pressure is increased over the continents of Asia, Europe, and North America, and consequently air-currents are poured in upon the northern part of the Atlantic in larger volume and with accelerated velocity; and since, at the

same time, the temperature is everywhere falling, the whole atmosphere becomes saturated with vapour. This accumulated vapour is discharged in those furious storms of wind and rain which strew our shores with wrecks, and carry misery and desolation into the hearths of our seafaring population. Considering the important interests at stake, no amount of labour and no expense can be regarded as too great which might lead to a better understanding of these great atmospheric disturbances.

TABLE I.—FOR REDUCING BAROMETRIC OBSERVATIONS TO THE FREEZING-POINT (32° F.)

Temp. Fah.	ENGLISH INCHES.								Temp. Fah.
°	27	27.5	28	28.5	29	29.5	30	30.5	°
29	−.001	−.001	−.001	−.001	−.001	−.001	−.001	−.001	29
30	.004	.004	.004	.004	.004	.004	.004	.004	30
31	.006	.006	.006	.006	.007	.007	.007	.007	31
32	.008	.009	.009	.009	.009	.009	.009	.010	32
33	.011	.011	.011	.012	.012	.012	.012	.012	33
34	.013	.014	.014	.014	.014	.015	.015	.015	34
35	.016	.016	.016	.017	.017	.017	.018	.018	35
36	.018	.019	.019	.019	.020	.020	.020	.021	36
37	.021	.021	.021	.022	.022	.022	.023	.023	37
38	.023	.023	.024	.024	.025	.025	.026	.026	38
39	.025	.026	.026	.027	.027	.028	.028	.029	39
40	.028	.028	.029	.029	.030	.030	.031	.031	40
41	.030	.031	.031	.032	.033	.033	.034	.034	41
42	.033	.033	.034	.034	.035	.036	.036	.037	42
43	.035	.036	.036	.037	.038	.038	.039	.040	43
44	.037	.038	.039	.040	.040	.041	.042	.042	44
45	.040	.041	.041	.042	.043	.044	.044	.045	45
46	.042	.043	.044	.045	.045	.046	.047	.048	46
47	.045	.046	.046	.047	.048	.049	.050	.051	47
48	.047	.048	.049	.050	.051	.052	.052	.053	48
49	.050	.050	.051	.052	.053	.054	.055	.056	49
50	.052	.053	.054	.055	.056	.057	.058	.059	50
51	.054	.055	.056	.057	.058	.059	.060	.061	51
52	.057	.058	.059	.060	.061	.062	.063	.064	52
53	.059	.060	.061	.063	.064	.065	.066	.067	53
54	.062	.063	.064	.065	.066	.067	.068	.070	54
55	.064	.065	.066	.068	.069	.070	.071	.072	55
56	.066	.068	.069	.070	.071	.073	.074	.075	56
57	.069	.070	.071	.073	.074	.075	.076	.078	57
58	.071	.073	.074	.075	.077	.078	.079	.081	58
59	.074	.075	.076	.078	.079	.080	.082	.083	59
60	.076	.077	.079	.080	.082	.083	.085	.086	60
61	.078	.080	.081	.083	.084	.086	.087	.089	61
62	.081	.082	.084	.085	.087	.088	.090	.091	62
63	.083	.085	.086	.088	.089	.091	.093	.094	63
64	.086	.087	.089	.090	.092	.094	.095	.097	64
65	.088	.090	.091	.093	.095	.096	.098	.100	65
66	.090	.092	.094	.096	.097	.099	.101	.102	66
67	.093	.095	.096	.098	.100	.102	.103	.105	67
68	.095	.097	.099	.101	.102	.104	.106	.108	68
69	.098	.100	.101	.103	.105	.107	.109	.110	69
70	.100	.102	.104	.106	.108	.109	.111	.113	70
71	.102	.104	.106	.108	.110	.112	.114	.116	71
72	.105	.107	.109	.111	.113	.115	.117	.119	72
73	.107	.109	.111	.113	.115	.117	.119	.121	73
74	.110	.112	.114	.116	.118	.120	.122	.124	74
75	.112	.114	.116	.118	.120	.122	.125	.127	75
76	.114	.117	.119	.121	.123	.125	.127	.129	76
77	.117	.119	.121	.123	.126	.128	.130	.132	77
78	.119	.122	.124	.126	.128	.130	.133	.135	78
79	.122	.124	.126	.128	.131	.133	.135	.137	79
80	.124	.126	.129	.131	.133	.136	.138	.140	80
81	.126	.129	.131	.134	.136	.138	.141	.143	81
82	.129	.131	.134	.136	.138	.141	.143	.146	82
83	.131	.134	.136	.139	.141	.143	.146	.148	83
84	.134	.136	.139	.141	.144	.146	.149	.151	84
85	.136	.139	.141	.144	.146	.149	.151	.154	85
86	.138	.141	.144	.146	.149	.151	.154	.156	86
87	.141	.143	.146	.149	.151	.154	.157	.159	87
88	.143	.146	.149	.151	.154	.157	.159	.162	88
89	.146	.148	.151	.154	.156	.159	.162	.165	89
90	.148	.151	.153	.156	.159	.162	.164	.167	90

Table II.—For Converting Millimetres into English Inches and Decimals.

A millimetre equals 0.03937079 *English inch.*

Milli-metres.	Inches.	Milli-metres.	Inches.	Milli-metres.	Inches.	Milli-metres.	Inches	Milli-metres.	Inches.
661	26.024	687	27.048	713	28.071	739	29.095	765	30.119
662	26.063	688	27.087	714	28.111	740	29.134	766	30.158
663	26.103	689	27.126	715	28.150	741	29.174	767	30.197
664	26.142	690	27.166	716	28.189	742	29.213	768	30.237
665	26.182	691	27.205	717	28.229	743	29.252	769	30.276
666	26.221	692	27.245	718	28.268	744	29.292	770	30.316
667	26.260	693	27.284	719	28·308	745	29.331	771	30.355
668	26.300	694	27.323	720	28.347	746	29.371	772	30.394
669	26.339	695	27.363	721	28.386	747	29.410	773	30.434
670	26.378	696	27.402	722	28.426	748	29.449	774	30.473
671	26.418	697	27.441	723	28.465	749	29.489	775	30.512
672	26.457	698	27.481	724	28.504	750	29.528	776	30.552
673	26.497	699	27.520	725	28.544	751	29.567	777	30.591
674	26.536	700	27.560	726	28.583	752	29.607	778	30.630
675	26.575	701	27.599	727	28.623	753	29.646	779	30.670
676	26.615	702	27.638	728	28.662	754	29.686	780	30.709
677	26.654	703	27.678	729	28.701	755	29.725	781	30.749
678	26.693	704	27.717	730	28.741	756	29.764	782	30.788
679	26.733	705	27.756	731	28.780	757	29.804	783	30.827
680	26.772	706	27.796	732	28.819	758	29.843	784	30.867
681	26.812	707	27.835	733	28.859	759	29.882	785	30.906
682	26.851	708	27.875	734	28.898	760	29.922	786	30.945
683	26.890	709	27.914	735	28.938	761	29.961	787	30.985
684	26.930	710	27.953	736	28.977	762	30.001	788	31.024
685	26.969	711	27.993	737	29.016	763	30.040	789	31.064
686	27.008	712	28.032	738	29.056	764	30.079	790	31.103

Tenths of a Millimetre in the Decimal of an Inch.

0	1	2	3	4	5	6	7	8	9
0.000	0.004	0.008	0.012	0.016	0.020	0.024	0.028	0.031	0.035

Table III.—For Converting French or Paris Lines into English Inches.

A Paris Line equals 0.088814 *English Inch.*

Paris Lines.	English Inches.	Paris Lines.	English. Inches.	Paris Lines.	English Inches.	Paris Lines.	English Inches.	Paris Lines.	English Inches.
288.0	25.578	300.0	26.644	312.0	27.710	324.0	28.776	336.0	29.842
288.5	25.623	300.5	26.689	312.5	27.754	324.5	28.820	336.5	29.886
289.0	25.667	301.0	26.733	313.0	27.799	325.0	28.865	337.0	29.930
289.5	25.712	301.5	26.777	313.5	27.843	325.5	28.909	337.5	29.975
290.0	25.756	302.0	26.822	314.0	27.888	326.0	28.953	338.0	30.019
290.5	25.800	302.5	26.866	314.5	27.932	326.5	28.998	338.5	30.064
291.0	25.845	303.0	26.911	315.0	27.976	327.0	29.042	339.0	30.108
291.5	25.889	303.5	26.955	315.5	28.021	327.5	29.087	339.5	30.152
292.0	25.934	304.0	26.999	316.0	28.065	328.0	29.131	340.0	30.197
292.5	25.978	304.5	27.044	316.5	28.110	328.5	29.175	340.5	30.241
293.0	26.023	305.0	27.088	317.0	28.154	329.0	29.220	341.0	30.286
293.5	26.067	305.5	27.133	317.5	28.198	329.5	29.264	341.5	30.330
294.0	26.111	306.0	27.177	318.0	28.243	330.0	29.309	342.0	30.374
294.5	26.156	306.5	27.221	318.5	28.287	330.5	29.353	342.5	30.419
295.0	26.200	307.0	27.266	319.0	28.332	331.0	29.397	343.0	30.463
295.5	26.245	307.5	27.310	319.5	28.376	331.5	29.442	343.5	30.508
296.0	26.289	308.0	27.355	320.0	28.420	332.0	29.486	344.0	30.552
296.5	26.333	308.5	27.399	320.5	28.465	332.5	29.531	344.5	30.596
297.0	26.378	309.0	27.444	321.0	28.509	333.0	29.575	345.0	30.641
297.5	26.422	309.5	27.488	321.5	28.554	333.5	29.619	345.5	30.685
298.0	26.467	310.0	27.532	322.0	28.598	334.0	29.664	346.0	30.730
298.5	26.511	310.5	27.577	322.5	28.643	334.5	29.708	346.5	30.774
299.0	26.555	311.0	27.621	323.0	28.687	335.0	29.753	347.0	30.818
299.5	26.600	311.5	27.666	323.5	28.731	335.5	29.797	347.5	30.863

Hundredths of a Line.

	English Inch.		English Inch.		English Inch.		English Inch.		English Inch.
1	.001	11	.010	21	.019	31	.028	41	.037
2	.002	12	.011	22	.020	32	.029	42	.038
3	.003	13	.012	23	.021	33	.030	43	.039
4	.004	14	.013	24	.022	34	.031	44	.040
5	.004	15	.013	25	.022	35	.031	45	.040
6	.005	16	.014	26	.023	36	.032	46	.041
7	.006	17	.015	27	.024	37	.033	47	.042
8	.007	18	.016	28	.025	38	.034	48	.043
9	.008	19	.017	29	.026	39	.035	49	.044
10	.009	20	.018	30	.027	40	.036	50	.045

TABLE IV.—FOR REDUCING BAROMETRIC OBSERVATIONS TO THE LEVEL OF THE SEA; AND CONVERSELY, FOR THE DETERMINATION OF HEIGHTS BY THE BAROMETER.

Height in feet.	MEAN TEMPERATURE OF THE AIR.										Differences.
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	
	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
10	.012	.012	.012	.011	.011	.011	.011	.011	.010	.010	.000
20	.025	.024	.023	.023	.022	.022	.022	.021	.021	.020	.001
30	.037	.036	.035	.034	.034	.033	.032	.032	.031	.030	.001
40	.049	.048	.047	.046	.045	.044	.043	.042	.041	.040	.001
50	.061	.060	.059	.057	.056	.055	.054	.053	.052	.051	.002
60	.074	.072	.070	.069	.067	.066	.065	.063	.062	.061	.002
70	.086	.084	.082	.080	.079	.077	.075	.074	.072	.071	.003
80	.098	.096	.094	.092	.090	.088	.086	.084	.083	.081	.003
90	.110	.108	.106	.103	.101	.099	.097	.095	.093	.091	.003
100	.123	.120	.117	.115	.112	.110	.108	.105	.103	.101	.004
110	.135	.132	.129	.126	.124	.121	.118	.116	.114	.111	.004
120	.148	.144	.141	.138	.135	.132	.129	.126	.124	.121	.004
130	.160	.156	.153	.149	.146	.143	.139	.137	.134	.131	.005
140	.172	.168	.164	.160	.157	.154	.150	.147	.144	.141	.005
150	.184	.179	.175	.171	.168	.165	.160	.157	.154	.151	.006
160	.196	.191	.187	.183	.179	.175	.171	.168	.164	.161	.006
170	.208	.203	.198	.194	.190	.186	.182	.178	.175	.171	.006
180	.220	.215	.200	.206	.201	.197	.192	.189	.185	.181	.007
190	.232	.227	.222	.217	.212	.208	.203	.199	.195	.191	.007
200	.244	.238	.233	.228	.223	.218	.213	.209	.205	.201	.007
210	.256	.250	.245	.239	.234	.229	.224	.219	.215	.211	.008
220	.268	.262	.256	.250	.245	.240	.235	.230	.225	.221	.008
230	.280	.273	.268	.261	.255	.250	.245	.240	.235	.231	.008
240	.292	.285	.279	.272	.266	.261	.256	.250	.245	.241	.009
250	.305	.297	.290	.284	.278	.272	.266	.260	.255	.250	.009
260	.316	.309	.302	.295	.289	.283	.277	.271	.265	.260	.009
270	.328	.320	.313	.306	.299	.293	.287	.281	.275	.270	.010
280	.340	.332	.325	.317	.310	.304	.298	.291	.285	.280	.010
290	.353	.344	.336	.329	.322	.315	.308	.302	.296	.290	.010
300	.365	.356	.348	.340	.333	.326	.319	.312	.306	.300	.011
310	.377	.368	.360	.352	.344	.337	.329	.322	.316	.310	.011
320	.389	.380	.372	.363	.355	.348	.340	.333	.326	.320	.012
330	.401	.391	.383	.374	.366	.358	.350	.343	.336	.329	.012
340	.413	.403	.394	.385	.377	.369	.361	.354	.346	.339	.012
350	.425	.415	.406	.397	.388	.380	.371	.364	.356	.349	.013
360	.438	.427	.417	.408	.399	.390	.382	.374	.366	.359	.013
370	.450	.439	.429	.419	.410	.401	.392	.384	.376	.369	.013
380	.462	.451	.440	.430	.421	.412	.402	.394	.386	.378	.014
390	.474	.463	.452	.442	.432	.422	.413	.405	.396	.388	.014
400	.486	.475	.464	.453	.443	.433	.424	.415	.407	.398	.014
410	.498	.487	.475	.464	.454	.444	.434	.425	.417	.408	.015
420	.510	.498	.486	.475	.465	.455	.444	.435	.427	.418	.015
430	.522	.509	.497	.486	.476	.465	.455	.446	.437	.427	.015
440	.534	.521	.509	.497	.487	.476	.465	.456	.447	.437	.016
450	.546	.532	.520	.508	.498	.487	.476	.466	.457	.447	.016
460	.558	.544	.532	.520	.509	.498	.486	.477	.467	.457	.017
470	.570	.556	.543	.531	.520	.508	.497	.487	.477	.467	.017
480	.581	.568	.555	.542	.530	.519	.507	.497	.487	.477	.018
490	.593	.579	.566	.553	.541	.529	.518	.507	.497	.486	.018
500	.605	.591	.577	.564	.551	.539	.528	.517	.507	.496	.018

TABLE IV.—*continued.*

Height in feet.	Mean Temperature of the Air.										Differences.
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	
	Inch.	Inch.	Inch	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
510	.617	.602	.588	.575	.562	.550	.538	.527	.516	.506	.018
520	.629	.614	.600	.586	.573	.561	.549	.537	.526	.515	.019
530	.640	.625	.611	.597	.584	.571	.559	.547	.536	.525	.019
540	.652	.637	.622	.608	.594	.581	.569	.557	.546	.535	.019
550	.664	.648	.633	.619	.605	.592	.579	.567	.556	.545	.020
560	.676	.660	.644	.629	.615	.602	.589	.577	.565	.554	.020
570	.688	.672	.656	.641	.626	.613	.600	.587	.575	.564	.020
580	.699	.683	.667	.652	.637	.623	.610	.597	.585	.573	.021
590	.711	.694	.678	.663	.648	.634	.620	.607	.595	.583	.021
600	.723	.706	.690	.674	.659	.644	.631	.617	.605	.592	.021
610	.734	.717	.701	.685	.670	.655	.641	.627	.614	.602	.022
620	.746	.729	.712	.696	.680	.665	.651	.637	.624	.611	.022
630	.758	.740	.723	.707	.691	.676	.661	.647	.634	.621	.023
640	.770	.752	.735	.718	.702	.686	.671	.657	.644	.631	.023
650	.782	.764	.746	.729	.713	.697	.682	.667	.653	.640	.023
660	.794	.775	.757	.740	.723	.707	.692	.677	.663	.650	.024
670	.806	.787	.768	.751	.734	.718	.702	.687	.673	.659	.024
680	.818	.798	.779	.762	.744	.729	.712	.697	.683	.669	.024
690	.830	.810	.791	.773	.755	.739	.723	.708	.693	.679	.025
700	.842	.822	.803	.784	.766	.749	.733	.718	.703	.689	.025
710	.853	.833	.814	.795	.777	.760	.743	.728	.713	.698	.025
720	.865	.844	.824	.805	.787	.770	.753	.738	.722	.707	.026
730	.876	.855	.835	.816	.798	.780	.763	.748	.732	.717	.026
740	.888	.867	.846	.826	.808	.791	.774	.758	.742	.726	.026
750	.900	.878	.857	.837	818	.801	.784	.768	.752	.736	.027
760	.911	.889	.868	.848	.829	.811	.794	.777	.761	.746	.027
770	.923	.901	.879	.859	.840	.822	.804	.787	.771	.755	.027
780	.935	.913	.891	.870	.851	.832	.814	.797	.781	.765	.028
790	.947	.924	.902	.881	.862	.843	.825	.807	.791	.775	.028
800	.959	.936	.914	.893	.873	.853	.835	.817	.801	.785	.028
810	.970	.947	.925	.904	.883	.864	.845	.827	.810	.794	.029
820	.982	.958	.935	.914	.894	.874	.855	.837	.820	.804	.029
830	.994	.970	.947	.925	.904	.884	.865	.847	.830	.813	.029
840	1.005	.981	.958	.936	.015	.895	.876	.857	.839	.822	.030
850	1.017	.992	.969	.947	.925	.905	.886	.867	.849	.831	.030
860	1.028	1.003	.979	.957	.936	.915	.896	.876	.858	.840	.030
870	1.040	1.015	.991	.968	.946	.925	.906	.886	.868	.850	.031
880	1.051	1.026	1.002	.979	.957	.936	.916	.896	.877	.859	.031
890	1.063	1.037	1.013	.990	.968	.946	.926	.906	.887	.869	.032
900	1.075	1.049	1.024	1.001	.979	.957	.936	.916	.897	.879	.032
910	1.086	1.060	1.035	1.012	.989	.967	.946	.926	.906	.888	.032
920	1.098	1.071	1.046	1.022	.999	.977	.956	.935	.916	.897	.033
930	1.109	1.082	1.056	1.033	1.010	.988	.966	.945	.925	.906	.033
940	1.120	1.093	1.067	1.043	1.020	.998	.976	.955	.935	.916	.033
950	1.132	1.105	1.079	1.054	1.030	1.008	.986	.965	.945	.925	.034
960	1.144	1.116	1.090	1.065	1.041	1.018	.996	.975	.954	.935	.034
970	1.155	1.128	1.101	1.076	1.052	1.029	1.006	.985	.964	.944	.034
980	1.167	1.139	1.112	1.087	1.063	1.040	1.017	.995	.974	.954	.035
990	1.178	1.150	1.123	1.098	1.073	1.050	1.027	1.005	.983	.963	.035
1000	1.190	1.161	1.134	1.108	1.084	1.060	1.037	1.015	.993	.972	.035

TABLE V.—COMPARISON OF THE CENTIGRADE THERMOMETER WITH FAHRENHEIT'S AND REAUMUR'S, GIVING THE CORRESPONDING VALUES FOR EACH DEGREE, FROM +50° TO —41° CENTIGRADE.

Cent.	Fahr.	Reau.	Cent.	Fahr.	Reau.	Cent.	Fahr.	Reau.	Cent.	Fahr.	Reau.
°	°	°	°	°	°	°	°	°	°	°	°
50	122.0	40.0	27	80.6	21.6	4	39.2	3.2	—19	— 2.2	—15.2
49	120.2	39.2	26	78.8	20.8	3	37.4	2.4	—20	— 4.0	—16.0
48	118.4	38.4	25	77.0	20.0	2	35.6	1.6	—21	— 5.8	—16.8
47	116.6	37.6	24	75.2	19.2	1	33.8	0.8	—22	— 7.6	—17.6
46	114.8	36.8	23	73.4	18.4	0	32.0	0.0	—23	— 9.4	—18.4
45	113.0	36.0	22	71.6	17.6	— 1	30.2	— 0.8	—24	—11.2	—19.2
44	111.2	35.2	21	69.8	16.8	— 2	28.4	— 1.6	—25	—13.0	—20.0
43	109.4	34.4	20	68.0	16.0	— 3	26.6	— 2.4	—26	—14.8	—20.8
42	107.6	33.6	19	66.2	15.2	— 4	24.8	— 3.2	—27	—16.6	—21.6
41	105.8	32.8	18	64.4	14.4	— 5	23.0	— 4.0	—28	—18.4	—22.4
40	104.0	32.0	17	62.6	13.6	— 6	21.2	— 4.8	—29	—20.2	—23.2
39	102.2	31.2	16	60.8	12.8	— 7	19.4	— 5.6	—30	—22.0	—24.0
38	100.4	30.4	15	59.0	12.0	— 8	17.6	— 6.4	—31	—23.8	—24.8
37	98.6	29.6	14	57.2	11.2	— 9	15.8	— 7.2	—32	—25.6	—25.6
36	96.8	28.8	13	55.4	10.4	—10	14.0	— 8.0	—33	—27.4	—26.4
35	95.0	28.0	12	53.6	9.6	—11	12.2	— 8.8	—34	—29.2	—27.2
34	93.2	27.2	11	51.8	8.8	—12	10.4	— 9.6	—35	—31.0	—28.0
33	91.4	26.4	10	50.0	8.0	—13	8.6	—10.4	—36	—32.8	—28.8
32	89.6	25.6	9	48.2	7.2	—14	6.8	—11.2	—37	—34.6	—29.6
31	87.8	24.8	8	46.4	6.4	—15	5.0	—12.0	—38	—36.4	—30.4
30	86.0	24.0	7	44.6	5.6	—16	3.2	—12.8	—39	—38.2	—31.2
29	84.2	23.2	6	42.8	4.8	—17	1.4	—13.6	—40	—40.0	—32.0
28	82.4	22.4	5	41.0	4.0	—18	—0.4	—14.4	—41	—41.8	—32.8

Comparison of the Scales for each Tenth of a Degree.

Cent. . .	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Fahr. . .	0.18	0.36	0.54	0.72	0.9	1.08	1.26	1.44	1.62	1.8
Reau. . .	0.08	0.16	0.24	0.32	0.4	0.48	0.56	0.64	0.72	0.8
Fahr. . .	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Cent. . .	0.06	0.11	0.17	0.22	0.28	0.33	0.39	0.44	0.5	0.56
Reau. . .	0.04	0.09	0.13	0.18	0.22	0.27	0.31	0.36	0.4	0.44
Reau. . .	0.1	0.2	0.3	0 4	0.5	0.6	0.7	0.8	0.9	1.0
Fahr. . .	0.22	0.45	0.67	0.9	1.12	1.35	1.57	1.80	2.02	2.25
Cent. . .	0.12	0.25	0.37	0.5	0.62	0.75	0.87	1.00	1.12	1.25

TABLE VI.—SHOWING THE ELASTIC FORCE OF AQUEOUS VAPOUR, IN INCHES OF MERCURY, FROM 0° TO 80°, calculated from the Experiments of Regnault.

From Mr Glaisher's Hygrometric Tables.

The intermediate tenths of degrees may be easily interpolated.

Temp.	Force of vapour.	Temp.	Force of vapour	Temp.	Force of vapour.	Temp.	Force of vapour.	Temp.	Force of vapour.
°	Inch.	°	Inch.	°	Inch.	°	Inch.	°	Inch.
0	.044	29.5	.163	39.7	.244	47.3	.327	54.7	.428
1	.046	30.0	.167	40.0	.247	47.5	.329	55.0	.433
2	.048	30.5	.170	40.3	.250	47.7	.331	55.5	·441
3	.050	31.0	.174	40.5	.252	48.0	.335	56.0	.449
4	.052	31.5	.177	40.7	.254	48.3	.339	56.5	.457
5	.054	32.0	.181	41.0	.257	48.5	.342	57.0	.465
6	.057	32.5	.184	41.3	.260	48.7	.344	57.5	.473
7	.060	33.0	.188	41.5	.262	49.0	.348	58.0	.482
8	.062	33.5	.192	41.7	.264	49.3	.352	59.0	.500
9	.065	34.0	.196	42.0	.267	49.5	.355	60.0	.518
10	.068	34.5	.199	42.3	.270	49.7	.357	61.0	.537
11	.071	35.0	.204	42.5	.272	50.0	.361	62.0	.556
12	.074	35.3	.206	42.7	.274	50.3	.365	63.0	.576
13	.078	35.5	.208	43.0	.277	50.5	.367	64.0	.596
14	.082	35.7	.209	43.3	.280	50.7	.370	65.0	.617
15	.086	36.0	.212	43.5	.283	51.0	.374	66.0	.639
16	.090	36.3	.214	43.7	.285	51.3	.378	67.0	.661
17	.094	36.5	.216	44.0	.288	51.5	.381	68.0	.684
18	.098	36.7	.218	44.3	.292	51.7	.384	69.0	.708
19	.103	37.0	.220	44.5	.294	52.0	.388	70.0	.733
20	.108	37.3	.223	44.7	.296	52.3	.393	71.0	.759
21	.113	37.5	.225	45.0	.299	52.5	.396	72.0	.785
22	.118	37.7	.226	45.3	.303	52.7	.399	73.0	.812
23	.123	38.0	.229	45.5	.305	53.0	.403	74.0	.840
24	.129	38.3	.231	45.7	.307	53.3	.407	75.0	.868
25	.135	38.5	.233	46.0	.311	53.5	.410	76.0	.897
26	.141	38.7	.235	46.3	.315	53.7	.413	77.0	.927
27	.147	39.0	.238	46.5	.317	54.0	.418	78.0	.958
28	.153	39.3	.240	46.7	.319	54.3	.422	79.0	.990
29	.160	39.5	.242	47.0	.323	54.5	.425	80.0	1.023

Table VII.—Factors for Multiplying the Excess of the Dry-bulb Thermometer over that of the Wet-bulb, to find the Excess of the Temperature of the Air above that of the Dew-point.

From Mr Glaisher's Hygrometric Tables.

Dry-bulb Ther.	Factor.	Dry-bulb Ther.	Factor.	Dry-bulb Ther.	Factor.	Dry-bulb Ther.	Factor.	Dry-bulb Ther.	Factor.
°		°		°		°		°	
10	8.78	28	5.12	46	2.14	64	1.83	82	1.67
11	8.78	29	4.63	47	2.12	65	1.82	83	1.67
12	8.78	30	4.15	48	2.10	66	1.81	84	1.66
13	8.77	31	3.70	49	2.08	67	1.80	85	1.65
14	8.76	32	3.32	50	2.06	68	1.79	86	1.65
15	8.75	33	3.01	51	2.04	69	1.78	87	1.64
16	8.70	34	2.77	52	2.02	70	1.77	88	1.64
17	8.62	35	2.60	53	2.00	71	1.76	89	1.63
18	8.50	36	2.50	54	1.98	72	1.75	90	1.63
19	8.34	37	2.42	55	1.96	73	1.74	91	1.62
20	8.14	38	2.36	56	1.94	74	1.73	92	1.62
21	7.88	39	2.32	57	1.92	75	1.72	93	1.61
22	7.60	40	2.29	58	1.90	76	1.71	94	1.60
23	7.28	41	2.26	59	1.89	77	1.70	95	1.60
24	6.92	42	2.23	60	1.88	78	1.69	96	1.59
25	6.53	43	2.20	61	1.87	79	1.69	97	1.59
26	6.08	44	2.18	62	1.86	80	1.68	98	1.58
27	5.61	45	2.16	63	1.85	81	1.68	99	1.58
								100	1.57

TABLE VIII.—FOR COMPARING THE PRESSURE AND THE VELOCITY OF THE WIND. Calculated from the Formulæ, $V^2 \times .005 = P$; and $\sqrt{200 \times P} = V$.

From Instructions for taking Meteorological Observations, by Colonel Sir Henry James, R.E., F.R.S., &c.

Oz. per square foot.	Miles per hour.	lb. per square foot.	Miles per hour.	lb. per square foot.	Miles per hour.	lb. per square foot.	Miles per hour.	lb. per square foot.	Miles per hour.
0.25	1.77	1.	14.14	4.50	30.00	11	46.90	24	69.28
0.50	2.50	1.25	15.81	5.	31.62	12	48.99	26	72.11
0.75	3.06	1.50	17.32	5.50	33.17	13	50.99	28	74.83
1.	3.54	1.75	18.71	6.	34.64	14	52.92	30	77.46
2.	5.00	2.	20.00	6.50	36.06	15	54.77	32	80.00
3.	6.12	2.25	21.21	7.	37.42	16	56.57	34	82.46
4.	7.07	2.50	22.36	7.50	38.73	17	58.31	36	84.85
5.	7.90	2.75	23.45	8.	40.00	18	60.00	38	87.18
6.	8.66	3.	24.49	8.50	41.23	19	61.64	40	89.44
8.	10.00	3.25	25.50	9.	42.43	20	63.24	42	91.65
10.	11.18	3.50	26.46	9.50	43.59	21	64.81	45	94.87
12.	12.25	3.70	27.39	10.	44.72	22	66.33	48	97.98
14.	13.23	4.	28.28	10.50	45.82	23	67.82	50	100.00

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⁂ *The figures, unless where otherwise expressed, refer to paragraphs, and not to pages.*

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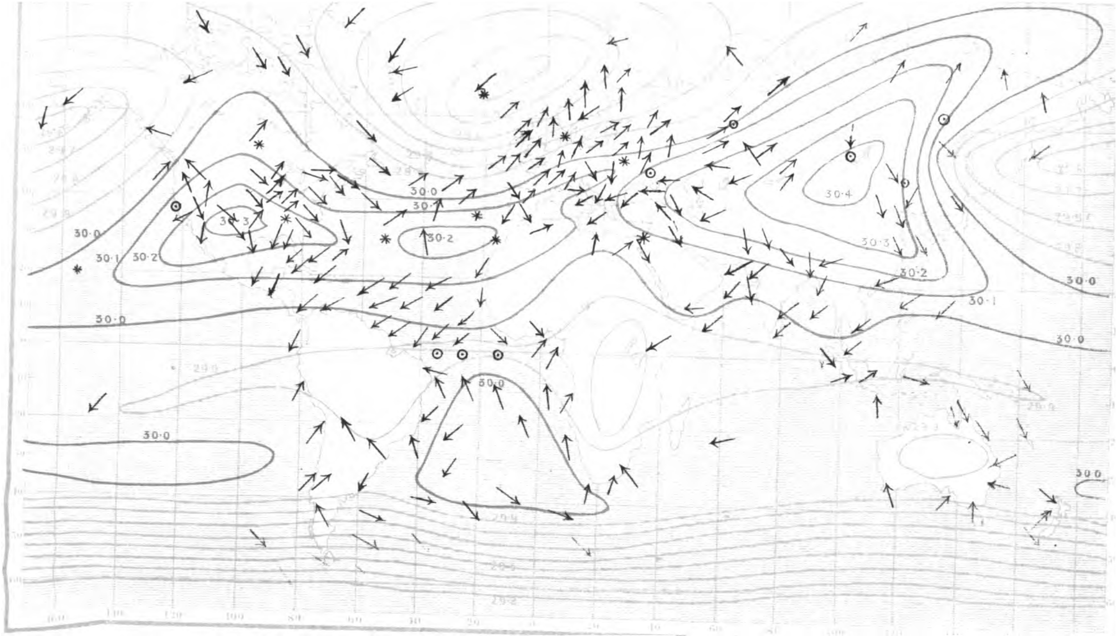
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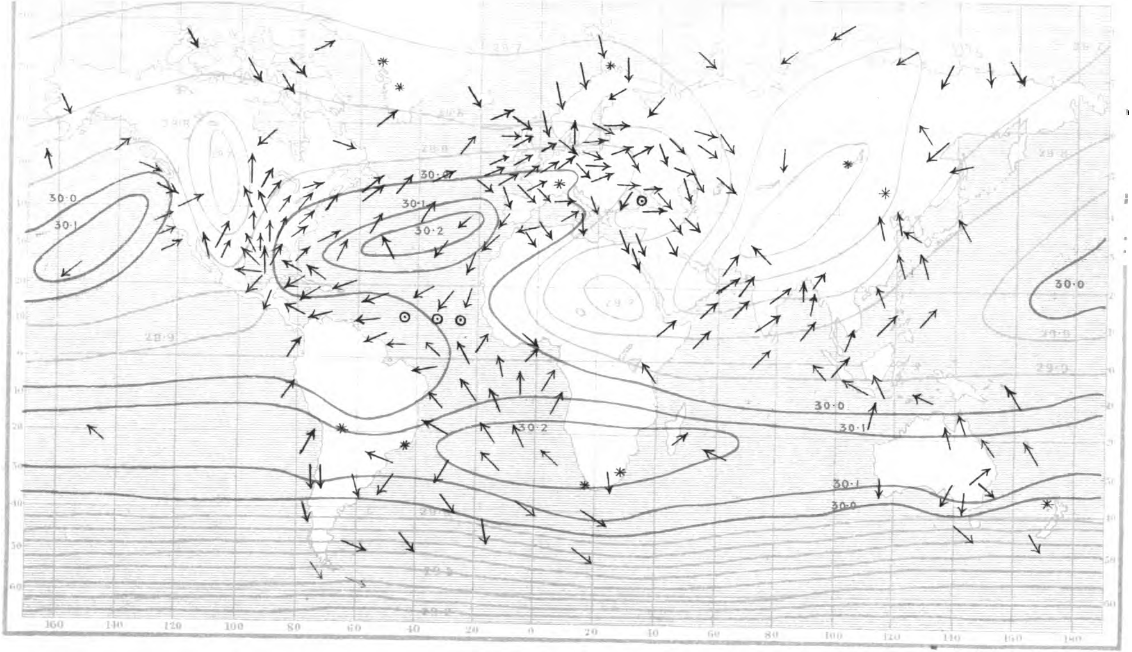
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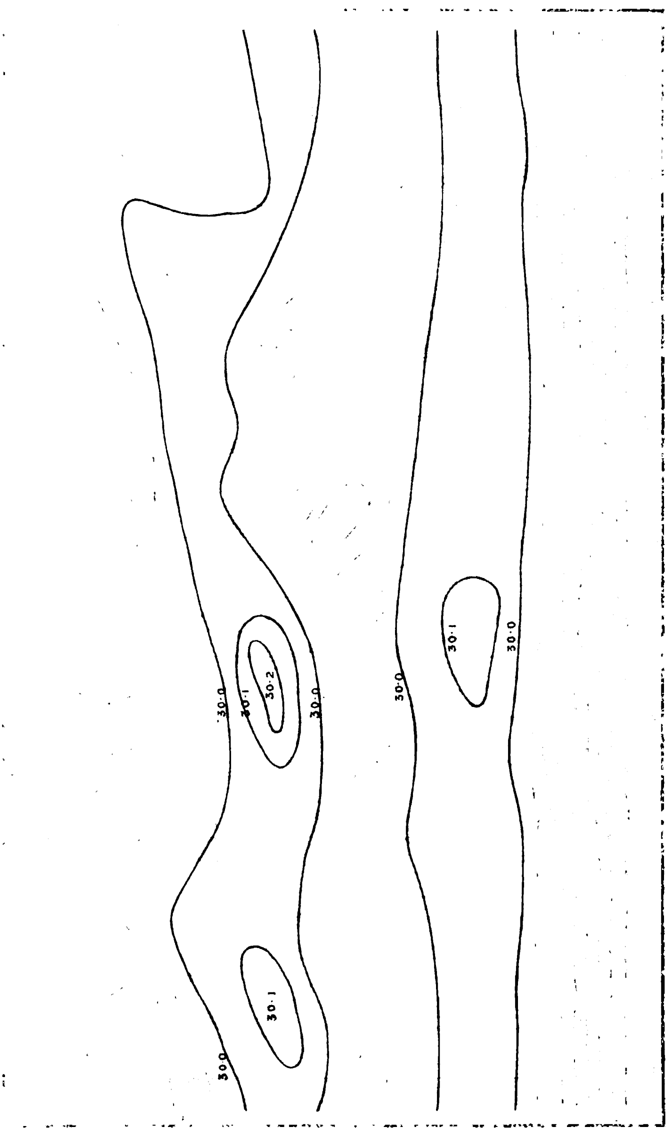
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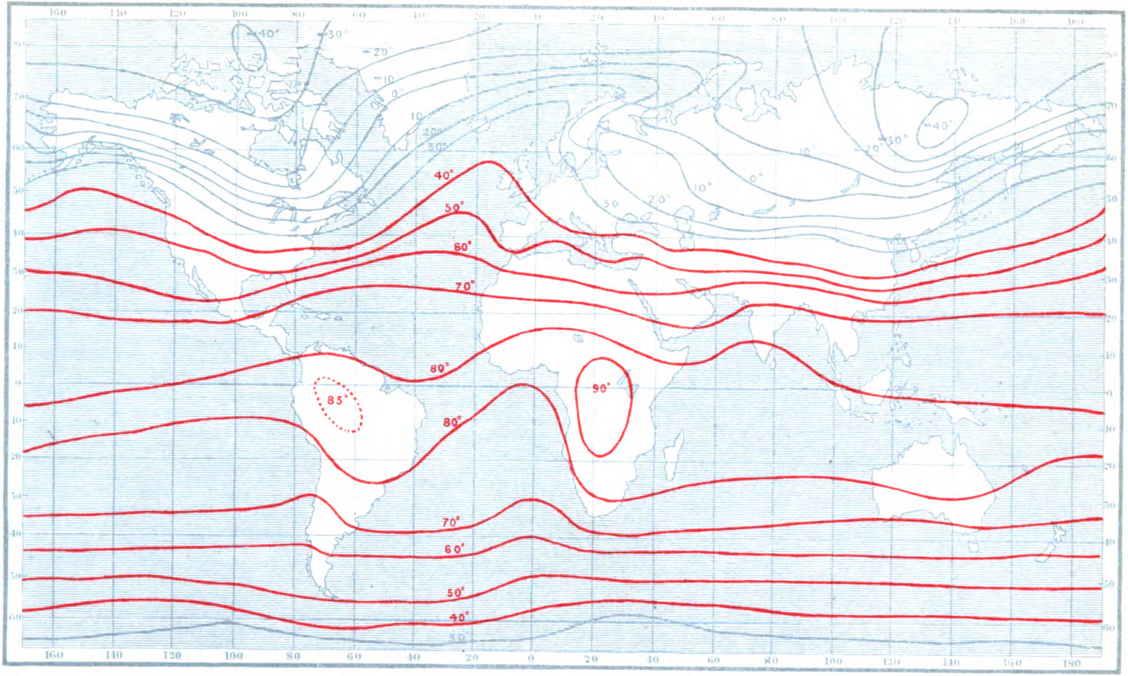

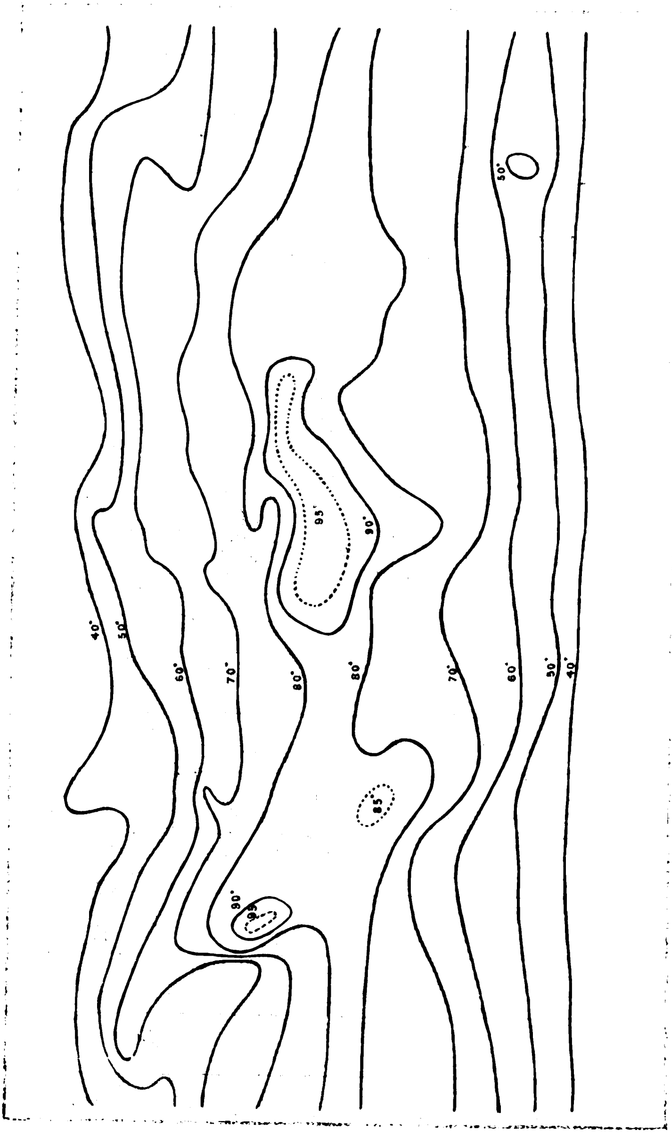
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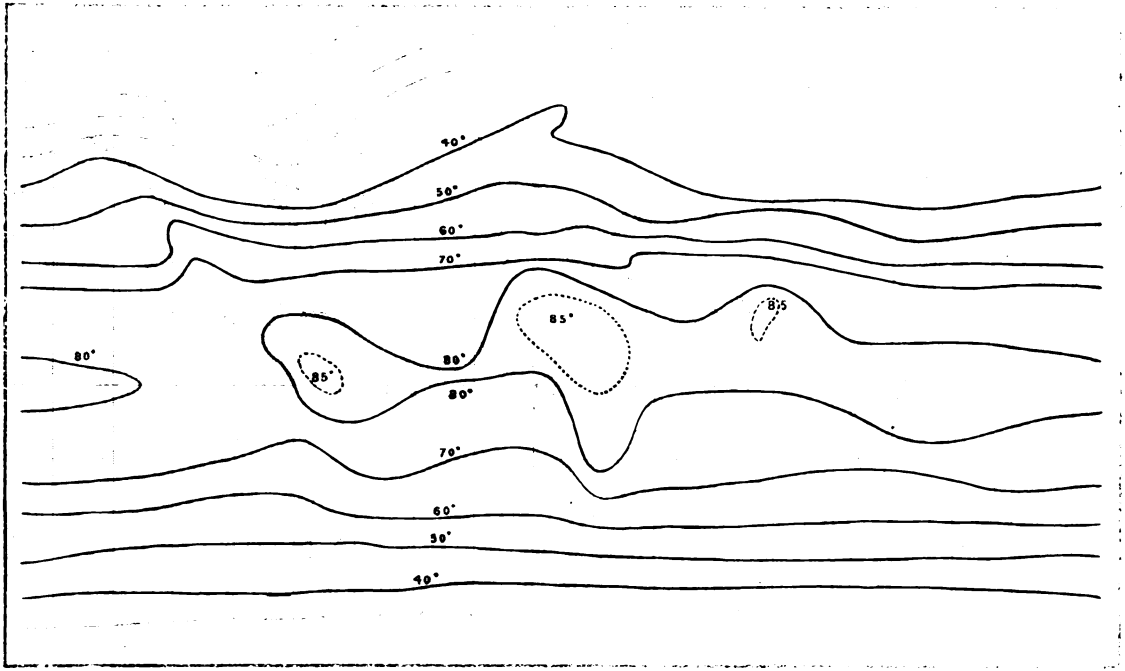
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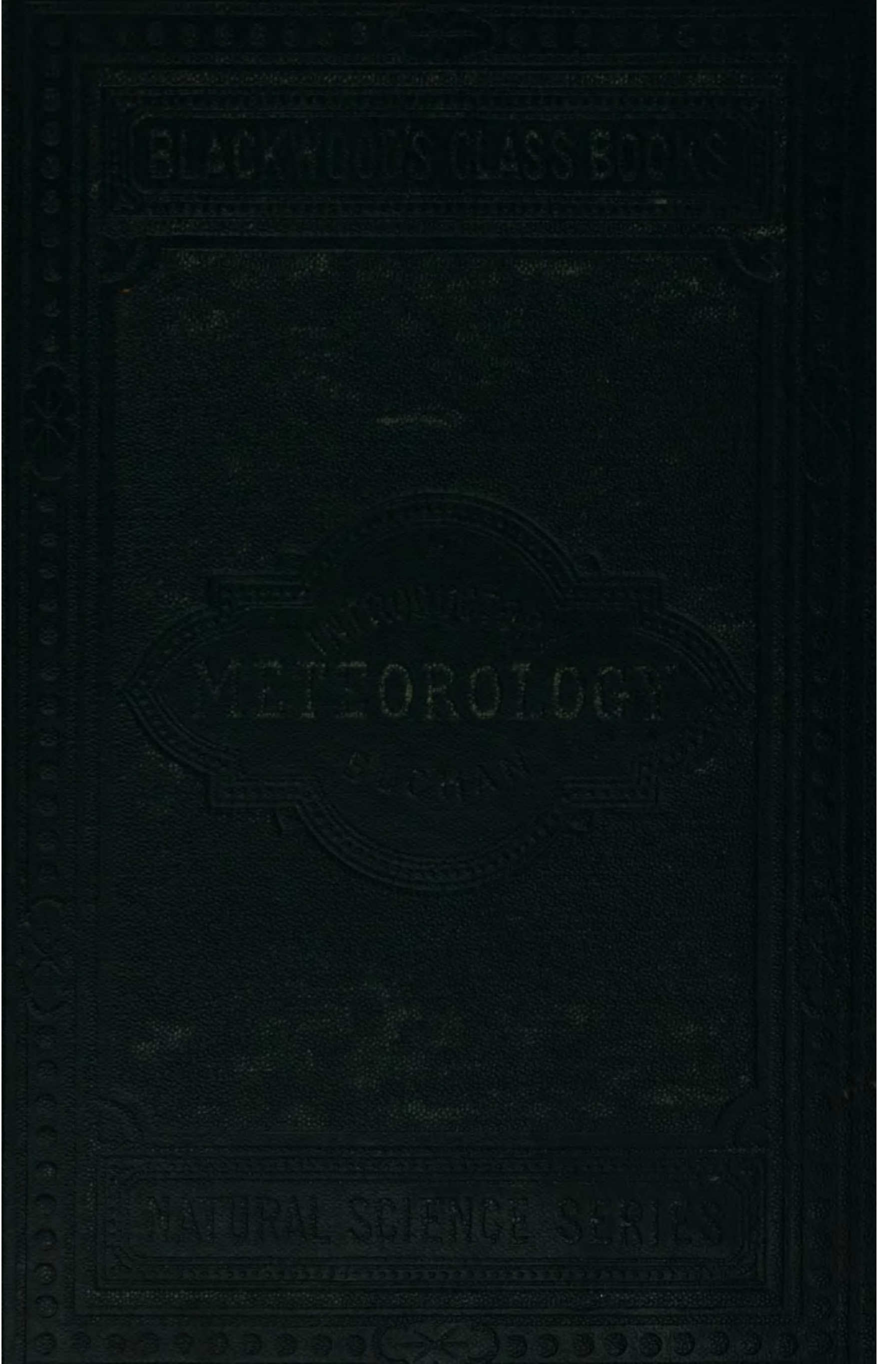

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