HANDY BOOK

OF

METEOROLOGY

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PREFACE TO THE SECOND EDITION.

THE object which the author of this treatise has kept steadily in view has been to set the subject of Meteorology before the general mind in such a way as shall engage on its behalf a widespread interest, to which, from its intimate connection with our welfare and happiness, it is in every way entitled. Frequent occasion is taken to point out the bearings of the science on the practical affairs of life. The information is brought down to the present time, thus rendering it a handy book of reference on subjects connected with weather and climate.

The Isothermal Charts for July, January, and the year, Plates IV., V., and VI., have been adapted from Dové's Monthly and Yearly Isothermals, 1864, and the same author's Charts given in 'The Distribution of Heat over the Surface of the Globe, 1853.'

The Isobarometric Charts for July, January, and the year, Plates I., II., and III., are new. They formed the subject of a paper read before the Royal Society of Edinburgh on the 16th March 1868. The mode of their construction is described in the text. Though the first attempts at the construction of such charts, they may be regarded as close approximations to the statement of the atmospheric pressure of the globe, owing to the comparatively large number of places from which barometric observations have been obtained, and to the circumstance that fewer places are required to represent the pressure over any portion of the earth's surface than are required to show the temperature, the winds, or the rainfall.

Since the information conveyed by isobarometric charts forms the basis of Meteorology, it has been necessary, in preparing this edition for the press, to recast the greater part of the work. The chapters on "The Distribution of Atmospheric Pressure over the Globe," and "The Relation of Atmospheric Pressure to the Temperature," are wholly new, and the Chapter on "Winds" is almost altogether new. The intimate connection of temperature with pressure is illustrated by the exceptional weather of last year (1867), the chief instances adduced being the mild weather of February; the unprecedentedly cold weather of March, which proved so injurious to vegetation; the cold weather of July, so disastrous in its effects on the crops; and the singularly fine weather of November. The great frost of Christmas 1860, the warm weather of September 1866, and the cold weather in the south of Europe in January 1868, are considered in the same relations. Attention is thus directed to the proximate causes of exceptional weather, and remarks are made with the view of suggesting how this knowledge may be turned to practical account. The importance of Iceland as the key to the climates of the greater part of North America and Europe is pointed out.

The subject of STORMS is more specially discussed, as being, from the practical application of the results of the inquiry to the prediction of storms, and consequently to the saving of life and property, a question the importance of which it would be difficult to overestimate. As the subject has been considered from the observational side, it follows that the law of storms, so far as enunciated, is to be regarded not as mere theory, but as the result of generalisations of observed facts. In the few cases where theoretical opinions are advanced, their theoretical nature is distinctly stated. The proximate cause of high winds is illustrated by the Great Hurricane which was so severely felt at Edinburgh on the 24th January 1868. The observations made by observers of the Scottish Meteorological Society at the time, supplied the materials for placing the relation of wind-force to differences of pressure in a very clear light. A new chapter has been added on " Weather and Storm-Warnings."

Other features of storms yet remaining to be investigated, and many undetermined points, in reference particularly to the diathermancy and distribution of the aqueous vapour of the atmosphere, solar and terrestrial radiation, the temperature of the soil, and ocean meteorology, are stated, in order that the attention of meteorologists may be directed to the most fruitful fields of research which the science presents.

Meteorology has been too long treated with neglect, both in popular and in liberal systems of education. In the popular education of this country it cannot be said to hold a place; and even in a University course, though classed among the subjects embraced by Natural Philosophy, its position in the curriculum of studies is little more than nominal. The causes of this neglect are not far to seek:—the chief being the absurd pretensions of weather-prophets and other prognosticators; the free and bad use long made of electricity and other imperfectly understood agents to explain the causes of atmospheric disturbances; the fewness of the observed facts in comparison with the vastness of the weather-changes they were adduced to explain; but above all, the real difficulty of the subject, owing to the manifold influences in operation. But now that Meteorology has discarded all pretensions and theories, except in so far as the latter are the legitimate result of observation, it has acquired rapid development, and established its claim to be regarded as the youngest of the sciences.

In consequence of this, a great and growing interest on the subject is spreading among all classes, as is evinced by the number of meteorological instruments purchased, by the many zealous and self-denying observers in all parts of the civilised world, and by the still more numerous class who volunteer their services as observers. But since a knowledge of the elementary principles of Meteorology is not yet very generally diffused, much time and labour are often wasted from the use of imperfect instruments and imperfect methods of observation. To meet this want, the author has particularly described the various instruments in use, given directions for placing them in situations and in positions best suited for observation, pointed out how they are liable to get out of order, and explained the methods by which they may be put right when they happen to go wrong. The methods of reducing Meteorological Observations are explained at length, and tables are given for facilitating the work.

DIRECTIONS TO METEOROLOGICAL OBSERVERS IN REGARD TO THE PUBLICATION OF THEIR STATISTICS.—The height of barometers above the level of the sea, accurately ascertained, is a serious desideratum in not a few published abstracts of Meteorological Observations. The labour which, in preparing this edition, the omission, or rough and incorrect statements, of heights has occasioned, has been excessive. In many cases it was necessary to ascertain the heights, or check those given, by the method of the barometric measurement of heights—viz., by selecting a number of days during which the barometer remained steady over the region in which the place was situated, and then calculating the height from the pressure and temperature at the place as compared with places in the vicinity whose heights were known. When the place was isolated from other stations the annoyance was still greater. Thus, since the height of Santiago de Chile, usually given at 2600 feet, is evidently 500 or 600 feet too high, the observations at this important station had reluctantly to be omitted in the construction of the Isobarometric Charts. Meteorological societies and observers should lose no time in rectifying this flagrant omission.

In publishing monthly or other Abstracts of Barometric Observations, the following information ought to be given:—1. The hour or hours of observation; 2. The height of the cistern of the barometer above the sea; 3. The latitude and longitude; 4. The barometer reduced to 32° F., and corrected for instrumental errors, but not corrected for daily range; 5. The mean temperature of the air. A column of the observations reduced to sea-level may be added; but in such cases the reduction to 32° only should also be given. If these simple directions were observed, much labour and annoyance would be saved, and the value of the observations would be correspondingly enhanced. What meteorologists ask for, are simply the results of actual observations. It would be difficult to name any abstracts which excel, in these respects, those issued by P. Secchi.

Since storms and other important questions of Meteorology can only be discussed by Synchronous Charts which represent the weather at specified hours, it is indispensable, in publishing daily observations, to state the hour or hours at which they were made. When this is not done, much confusion and unsatisfactoriness is the result. Sometimes daily barometric means alone are published; that is, if three observations are made a-day, none of these three observations, but a mean deduced from them, is published,—a figure which in discussing storms is in all cases of little use, and in cases when the storm is passing the place, absolutely of no use; and it cannot be used in determining the amplitude of the barometer fluctuations accompanying storms and other weather-changes. By this mode of publishing daily observations, a considerable proportion of the observations published in the 'Annales de l'Observatoire Physique Central de Russie,' the greatest storehouse of meteorological facts in the world, are unfortunately deprived of a great part of their value. Indeed, if instead of daily barometric means, one daily observation at a specified hour had been given at the stations, it might have been possible to prepare synchronous charts of the greater part of the northern hemisphere. The observations published by the Meteorological Institute of Norway may be referred to as models of daily Meteorological Records. Uniformity in the methods of observation practised by Meteorologists is also most desirable. A SECOND BRUSSELS CONFERENCE is perhaps the only means by which the advantages of uniformity of observation and of publication of results may be secured.

June 1868.

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METEOROLOGY.

CHAPTER I.

HISTORY AND SCOPE OF METEOROLOGY.

1. Meteorology 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 multifarious phenomena of the atmosphere that relate to weather and climate, their relations to each other, and the laws to which they are subject.

2. The objects which astronomy takes cognisance of being few in number, and the laws by which their motions are regulated being also few, it is comparatively easy to account for the phenomena, and, from a few data, to assign to the heavenly bodies their past, present, and future positions. But it is quite different with meteorology. Owing to the complexity and intricacy of the phenomena, and the manifold influences by which they are modified and determined, it would be a task, even supposing the data before us, beyond the compass of the human intellect to give a rational and perfectly satisfactory explanation of them. Viewed in this light, meteorology is the most difficult and involved of the

sciences; hence the only procedure admissible in the first place is long and patient observation, and a faithful recording of the facts observed.

3. 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 the 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 enjoyed against the inclemency of the seasons, the appearances which were found by experience to precede changes of weather were eagerly 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.

4. Aristotle was the first who collected, in his work 'On Meteors,' the popular prognostics of the weather. A number of these were derived from the Egyptians, who had long studied the science as a branch of astronomy, while a large number were the fruit of his own observation, and bear the mark of his singularly acute and reflective mind. Theophrastus, one of Aristotle's pupils, next took up the subject, classifying the commonly received opinions of the weather under four heads—viz., the prognostics of rain, wind, storms, and fine weather. He contented himself with discussing the subject purely in its popular and practical bearings, making no attempt to explain phenomena the occurrence of which appeared so irregular and capricious. Cicero, Virgil, and a few other writers, also wrote on the weather, but made no substantial additions to our knowledge; indeed, the treatise of Theophrastus contains nearly all that was known down to comparatively recent times. Partial explanations were at-

tempted by Aristotle and Lucretius, but as they had not the elements necessary for such an inquiry, owing to the general ignorance which prevailed on matters of physical research, their explanations were necessarily vague, and abounded with references to superstitious beliefs, often ridiculous and absurd.

5. Meteorology remained in this 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.

6. *The Barometer.*—The invention of the barometer 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 barometric column, what was passing in the more elevated regions of the atmosphere, largely extended our knowledge of this element. It should be further remarked that the value of the barometer as an indicator of the weather gave an additional impetus to the study of the science.

7. *The Thermometer.*—The invention of the *air-thermometer*, by Sanctorio of Padua, in 1590, laid the foundation of a salutary revolution 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 the 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.

8. 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 in constructing 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 by any one at pleasure, the indications being in all cases absolutely the same. This great invention soon bore excellent fruit. Small portable thermometers were constructed by Fahrenheit, which, being carried by travellers and medical men over every part of the world, furnished observations of the most valuable description. The comparative temperatures of different countries became known, and the exaggerated accounts of travellers with regard to excessive heat and cold prevailing in foreign countries, were reduced to their proper value. 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.

9. *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, an instrument of great value in meteorology, as 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.

10. 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 of the utmost value 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.

11. The theory of the *Trade-Winds* was first propounded by John 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.

12. 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 and varied 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, with their effect on the barometer, and their relations to temperature and 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, with an acuteness, a fulness, and a breadth of view, which leave nothing to be desired.

13. 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. When it is considered that he missed the point of the argument in continuing to entertain the notion that the cold accompanying dew comes *after* instead of *before* its deposition, the genius he manifested in his experiments will appear all the more wonderful. It was reserved for Dr Wells to collect the different observations into a coherent whole, and account for all of them by the theory of dew he propounded—a theory so just and so complete that all 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 made to meteorology. The subject of radiation had been discussed by Halley, but his inquiries had reference only to solar radiation, or radiation from the sun to the earth. Radiation outwards from the earth towards space, or terrestrial radiation, was first taken account of by Lambert, in his 'Pyrometrie,' published in 1779. Prevost of Geneva had also published his 'Essay on Radiant Heat' in 1809, or five years before the appearance of Dr Wells's treatise. But as Dr Wells had not seen these essays, his discoveries regarding radiation were original and independent. He made this all-important observation, or rather discovery, which neither Wilson nor Prevost had suspected—viz., that during those nights when dew is deposited, the temperature of bodies on the earth's surface is colder than that of the surrounding air. He also ingeniously applied the principles laid down in the essay to explain the manufacture of ice during night at Benares in India.

14. 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. Though the

practical advantages he anticipated as likely to flow from it have not been realised, yet this difficult, and, in some points, still obscure department of meteorology, is indebted to him more than to any other philosopher. The law of the diffusion of vapour through the air, its influence on the barometric pressure, and its relations to the other constituents of the atmosphere, are among the least satisfactorily determined questions in meteorology. Since this element is so important as an indicator of storms and other changes of the weather, it is to be hoped that it will soon be more thoroughly investigated.

15. A most important addition to our knowledge of the vapour of the atmosphere was made in 1862 by Professor Tyndall of London 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 is to be expected that the discovery of the relations of atmospheric vapour to heat will soon be turned to account in explaining many questions in meteorological science.

16. Humboldt's treatise on 'Isothermal Lines,' 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,' has given 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 has been arrived at. The idea has been carried out with greater fulness of detail by the Government of the United States of America, in the beautiful and elaborate series of 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 accurate observations. Temperature Charts of the British Islands have also been published by the Scottish Meteorological Society, for the months of January, April, July, and October, these months being considered as representative of the four seasons. It is to be hoped, considering how much yet remains to be done in this direction, that Societies and Governments will undertake the preparation and publication of similar charts, which are of inestimable value, not merely as indicating the climates of different countries, but also as showing how the temperature of one country may, by the intervention of the winds, be affected by the temperature of surrounding countries. The important influence which the temperature of one country, differing materially from that of a neighbouring one at a particular season, has in causing unsettled and stormy weather in both at that time, is too obvious to be longer dwelt upon.

17. In connection with terrestrial temperature, the laborious investigations of Dové, Buys Ballot, Jelinek, Quetelet, Hansteen, 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.

18. 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.

19. The establishment of Meteorological Societies during the last twenty 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 carefully-conducted 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, the Netherlands, and other European countries, 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 self-denying exertions of Mr G. J. Symons, London, about 1500 rain-gauges are now registering the rainfall of the British Islands. An inquiry has been carried on during the last six years, having for its object the determination of the causes which affect the rainfall in the basins of the Rhône and Saône. Observers in Germany and Great Britain have been secured to co-operate with the French observers, and under the able management of M. Fournet, important results respecting the rainfall and the progress of storms will be obtained, from which it is hoped measures may be taken to avert the calamity occasioned by those great floods which periodically carry devastation and ruin over that part of France.

20. 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 peo-

ple, 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.

21. 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 Captain 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.

22. *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 overestimate 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 is intimated to the central office in Washington, followed in its march by the telegraph, and timely warning of its approach is sent to the coasts which it will visit. The United States of America is thus favourably

circumstanced for carrying out effectually the system of storm-warnings.

23. 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 is 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 in the atmospheric pressure, the centre of 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 when the maximum depression is still at a considerable distance out in the ocean; and collateral information pointing to an advancing storm is to 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 have not the same advantages towards arriving at the degree of certainty of the American predictions, and so of telegraphing to ports on the west coast 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 effect to this idea constitutes the splendid contribution to practical meteorology made by Admiral Fitzroy in February 1861, by the system of storm-warnings which has since been adopted by almost every country in Europe—a service which has made his name a household word, and entitled him to be considered as a public benefactor.

24. Considering the practical application of the knowledge of storms towards the saving of life and property, it is a duty incumbent on European meteorologists (being the most important practical problem they have to solve) to examine, analyse, and carefully study in detail the storms which have traversed Europe during the last few years,—when, from the growing popularity of the science, meteorological stations have largely increased—with the view

of ascertaining 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. In carrying out this extensive investigation, the 'Bulletin International' of Le Verrier, published daily, 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.

25. The next important step to be taken in the development of the capabilities of the science to promote the interests of humanity, will, we trust, be the giving practical effect to a suggestion made by a writer in the 'Athenæum' of the 28th September 1867, to the effect that Mr Reuter should add to his telegraphic messages a line, which need not consist of more than six letters and as many figures, announcing the state of the weather from all points of his world-wide correspondence. Thus, B. 30.15, T. 51, N.E., with R., S., F., would indicate that the barometer was 30.15 inches, the temperature 51°, the wind from the N. E., and R., S., and F., rain, snow, or fair, as the case may be. The benefit of such a practice would, it is justly added, be incalculable, for ere long all who are interested in the weather would be better prepared to take advantage of the warnings of storms on all occasions, particularly during the seasons of the year when gales most frequently occur. Much might also be contributed to the meteorology of the globe by missionaries sent out to the islands of the Pacific, and other parts of the world remote from civilised society. If possessed of the principal meteorological instruments, and of a moderate knowledge of the science, the missionary could not fail to benefit his fellow-men, and legiti-

mately increase his influence over them, by often warning them of approaching storms and other changes of the weather. This can be done more easily and with great certainty in tropical and subtropical countries, where a fall of the barometer slightly greater than usual, and a change of the wind from its ordinary direction, indicate the presence of a storm at no great distance. By closely watching the wind and the barometer, the course the storm is taking can be readily known.

26. 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 receives in our educational system. There are, however, a few noteworthy exceptions. Meteorology has been taught for upwards of thirty years in the Dollar Institution, which has long been distinguished for the lead it has taken in incorporating science into its curriculum of study. This example has recently been followed by the Roman Catholic College at Stonyhurst, the Grammar School of Aberdeen, the High School of Inverness, Lerwick Educational Institute, Elgin Institution, Larchfield Academy, and other schools in the country. But 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. As contributing towards this desired result, the name of Mr Thomas H. Core,

now of the International College, London, deserves special mention, in respect of his having, while mathematical master in the Church of Scotland's Normal School, Edinburgh, systematically trained the students to regular habits of meteorological observation. 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.

27. THE *Barometer* is the instrument employed to measure 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), 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 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.*

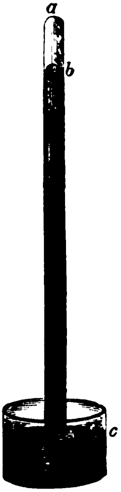

Fig. 1.

28. 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 the diminished pressure and its great elasticity, air becomes less dense as we ascend, the real height is very much greater, being, it is supposed, about 210 miles.

29. Other fluids may be used in the construction of 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 not 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 it exerts so slight a pressure that the amount of the depression, even at the ordinary temperature of a sitting-room, could not be measured by the most finely graduated vernier. Since no fluid approaches mercury in this respect, it is universally used in constructing the best barometers.

30. The tubes of barometers must be filled with pure mercury. If the mercury be not pure the density will be different, 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.

31. In filling tubes, air and moisture get mixed up with the mercury, and, if not expelled, will soon ascend to the top of the tube, and, forming an atmosphere there, will depress the column. The air and moisture are expelled by boiling the mercury in the tube—always a difficult operation,

requiring the utmost precaution, so as to expel the air wholly without breaking the tube. As it is absolutely 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 must not have been completely expelled.

32. Barometers are commonly divided into two classes—*cistern barometers* and *siphon barometers*, the more important of these 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 tube, to make it complete. Cistern barometers are subject to two sorts of error, the one arising from capillarity, and the other from changes of level in the cistern as the mercury rises and falls in the tube.

33. The effect of *capillarity* is to depress the column, the amount of the depression depending on the internal diameter of the glass tube. 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. Hence cistern barometers require an addition to be made to the observed height to give the true height.

34. The other error is technically called the *error of capacity*, and 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 back 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 to apply a correction proportioned to this rate. This is not only a clumsy method, but, as it involves some computation, it would give rise to frequent mistakes. The error is the less the more the surface of the cistern exceeds that of the column in the tube, because the fall or rise in the tube is spread over a larger surface. Hence it is desirable that the cisterns of barometers be made as large as possible.

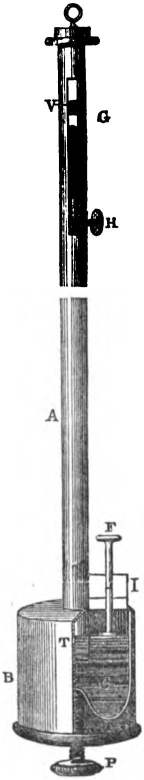

Fig. 2.

35. 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 that modification of it in most general use in this country, 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 is raised or depressed at will. F is a small ivory piston, to the foot of which is attached a float, which rests on the surface of the cistern, and moves freely between the two ivory supports, I. There will also be observed hori-

zontal lines on the ivory float and supports, *which are drawn so as to lie in the same straight line only when the surface in the cistern is at the neutral point* from which the scale, G, of the instrument has been graduated. Hence, then, with every observation, the screw, P, must be turned either way till these lines lie in 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 column. 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 required to be taken, 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. 3. 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.

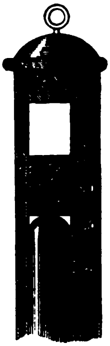
Fig. 3.

36. A *Travelling Barometer*, fig. 4, has been constructed by Adie of London, which, since it possesses several advantages as a practical instrument, deserves to be noticed. 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 counterbalances the error of capacity. The diameter

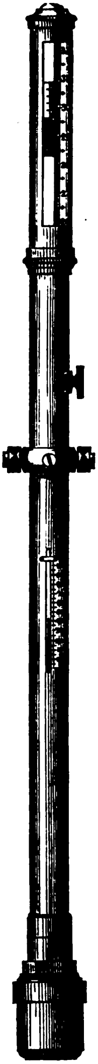
Fig. 4.

Fig. 5.

of the glass tube is generally contracted in its middle part, by which risk of breakage from "pumping" as it is conveyed from place to place is so much lessened that the instrument may be sent as a parcel by rail, if only the most 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 what is commonly called the *Marine Barometer.* It is also frequently made with an air chamber, 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. Since this barometer may be conveyed from place to place with comparative safety, it is not liable to injury from the introduction of air into the Torricellian vacuum; and as it requires no preliminary adjustment of the cistern before making an observation, it is rapidly gaining favour with the public.

37. As the common cistern barometers are liable to be deranged by the introduction of air into their tubes on removal 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 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 may escape. 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 operation to get it wholly ex-

pelled. After repeated trials, however, it is generally accomplished; and the clear metallic click of the mercury, when struck against the top of the tube, by gently inclining the barometer, will show when the whole of the air has been got rid of. On hanging up the barometer, care must be taken to lower the mercury in the tube 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.

38. In hanging or fixing the barometer, a perfectly perpendicular position *must* be secured; for if this be not attended to, 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.

39. The *Siphon Barometer*, 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 surface of the mercury in the lower limb to the neutral point of the scale, and the pressure is seen 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 chance of mistake

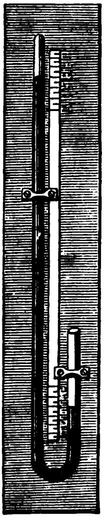

Fig. 6.

which would frequently arise in taking the difference of the two; and, 2, the free contact of the open lower limb with the air, by which the mercury gets foul, and, adhering to the tube, impedes the smooth working of the instrument. In narrow tubes this becomes a very serious objection.

40. 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 indicating roughly the more marked atmospheric fluctuations which are generally accompanied by changes of the weather.

41. It may be proper to refer here to what opticians have called the *Fitzroy Barometer*, which is a modified form of the siphon barometer. The lower limb is blown into a moderately sized bulb, so as to resemble 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 not unfrequently sold as a scientific instrument, to the annoyance of the buyer when he comes to understand its real value. It is useful as a weather indicator, in which respect it is a considerable improvement on the ordinary wheel barometer.

42. *Howson's Barometer* deserves to be noticed, not only

for the great ability and ingenuity displayed in its invention, but because it may be justly considered as the best adapted for scientific purposes of that class of barometers which aim at great sensitiveness by increased range being given to their fluctuations. Fig. 7 shows the essential and peculiar parts of the instrument. A is the barometer tube, which is of large diameter, and longer than the ordinary sort, so as to admit of a greater length of range. B is a cylindrical cistern, having attached to the bottom of it a long hollow tube or stalk, *c*, hermetically sealed, springing to a height of about 28 inches above the fixed level of the mercury in the cistern. This stalk terminates a little below the upper level of the mercury, *a*, and its upper end is therefore exposed to no more downward pressure than that of the mercury above it; consequently there is an excess of upward pressure from the atmosphere which tends to raise the cistern. When the excess of upward pressure is exactly balanced by the weight of the cistern with its stalk and contained mercury up to *b*, an equilibrium will be established which will keep the cistern stationary or hanging in suspension. Suppose now that the atmospheric pressure acting on the cistern is increased, and that the thickness of the glass tube, A, immersed in the cistern, is nothing, the cistern will continue to ascend to an indefinite extent, there being nothing to stop it. The glass is, however, a substance of some thickness, displacing mercury as it is plunged into the cistern; and as it thus presents a resistance to the ascent of the cistern, the latter will come to rest when the quantity of mercury displaced is equivalent to the increase of pressure. The extent of range which this instrument possesses above the ordinary barometer is determined by the ratio of the internal area of the tube, A, to the annulus of glass which bounds it. If these two be equal the range is doubled, and if the internal area be greatly in excess the range is proportionately increased.

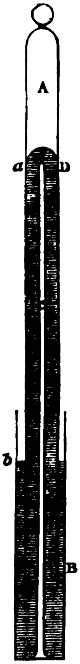

Fig. 7.

43. The principle on which the *Aneroid Barometer* 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 an index-hand which moves upon a dial. As it is very portable, and is not liable to be broken in carriage like mercurial barometers, it is peculiarly suited for nautical purposes, and for taking the heights of mountains. It requires, however, to be occasionally 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 index-hand. 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 of this instrument is liable to get fouled, in which state I have seen them 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. Aneroids therefore, like our watches, require to be occasionally cleaned.

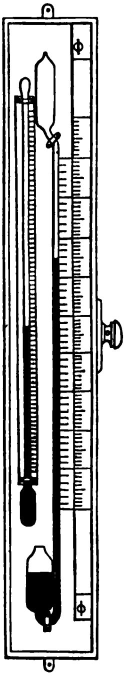

Fig. 8.

44. The *Sympiesometer*, fig. 8, was invented by Adie. It consists of a glass tube, 18 inches in length and $\frac{3}{4}$ 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 glycerin. 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 air 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 being used at sea and by travellers,

but it is not suited for exact observation. The glycerin used in filling the tube requires to be of a particular consistence, otherwise the air in the tube will be partially absorbed, and the instrument be thereby liable to change, as happened when the tube was filled, as it originally was, with hydrogen gas and oil of almonds.

45. The *Hermetic Barometer*, sometimes called *Poor Man's Weather-glass*, fig. 9, consists of a glass tube with a large, *nearly flat*, bulb of thin glass at the base, filled with common air and spirits of wine, and then hermetically closed. The thin glass bulb, being elastic, is subject to compression and dilatation as the atmospheric pressure is increased or diminished; and as a small quantity of air is left in the top of the tube, the column of spirits of wine rises or falls with the pressure of the air. To insure uniformity in its working, it requires to be kept as near as possible at the same temperature. It is of no use as a scientific instrument; but it may be referred to as the cheapest instrument by which variations in the atmospheric pressure may be roughly indicated. From the rapid absorption of the air by the spirits of wine, the indications change so quickly that in the short space of a year most of them will be found reading four or five tenths of an inch too high. If the tubes were filled as those of sympiesometers are, this objection would be obviated.

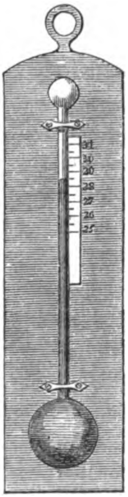

Fig. 9.

46. *How to use the Vernier.*—A 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. 10 and 11) of a piece similar to the scale of the barometer, and along which it slides. It will be observed from fig. 10, that ten divisions of the vernier are exactly equal to eleven divisions of the scale; that

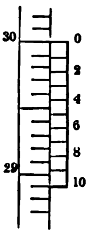

Fig. 10.

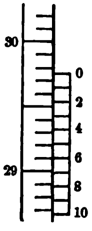

Fig. 11.

is, to eleven tenths of an inch. Hence each division of the vernier is equal to a tenth of an inch, together with the 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 page 19—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. 10, then the height of the barometer is 30.00 inches. But if they stand as in fig. 11, 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.

(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 the 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 thousandths of an inch. This vernier is always used with the best barometers; and though a little troublesome to most people to read at first, yet if the method of reading the simpler one be understood, the difficulty will be easily overcome.

47. *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 its mercury 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 expansion of the mercury under a higher temperature. 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°. The correction for this reduction is found by dividing by 9990 the difference between the observed temperature and 32°, and subtracting or adding the result to the observed height, according as the temperature is above or below 32°.

48. 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.

49. 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 is the same as that of the column of mercury. Now, if we suppose the mercurial column to be 30 inches, which is nearly the average height at the level of the sea, and its base 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 on every square inch of the earth's surface is 14.7 lb.

50. *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.

51. 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 meas-

ure 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.

52. *Correction for Height.* — In comparing barometric observations at different places, we must take account of their respective heights above the sea; for as we rise above the level of the sea, a portion of the atmosphere is left behind, and the pressure being thereby diminished, 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 technically called "*correction for height.*" The amount of this correction is determined by the height of the place above the sea; the atmospheric pressure and temperature 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.

53. 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.

54. 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 it does 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 than 0.003 inch at the equator and at the poles.

55. 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, as determined by 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 $3\frac{1}{2}$ feet above places at a height of $87\frac{1}{2}$ feet; and the atmospheric pressure being thus increased by the weight of the $3\frac{1}{2}$ 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—

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

56. 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 on a vertical (par. 53) 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 normal

height of the barometer has been assumed to be 30 inches in constructing the table.

57. 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 are obtained from those for 10, 20, 30, &c., by simply shifting the decimal point one place to the right; 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,	0.411	inch.
,,	8	,,	.009	,,
,,	388	,,	0.420	,,

58. 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.

59. (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; that is, the mean temperature of the whole stratum of air from the higher station down to sea-level. Since the temperature falls one degree for about 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°.

60. (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 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, the more accurate methods of reducing barometric observations to sea-level given in Guyot's admirable 'Meteorological and Physical Tables,' which ought to be in every practical meteorologist's hands, should be adopted.

61. *Example 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.),	+.291	,,
Reduced to 32° and sea-level, ...	30.023	,,

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 30.023 instead of 29.820.

62. *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 it would 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 whose height it is required to determine,

and the other at the level of the sea, or at a place whose height is known, and as near the former place as possible. 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 the 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 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 where simultaneous observations cannot be had at the 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.

63. *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 recurring 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 may be ascertained from the height of the barometer without an error of more than 15 or 17 minutes on the average. This horary 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.

64. At Calcutta, where, as in other tropical climates, the

hourly variation of the barometer each day 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 represent the seasons. They are the mean 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 least maximun 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 at the highest and the lowest respectively — thus suggesting a connection between the daily barometric oscillation and the daily march of temperature.

65. 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. Hence 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.

66. 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 watery particles, the vapour 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.

67. Hence, as regards temperature, the barometer is subject to a maximum and minimum pressure each day,—the maximum occurring at the period of greatest cold, and the minimum at 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 least.

68. Thus, taking both causes into consideration, the maximum in the forenoon is brought about by the rapid evapora-

tion 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 flows away to meet the diurnal wave of cold advancing from the eastwards. Hence 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, now considerably to the westward, 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.

69. 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 is the 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.

70. 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	.136
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 Great Britain 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.

71. 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.

72. 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 were observed in each of the years I have examined. 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.

73. 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 to be applied to observations made at the different hours of the day, in order to reduce them to the true mean. 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 where they are not applicable, thus leading to a good deal of confusion.

74. The legitimate use of these corrections is in their application to long averages when it is necessary to compare together the atmospheric pressure in different regions which differ in the hours of observation, or in the amounts of the variations at the same hours. Their illegitimate use, which should be discouraged, is in applying them to the means of single months or of single years, and publishing the results as the true means, without *note or comment of what has been done.* Thus, at St Petersburg for July, the correction deduced from the hourly observations of three years is +0.002. Applying this correction to each of the means of the 9 A.M. and 9 P.M. observations of the three Julys, we obtain as the "corrected" means, 29.906, 29.885, and 29.798 inches. The

true means deduced from the 24 observations made each day, were 29.906, 29.882, and 29.800 inches. Thus the applied correction was right in one year, 0.003 too great in another, and 0.002 too small in the third year. Still greater error arises in applying the means of one place to the means of single months of another place which is under quite different meteorological conditions. Meteorologists ought only to publish actual observations; or if they correct their observations, they should accompany them with a clear statement of what has been done.

75. *Annual Variation.*—When it is summer in the one hemisphere, it is winter in the other. In the hemisphere where summer prevails, the whole air, being warmer than in the other hemisphere, expands both vertically and laterally. As a consequence of the lateral expansion there follows a transference of part of the air from the warm to the cold hemisphere along the earth's surface ; and, as a consequence of the vertical expansion, an overflow in the upper regions of the atmosphere in the same direction. Hence, in so far as the dry air of the atmosphere is concerned, the atmospheric pressure will 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 will be there condensed into rain, and being thereby withdrawn from the atmosphere, the barometer pressure will be diminished; but the dry air which the vapour brought with it from the warm hemisphere will remain, thus tending to increase the pressure. The annual variation is well seen from a comparison of Plates I. and II.

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

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

77. At Calcutta, 22° 33′ N. lat., the pressure is 29.530 inches in July, and 30.010 inches in January, thus showing a difference of 0.480; and at Rio de Janeiro, 22° 57′ S. lat., it is 29.744 inches in January (summer), and 29.978 inches in July (winter), the difference being 0.234 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 Central Asia is conveyed southward over India.

78. At places where the amount of vapour in the air varies little from month to month, but the variations of 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 29.117 inches and 28.187 inches, and in January 29.807 inches and 28.774 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.

79. At Reykjavik, in Iceland, the pressure in June is 29.717 inches, and in December 29.273 inches; at Sandwick, Orkney, 29.775 inches, and 29.623 inches; and at Sitka, in what was Russian America, 29.814 inches, and 29.631 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 high summer pressures are due to the cool summer temperature as compared with surrounding countries, thus causing an *overflow from these regions* in the more elevated parts of the atmosphere. On the other hand, the low winter pressures are due to the comparatively high winter temperatures causing an *outflow towards adjoining*

countries, and the large amount of moisture in the air in winter, and the heavy rainfall, which, by setting free great quantities of latent heat, still further augments and accelerates the outflow.

80. The variations in mean pressure are very slight, and not marked by any very decided regularity in their march through the seasons, at Dublin, Glasgow, London, Paris, and Rome. As compared with Barnaul and Reykjavik their temperature is at no season very different from that of surrounding countries, and the vapour and rainfall are at no time much in excess or defect, but are more equally distributed over the different months of the year.

81. At the Great St Bernard, 8174 feet above the sea, the pressure in summer is 22.364 inches, while in winter it is only 22.044 inches. At Padua, there is scarcely any difference in the pressure between summer and winter. The increase in the summer pressure at the Great St Bernard is no doubt due to the cause already referred to in par. 71—viz., the expansion of the air upward during the warm summer months, thus raising a larger portion of it above the barometer at the higher station. But at Santa Fé de Bogota, 8727 feet high, near the equator, and where, consequently, the difference between the temperature in July and January is very small, the difference in the pressures of the same months is also very small, being only 0.018 inch. At Guatemala, 4856 feet high, the mean pressure in January is 25.269 inches, and in July 25.247 inches, showing a difference of 0.022 inch.

82. There is a noteworthy peculiarity in the atmospheric pressure at Great Salt Lake City, Utah, United States, which is 4260 feet high. Though the mean July temperature is 79°.0 and the January 25°.0, yet the mean atmospheric pressures of these months is 25.645 and 25.880 inches respectively. This winter pressure, when reduced to sea-level, gives the extravagantly high mean of 30.440 inches for January—an amount nearly 0.300 inch greater than any other North American station. Those anomalous results are explained by the physical characteristics of the place. Great Salt Lake City

is situated in a vast natural depression in the high table-land of America, measuring 500 miles each way, and from which there is no outlet. The streams which water the country flow into the Salt Lake, and thence pass off by evaporation. Hence, during the winter months, cold air currents flow down into this bowl-shaped region, and there being no escape for them, the cold, dense air they bring with them settles in the lowest levels, thus causing a most unusual winter pressure for places at that height and temperature. The cold air thus accumulated is poured out down the passes which enter the region on all sides, thus causing those terrific blasts of cold, piercing wind which sweep down the gorges, and cut off almost all communication during the cold season.

CHAPTER III.

ATMOSPHERIC PRESSURE, ITS DISTRIBUTION OVER THE GLOBE.

83. 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 self-evident. Indeed it is impossible to discuss satisfactorily those inquiries which relate to prevailing winds, the varying temperature, and the rainfall over the world, till the isobarometric lines for the months have been laid down. These lines may be justly regarded as furnishing the key to all questions of meteorological inquiry. Some of the more important facts have been long known, in a general way—such as, the belt of low pressure in the equatorial regions, bounded on each side by the high pressures from which the north and south trades flow; the low pressures round the poles; the low pressures in the North Pacific and North Atlantic; and the low summer pressure of Central Asia. But so far as I am aware, no attempt has hitherto been made to state the facts numerically by means of isobarometric lines for the months in the same way as the temperature of the globe has been represented by Humboldt and Dové, by isothermal lines. These charts are offered as the first approximation to the solution of this im-important physical problem.

84. The enormous labour required to collect monthly barometric observations, and, in not a few cases, to find the means from daily observations—to average these—to correct for daily range—and reduce to sea-level,—is no doubt one of the chief

reasons why isobarometric charts have not hitherto been prepared. My leisure hours for a long time have been employed in preparing the materials for the thirteen Isobarometric Charts, for the twelve months and the year. Three of these are given in this Chapter—viz., the Charts for July, January, and the year.

85. The charts are drawn from observations made at 360 places, thus distributed over the globe—167 in Europe, 51 in Asia, 23 in Africa and adjoining islands, 63 in North America, 35 in South America, West India Islands, and Atlantic, and 21 in Australasia and the Antarctic Ocean. Of the European stations, 12 are in Scotland, 14 in England, 27 in Austria, 12 in Italy, 10 in France, 10 in the Netherlands, 9 in Norway, 57 in the Russian Empire, &c. The list might have been largely increased; thus a larger number might have been given from the Scottish stations, but the 12 given were judged sufficient to represent the mean atmospheric pressure of that country.

86. For the British Islands the means were uniformly taken for the ten years from 1857 to 1866, so that they might be strictly comparable with each other; and the means of several European places are for the same years. In the United States of America the means are uniform for the six years from 1854 to 1859. In selecting the stations, respect was paid to the obtaining of a good mean,—that is, observations for a sufficient number of years, to show as nearly as possible the true mean. At Bombay, for example, from 1847 to 1860, the lowest mean for July was 29.598 inches in 1851, and the highest 29.673 inches in 1853. This regularity in the pressure of the same month in different years is a feature common to all tropical countries, and hence, in such places, a few years were accepted as a good mean. On the other hand, since the mean pressure at Reykjavik, Iceland, during January 1867, was 29.913 inches; during February, 29.359 inches; and during March, 30.037 inches,—it is evident that a good many years are required to represent the mean of the months. Hence, a very subordinate place, if any at all, has

been given to observations from the places at which the observations did not extend over a considerable number of years.*

87. For many means I am indebted to the labours and writings of Buys Ballot, Carl Jelinek, Dové, Quetelet, and Kuppfer, and particularly to Secchi's admirable abstracts which have appeared from time to time in the 'Bulletino Meteorologico.' To the Royal Society of Edinburgh and to Professor C. Piazzi Smyth, Royal Observatory, Edinburgh, I return my most cordial thanks for giving me, at all times, access to their invaluable libraries.

88. In reducing to sea-level, Table IV. was used for all places that did not exceed 800 feet in height. For higher situations the reduction was made by means of Dippe's method, as detailed in Guyot's 'Mathematical and Physical Tables,' D, p. 60.

89. In the charts the isobarometric 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). In the centre of Africa, from which there are no observations, and where, consequently, the lines are hypothetical, they are made dotted lines.

90. MEAN ATMOSPHERIC PRESSURE FOR JULY.—It will be seen from Plate I., representing the mean pressure for July,

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* The following are a few of the places, with the number of years, for which the means are given:—Sitka, 15; Algiers, 10; Hobart Town, 25; St Louis, Mauritius, 13; Bogoslovsk, 26; Nijni-Tagilsk, 21; Barnaul, 19; Nertchinsk, 18; Pekin; 14; Calcutta, 11; Tiflis, 14; Baku, 17; Alagir, 15; Jakobshavn, 10; Reykjavik, 13; Hammerfest, 13; St Petersburg, 19; Archangel, 18; Zlatoust, 28; Lugan, 22; Christiania, Cracow, and Kursk, 27; Brussels, 33; Gand, 26; Geneva, 25; Ahun, 34; Verona, 73; Bologna, 45; Milan, 25; Turin, 74; and most of the Austrian stations from 14 to 18, &c.

that 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.

91. *Areas of Low Pressure.*—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 observations showing this depression near its centre are scanty; but as the North American observations show clearly a decreasing pressure from the coast towards the interior of the continent till it falls to 29.686 inches at Great Salt Lake City, there can be no doubt as to its existence. 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 no doubt under the average.

92. In the Antarctic Ocean the pressure is abnormally low throughout the year, with perhaps a slight tendency to an increase in winter (July). This singular permanent depression has been calculated from a mean of upwards of 100,000 sea observations.

93. *Areas of High Pressure.*—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 the same height at 20° S. lat.

94. The other region of high pressure is comparatively insignificant, stretching from California westwards across the Pacific to probably 150° E. long.

95. The effect which the peculiar distribution of the atmosphere during the summer months has on the surface-winds and on the temperature, will be better discussed in Chapters VI. and X., which treat of these subjects. It only remains here to say a few words on the chief causes which bring about this distribution—viz., the temperature primarily, and, secondarily, the moisture of the atmosphere.

96. As the sun is nearly at the greatest distance north of the equator in July, the greater part of his heat falls on the northern hemisphere. That portion of the heat which falls on the land is wholly absorbed by the thin superficial layer exposed to the heating rays, which therefore becomes quickly heated, together with the air resting upon it. On the other hand, the portion of the solar heat that falls on the ocean is not arrested at the surface, but a considerable part of it penetrates to some depth below the surface. Owing to the low specific heat of land as compared with water, the land is more quickly and more highly heated than the ocean by the sun. Further, as the atmosphere over land is much drier than that over the sea, fewer of the solar rays being absorbed where the air is drier, more heat falls upon the land, and consequently its temperature rises higher than that of the sea. From the above causes the summer temperature of continents greatly exceeds that of the ocean in the same latitudes. An examination of Plate IV. will show the abnormally high temperature which prevails in Asia, north of Africa, and North America during summer. Thus, the temperature of each of these regions is very high, and the air being in consequence specifically lighter, it ascends, as from a furnace, in a vast column thousands of miles in diameter. In this way the summer atmospheric pressure of continents is diminished. The amount of the diminution over nearly all the continent

of Asia is about half an inch. This is perhaps the finest example that can be adduced of the enormous mechanical power of the sun's heat, which first raises, and then removes about one-sixtieth part of the whole atmosphere from so large a portion of the earth's surface.

97. What comes of the air thus removed? It is evident that the columns of heated air will continue to ascend till they reach a height at which the pressure or tension of the air surrounding the ascending currents is less than that of the aërial columns themselves. In popular language, the warm air will ascend just as long as it continues to be buoyed up by the denser air which surrounds it. Hence when it attains a height at which the surrounding air is less dense than itself, it will no longer continue to ascend, but will flow laterally over those regions which offer the least resistance to its course—in other words, it will flow into those places where at that height the density is least.

98. Now those regions where at great heights the density of the air is least, are precisely those places where the mean temperature of the whole stratum of air reckoned from the level of the sea upwards is least, for the obvious reason that cold air being dense and heavy, the greater bulk of its mass is concentrated in the lower beds of the atmosphere, thus leaving the upper beds less dense and heavy. It follows from this that the greater proportion of the air which is removed from the continents of the northern hemisphere in summer, will flow over as an upper current into the southern hemisphere, and increase the atmospheric pressure there. The massing of the isobarometric lines which indicate a pressure above the average to the south of the equator at this season, is conclusive proof of the justness of this reasoning.

99. But at this time the mean temperature of the air over the ocean is much lower than that over the land: we should, therefore, expect to find high barometers in the northern hemisphere over the ocean, and particularly in that ocean which is most completely surrounded by heated land, which may thus pour over into it, by the upper currents of the

atmosphere, the heated air which rises from them; and the pressure is still farther increased by the upper current flowing from the region of calms. Now the North Atlantic is the ocean which most fully meets these conditions, being surrounded by the heated land of North America, South America, and North Africa. Consequently this ocean shows the greatest excess of atmospheric pressure as compared with other parts of the earth's surface in the same latitudes. The South Atlantic shows also a pressure as high; but this pressure is due both to the upper currents from South America and Africa, and to the increased pressure which prevails over the whole of the southern hemisphere at this season.

100. The extension of the area of high pressure from the North Atlantic into South-Western Europe is instructive. Taken in connection with what has been said, it brings before us in an impressive manner the subordinate position of Europe as a simple peninsula thrown out from the great Asiatic continent. The effect of the Mediterranean, Black Sea, Caspian Sea, North Sea, and Baltic Sea, in deflecting and otherwise determining the position of the curves, is very interesting. On a larger scale, and with the isobarometric lines drawn for every half-tenth of an inch of pressure, the influence of these seas on the atmospheric pressure, and thence on the summer climate of Europe, would more clearly appear.

101. But moist air, or air charged with the vapour of water, is considerably lighter than dry air; consequently when moist air accumulates over any region, an ascending current takes place. But as moist air ascends into the upper regions of the atmosphere, it is cooled below the point of saturation, condensation follows, and rain is precipitated. In the act of condensation heat is liberated, which, by heating the air in the higher parts of the atmosphere, tends still further to diminish the pressure, and so accelerate the ascent of the current. This influence of the vapour on the isobarometric curves is illustrated in different places in Plate I.

102. In the North Pacific, where at this season the two trade-winds meet and mingle, there occurs a belt of low pressure,

caused by the vapour accumulated by these constant winds. In the Atlantic, at 15° N. lat., there is a similar belt of low pressure,—at least lower than what prevails to the north and south of it. The nature of this region of low pressure will be best seen from the following figures, which give the mean pressure in the Atlantic for every 5° of latitude between 16° and 40° W. long.*:—

N. Lat.	Pressure.		Pressure.
35°	30.348	Equator	30.156
30°	30.266	S. Lat.	
25°	30.196	5°	30.164
20°	30.132	10°	30.194
15°	30.110	15°	30.250
10°	30.133	20°	30.348
5°	30.140	25°	30.336

In the above two cases the belt of lowest pressure marks out the region of calms and of constant rains, which will be referred to further on.

103. The crowding together of the isobarometric lines in the south and east of Asia is caused by the vapour which the summer monsoon brings to these regions, and which is there precipitated in a copious rainfall. The low pressures which prevail during all seasons in the Antarctic Ocean are no doubt due to the saturated state of the atmosphere resulting from the N.W. winds, which blow thither from an almost unbroken sheet of waters, which embraces the South Pacific, the South Atlantic, and the Indian Ocean, and which meet with little land to condense the vapour till they flow within the antarctic circle.

104. Mean Atmospheric Pressure for January—Plate II.—Since, speaking generally, the same conditions which bring about a high atmospheric temperature in summer from the effects of solar radiation, also bring about a low atmospheric

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* These figures are the means of the observations made by Captain Henry Toynbee, R.N., during five voyages to India, the results of which are given in an excellent paper which was published in the 'Proceedings of the Royal Society,' June 15, 1865.

temperature in winter from the effects of terrestrial radiation, we should expect to find the relations of the two hemispheres to each other in respect of atmospheric pressure reversed in January as compared with July. An inspection of Plate II., giving the isobarometric lines for January, shows that this is the case. Here we see the red lines, which indicate a pressure above the average, almost wholly confined to the northern hemisphere; whereas the blue lines, showing pressures below the average, are, except in two small patches, the only pressures prevailing in the southern hemisphere.

105. 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 —44°.0 at Yakutsk, which is 285 feet above the sea. The highest atmospheric pressure does not occur at this point, but at a considerable distance westward, near the sources of the Obi and Yenisei. The non-coincidence of the areas of greatest cold and greatest pressure may be explained by the proximity of Yakutsk to the area of low pressure in Kamtchatka, which may properly be regarded as a drain lowering the pressure of Eastern Asia. The effect of the mountain-systems of Asia, in particular the Yablonoi or Stanovoi Mountains, in shutting in the cold dense air within that region, and thus tending to increase the pressure, may be here referred to. Indeed, but for this high mountain-range, the singular distribution of the pressure which is seen to obtain from Yakutsk eastwards to Kamtchatka could not be maintained, and in all probability the whole winter pressure of Central Asia would be materially reduced. The sources of this high mean pressure must be upper currents flowing towards it and over it from the four regions of low pressure,—lying respectively to the east, the south, the south-east, and the west.

106. This area of high barometer is continued westward through Europe south of the North Sea and the Baltic; the north of Africa; the North Atlantic between 15° and 45° lat.;

North America, except the north and north-west; and the Pacific as far west probably as 150° W. long. Its breadth, as was to be expected, is doubled in North America, as compared with the Atlantic. As I have no observations from the central parts of the North American continent, the winter pressure of that region is given only hypothetically. It is, however, probably correct, since there is no mountain barrier stretching east and west across the continent damming up the dense cold air and preventing it from flowing over the United States. The effect of the Mediterranean and neighbouring seas, which are at this season warmer than the land surrounding them, in lowering the mean winter pressure, and thus breaking the continuity of the isobarometric line of 30.2, and preventing its extension from the Pacific to the mouth of the river Lena in Siberia, is well deserving of attention.

107. In addition to the Antarctic and Equatorial depressions, there are four areas of diminished pressure: two caused by their high temperature—viz., South America and South Africa; and the other two by their being vast reservoirs of moist air—viz., the northern part of the Atlantic, and the northern part of the Pacific, and the 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 doubtless in the overflow of air from the upper currents which set in towards it from the heated regions of South Africa and South America. The influence which this peculiar distribution of atmospheric pressure exercises on the storms of the Cape of Good Hope and of the southern parts of the Indian Ocean at this time of the year will be afterwards pointed out.

108. Over the North Atlantic occurs an extensive diminution of pressure, which deepens northwards till the greatest depression, 29.5, is reached in Iceland, or perhaps in a slightly lower depression nearly midway between that island and Spitzbergen. The widening of the isobarometric curves of 29.6 and 29.7 inches to the westward over Greenland, and to the eastward over the north of Norway and Russia, is an

interesting feature of this area of low pressure. 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 beyond Spitzbergen, and the larger amount of vapour poured into the atmosphere from its warmer waters, tends 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 explanation of the winter climate of Europe.

109. Another, and even a more remarkable depression, occurs in the North Pacific, having its curve of 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.

110. The position of the lowest equatorial pressure in the Indian Ocean, which determines the region of calms and constant rains, is peculiar in this, that it does not lie parallel to the equator, as might have been expected, but slanting from Tamatave in Madagascar, 18° S. lat., to the coast of Sumatra, in 5° S. lat. This is one among the many valuable results arrived at by Mr Charles Meldrum, Mauritius, in his laborious researches into the meteorology of the Indian Ocean. Moreover, it is in this trough that nearly all the tropical storms of the Indian Ocean have their origin.

111. MEAN ATMOSPHERIC PRESSURE FOR THE YEAR—PLATE III.—In Plate III., which gives the mean annual pressure of the atmosphere, the sums of the disturbing influences at work throughout the year in increasing or diminishing the weight of the atmosphere, are seen at once in the areas of high and the areas of low mean pressure in different parts of the globe.

112. *Regions of High Pressure.*—There are two such regions —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 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 difference 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.

113. *Regions of Low Pressure.*—Considered in a broad sense, there are only two regions of low pressure—one round each pole, bounded by, or contained within, the belts of high pressure just described. The most remarkable of these, in so far as it is known, is the region of low pressure surrounding the south pole. In reference to this singular depression, the registers of upwards of 100,000 observations have been examined, and the mean of them taken for the different latitudes, with the following result:—

Latitude South.	Mean Pressure in each.
45 to 50	29.740
50 to 55	29.460
55 to 60	29.240
60 to 65	29.130
65 to 70	29.070
70 to 75	28.910
75 to 80	28.960

It is to be regretted that as the longitudes were not taken into account in taking those means, the geographical distribution of this anomalous depression cannot yet be accurately defined. The depression round the north pole is divided into two distinct centres, at each of which a diminution of pressure, still 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 appear with greater distinctness if drawn on a polar projection of the northern hemisphere.

114. There is a smaller area of diminished pressure in Hindostan, which is entirely due to the low summer pressure of that region during the south-west monsoon.

115. 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 slight 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.

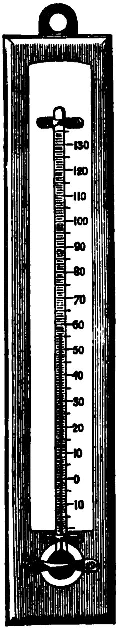

Fig. 12.

116. The temperature of the air is ascertained by the *Thermometer*, fig. 12, which consists of a small closed glass tube, having a bulb at one end, and partially filled with mercury or spirit of wine. Of these fluids mercury is the best, owing to its uniform expansion by heat; the quickness with which, from its low specific heat, it indicates changes of temperature; and the great range of its fluidity. A spirit thermometer must be used when the temperature falls below —37°.9, the point at which mercury freezes, as determined by Dr Balfour Stewart. Spirit thermometers are also of great use for registering the greatest cold.

117. The following points in the construction of thermometers must be attended to. The mercury should be pure and dry, and boiled so as to expel the air; the bore of the tube should be equal throughout; the bulb should be large in proportion to the bore, so that the degrees may be large and easily read; and no air should be left in the top of the tube. It is also most desirable that thermometers should be filled and hermetically sealed for at least a year before the scale is engraven on them. The reason is, that the fibres of the glass take some time to assume their permanent position; and since, in this transition state, the

atmosphere pressing on the exterior surface of the bulb constantly tends to push the mercury further up the vacuum above the column, the result is that the bulb becomes permanently contracted in size, and the column stands higher on the scale. Nothing is more common than to find such thermometers, after being some time in use, to read 0°.5 or 1°.0 higher than they did when previously compared with the standard. 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.

118. *Division of Thermometer Scales.*—Before the indications of different thermometers can be compared, 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 chosen 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, but if less it will be lower, the proportion being one degree of Fahrenheit for every 0.589 inch of pressure at moderate heights. Hence, when the barometer is 28.000, water will boil at 208°.6 instead of 212°. At Santa Fé de Bogota, which is 8727 feet high, and atmospheric pressure is 22.061 inches, water boils at 197°.46; in Mexico, at 7000 feet high, it boils at 200°; and at Quito, 9000 feet, it boils at 194°.

119. Advantage is taken of this circumstance *to measure roughly 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 ascertained. An observation should be made at a lower level where the height is known before ascending the moun-

tain 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 exact hour of the day of each observation should also be noted, so that the correction for daily variation may be applied.

120. The space on the scale between these two 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 its practical advantages over other scales are these: (1) The degrees are smaller than in the other scales, and hence greater exactness in observing is attained; and (2) as the temperature rarely falls below zero, the minus sign is seldom required,—an advantage of some value in summing up and printing tables of temperature.

121. 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 some other Continental countries, and is extremely convenient for purposes of scientific inquiry.

122. In Reaumur's thermometer the same space is divided into 80 parts, the freezing-point being the zero of the scale. It is in use in Germany and Russia.

123. It is often required to convert temperatures expressed in the Centigrade or Reaumur's scale into Fahrenheit's scale, and *vice versa*. 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—

$$F : C :: 9 : 5 \qquad F : R :: 9 : 4, \text{\&c.}$$

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 Reaumur's and Fahrenheit's from 140° to —40° F.

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

125. *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 on the top of 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, and thus permitting 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 get 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 is sometimes 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.

126. In *Phillips's Maximum Thermometer*, fig. 13, a portion of the mercurial column is detached and kept separate from the other part by a minute air-bubble. When in posi-

tion it is hung horizontally; then 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 registering the greatest heat. This is an excellent thermometer. Care, however, should be taken to select one in which the detached portion is little more than 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.

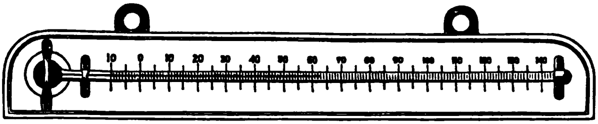

Fig. 13.

127. 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 therefore of some weight, it is liable to be shifted out of its place when shaken by accident, or by the wind during storms.

128. In selecting a Phillips's, or a Negretti and Zambra's thermometer for the registration of very high temperatures, such as those recorded by thermometers exposed to the sun's rays, care ought to 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 may be ascertained.

129. *Minimum Thermometers.—Rutherford's Minimum*, fig. 14, 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.

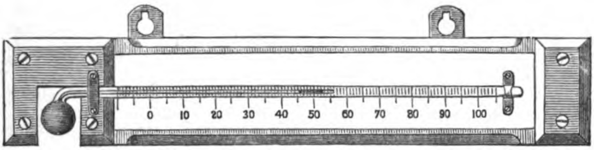

Fig. 14.

130. 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 which are exposed for common purposes outside windows. These I have often seen with a quantity of spirit equal to 12° detached from the column and settled in the top of the tube, my attention having been drawn to them by the accounts of cold—Siberian almost in intensity—alleged to prevail in certain

places. It is thus that many of our severest frosts find their way into the newspapers among other wonders. Spirit thermometers kept in the shade are also liable to the same derangement, but to a much less degree, because they are better protected from great heat. Generally the quantity of spirit evaporated is small, though sometimes it amounts to one degree. Observers should give special attention to this point, and the more especially so because it is by the temperature recorded by these thermometers that the chief elements of climate are determined.

131. *How to Unite the Broken Column of Spirit Thermometers.*—Fortunately 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 rest 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. Care should be taken that the heat is not 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 will serve instead.

132. 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, 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 the most ordinary vigilance be exercised by the observer in setting them right when the column happens to separate.

133. In *Hicks's Maximum and Minimum Thermometers*, both are combined into one column; but this composite instrument is inferior to the ordinary maximum and minimum thermometers made separate from each other. This is particularly apparent in registering extreme temperatures of short duration, because the tube is filled with two fluids, mercury and spirit, which, having different capacities for heat, expand unequally.

134. No thermometer ought to be used which has not been previously compared with some standard instrument, such as the Kew standard adopted in Great Britain, so that its errors, if any, at the different points of the scale may be ascertained. This is especially necessary in purchasing cheap instruments, many of which I have had occasion to reject as being from 1° to 3° wrong. The amount of the error frequently varies at different points of the scale; thus one I compared was correct at 60°, 3° too low at 45°, and 6° too low at 32°. Errors are also found, though rarely, in first-class thermometers. Thus, I recently compared a number of high-priced thermometers, every one of which was from 1°.2 to 1°.7 too high. But it would be unjust to omit paying a well-deserved compliment to opticians for the high degree of excellence and refinement now attained in the construction of meteorological instruments. I have compared many hundreds, and could name firms, none of whose thermometers, at or above a certain price, have been found to vary from the standard more than half a degree through the scale, and many of them not more than the tenth

of a degree; in other words, they might be considered as almost absolutely correct.

135. A good deal of annoyance arises from the frameworks of thermometers being made of unsuitable materials. When any wood except well-seasoned boxwood is used, it soon warps on exposure to the weather, and, the tube breaking, the thermometer is rendered useless. Porcelain scales also occasionally go to pieces, and the tubes are at the same time frequently snapped. The best frameworks are those made of zinc.

136. *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 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

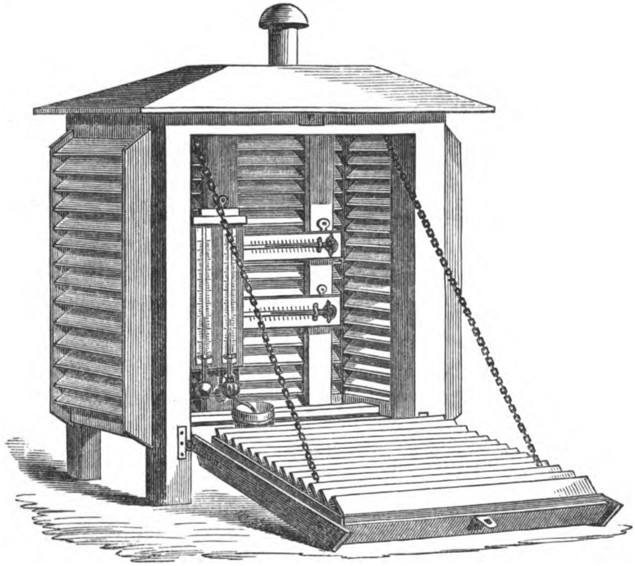

Fig. 15.

the circulation of the air be quite unimpeded, the thermometers are unduly exposed to radiation. All, therefore, that can be secured is a fair 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 extensively used by the observers of the Scottish Meteorological Society, and other meteorologists. A figure of the box, fig. 15, is here given, with the door let down to show the hanging of the thermometers inside. Fig. 16 shows the simple and ingenious method by which the louvre-boards are fixed.

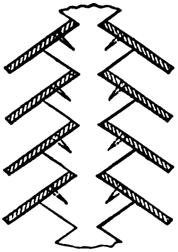

Fig. 16.

137. The box is screwed to four posts firmly fixed in the ground, and these posts and the box itself are painted white, being 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.

138. *Placing of the Thermometer-Box.*—The box should be placed at some distance from walls, or other objects likely to be heated by the sun; in an open space; and over old grass to which the sun has free access during the greater part of the day. For if it is 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 for the average of the district where they are placed. And if it is 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.

139. *Directions for taking Observations with the Thermometers.*—Having let down the lid of the box as in fig. 15, 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 is at the time, which gives 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 shut up.

140. *Mean Daily Temperature.*—If the thermometer be observed once each 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, Inverness, Greenwich, Rome, Calcutta, Madras, Bombay, 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.

141. It might have been supposed that the *daily minimum* would have occurred at the rising of the sun, or just before its rays had begun to heat the air; but observation is 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. As causes concerned in raising the temperature of the air before the sun's rays begin directly to influence it, may be mentioned—(1) heat reflected from the upper regions of the air, already heated as well as lighted up by the sun before it appears above the horizon; (2) heat liberated from the deposition of dew during the night; and (3) the slight influx of air from the warmer east towards the place of greatest cold, as evidenced by the daily fluctuations of the barometer, perhaps contributes in a small degree to the same result.

142. Within the tropics, and in temperate regions during winter—in other words, where the daily range of temperature is small—the *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 2½ P.M. to 3½ P.M.

143. To this general law of the time of its occurrence there are two 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, 8174 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 3½ 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.

144. In Melville Island, in the Arctic Ocean, there is no trace of a daily period during the absence of the sun in December and January; at Fort Bowen, the highest occurs in December at 9 A.M., and the lowest at 7 P.M., but at this place in January there is no trace of a daily period; at Igloolik, in North America, there is a daily fluctuation, but it is indistinctly marked. On the other hand, at Matotschin-Schar, in Spitzbergen, the daily range of temperature is well marked—the maximum during December occurring at 9 P.M., and the minimum at 8 A.M.; and during January, the maximum at 3 A.M., and two minima at 9 A.M. and 9 P.M.; or taking the mean of the whole period when the sun is invisible at this place, the maximum occurs at 8 P.M., and the minimum at 8 A.M.

145. Sir David Brewster has investigated the hourly observations of the three Scottish stations, and drawn many 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 finds that 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 observed 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.

146. He also conclusively establishes an 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 can exercise 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.

147. It is a singular coincidence that the means of observations of hours of the same name—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 very 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.

148. *Best Hours for Observation.*—Hence the best hours for thermometric and barometric 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.

149. *Daily Extremes.*—A comparison of the mean temperature with the mean of the daily extremes—that is, the mean warmest and mean coldest hour of the day—gives some interesting results. From about thirty places on the globe where those have been ascertained, if an average of six months be taken, the difference between the two does not exceed the third of a degree; the difference for any month seldom exceeds a degree, and the mean annual difference seldom more than half a degree. At Rio Janeiro the difference for any month does not amount to 0°.3, whereas at Catherinenburg, in the Ural Mountains, it exceeds this amount in every month but one. In some places the differences are all

in excess, in others they are all in defect; in some places an excess occurs in winter and a defect in summer, and in other places *vice versa.* In most places the greatest difference is in October and November, but in a few places the reverse holds good. Comparing the Leith and Greenwich observations, we find that the mean annual deviation at Leith is 0°.2, at Greenwich, 0°.7; the lowest monthly deviation at Leith, 0°.1, and at Greenwich, 0°.2; and the highest at Leith, 0°.6, and at Greenwich, 1°.1.

150. *Mean Temperature deduced from Maximum and Minimum Temperatures.*—Of late years, since the invention of self-registering thermometers, the mean temperature has been more commonly deduced from observations of the highest and lowest daily temperatures. Owing to the general use of these thermometers and the general adoption of 9 A.M. and 9 P.M. as the hours of observations, an interesting question may be raised—viz., Whether should the mean temperature of a place be deduced from observations with the common thermometer (usually the dry-bulb thermometer), or from the daily maximum and minimum temperatures? I have examined the maximum and minimum temperatures for a considerable number of places in Scotland, and, adopting the simple arithmetic mean of these temperatures as the mean temperature, I have found at places on the same side of the island, and in the same district, that this mean does not differ at any place from the mean of all the stations more than half a degree, generally only 0°.1 or 0°.2. At one or two places where the difference amounted to, or exceeded, half a degree, it turned out to have arisen from an error in one of the thermometers, which was discovered by this mode of examination. Hence, then, the indications of maximum and minimum thermometers give great uniformity of results, and so far are admirably adapted for investigations of mean temperature. I have compared the mean of the 9 A.M. and 9 P.M. temperatures with the mean of the maximum and minimum temperature for four years, but find considerable contrariety of results. Comparing the means of 55 places, which may be regarded as representing the whole of Scotland,

the mean annual difference is only 0°.1. In 15 out of the 48 months the difference did not exceed this small amount. In October 1861 the registering thermometers were 1°.0 higher, and in November 1862 they were 0°.9 lower than the other mean. These were the extreme differences, but the average difference was small, the one being sometimes above and sometimes below the other. On examining particular places great differences are apparent among those stations, the local situations of which are peculiar—such as being in close proximity to the sea, or being surrounded by hills. Thus, in open situations, the 9 A.M. and 9 P.M. means are in most cases about 0°.7 lower than those of the registering thermometers; at Braemar, in Aberdeenshire, the difference is 1°.0, whereas at Thirlestane Castle, in Berwickshire, it is only 0°.2, both places being in deep valleys surrounded by hills. On the other hand, at Aberdeen, previous to 1864, the 9 A.M. and 9 P.M. means were 1°.1 higher than those of the registering thermometors; but since that date, the situation of the observatory being changed, the two means have been nearly the same. There is little uniformity in the differences, even in the same month, from year to year. Thus, at Braemar, a station established by the late Prince Consort, and in every way a well-equipped and well-appointed station, the difference in July 1861 was 3°.0, whereas in July 1863 it was only 0°.3. At some places the greatest difference is in summer, whilst at other places it occurs in winter. It follows from this that the data supplied by observations of temperature taken at the above hours—and the remark may be extended to the observations of any two or three of the twenty-four hours—are not so trustworthy guides to a knowledge of the mean temperature, as are observations made by maximum and minimum thermometers.

151. The chief source of these different results of the 9 A.M. and 9 P.M. observations, is the modification of the law of the daily march of temperature, first stated by Sir David Brewster, and already referred to in par. 146. Thus it is evident that, if the shadow of a hill, or even of a tree, house, or wall, does not leave the place where the thermometers are situated till near

to or after the hour of observation, the temperature will from this cause be too low. Similarly, objects obstructing the sky-view at the observatory will retard the effects of radiation, and the thermometer will read higher at 9 P.M. than it would otherwise do. Again, if the instruments are placed in a low situation, with rising ground surrounding it wholly or in part, then during calm nights cold air will flow down upon the thermometers, thus hastening the period of the lowest temperature at the place. These considerations do not apply, or but slightly, to the observations of maximum and minimum thermometers. It need scarcely be added here, that if the dry bulb be not read immediately on approaching the instruments, but is allowed some time to be affected by the temperature of surrounding objects, and if care be not taken to have the bulb of the dry-bulb thermometer on the same level with the bulb of the minimum thermometer, the observations will be vitiated by errors which it will be impossible to rectify.

152. How far does the mean of the daily maximum and minimum temperatures represent the true mean temperature? This is a question of first importance in meteorology. The closest approximation we need make to the mean temperature is, to observe the temperature each hour, and the mean of these 24 observations may be accepted as the mean temperature. Hence the above question will be answered, if daily observations of the maximum and minimum temperatures be conjoined with the above. I have examined seven places where such observations have been made for a number of years—viz., St Petersburg, Tiflis, Catherinenburg, Barnaul, Nertchinsk, Pekin, and Calcutta; and have added to the tables the means for Brussels, as given in M. Ad. Quetelet's excellent 'Meteorology of Belgium, compared with that of the Globe, 1867,' and the means for Greenwich, prepared by Mr Glaisher, and published in the 'Transactions of the Royal Society' for 1848.

COMPARISON OF THE MEANS OF MAXIMUM AND MINIMUM DAILY TEMPERATURES, WITH OBSERVATIONS OF A COMMON THERMOMETER, OBSERVED TWENTY-FOUR TIMES A-DAY. *The former exceed the latter, except in one case, which is marked with a minus sign.*

	St Petersburg.	Tiflis.	Catherinenburg.	Barnaul.	Nertchinsk.	Pekin.	Calcutta.	Brussels.	Greenwich.
January,	0.1	0.5	0.5	0.9	1.2	0.8	1.0	0.7	0.2
February,	0.1	0.5	0.9	0.7	1.0	0.8	0.9	0.7	0.4
March,	0.2	0.7	0.5	0.6	0.6	0.9	1.0	0.8	1.0
April,	0.7	0.3	0.5	0.7	0.1	0.3	1.0	1.0	1.5
May,	0.8	0.5	0.5	0.3	—0.2	0.6	1.0	0.8	1.7
June,	0.9	0.4	0.8	0.7	0.0	0.6	0.7	0.8	1.8
July,	0.4	0.5	0.7	0.4	0.3	0.6	0.6	0.7	1.9
August,	0.5	0.6	0.6	0.5	0.5	0.6	0.8	0.9	1.7
September,	0.6	0.5	0.7	0.8	0.5	0.6	0.6	0.9	1.3
October,	0.4	0.6	0.7	0.9	0.8	0.7	0.7	1.0	1.0
November,	0.0	0.5	0.6	0.3	0.6	0.6	0.7	0.8	0.4
December,	0.1	0.3	0.5	0.7	0.8	0.6	0.9	0.5	0.0
Year,	0.4	0.5	0.6	0.6	0.5	0.6	0.8	0.8	1.1
No. of daily observations,	24	24	24	24	24	24	24	12	12
No. of years,	4	5	4	4	4	4	6	20	6

153. All these places, with the exception of Greenwich, show a remarkable uniformity—the mean temperature deduced from the mean of maximum and minimum observations being about half a degree above the true mean. So regular, 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.

154. The following is suggested as the cause of the higher temperature which self-registering thermometers give: It will be seen further on that the descent of the temperature during night is arrested near the dew-point—the heat which is given off in the condensation of the vapour into dew being sufficient to maintain the temperature near that point. Hence in the curve of the daily march of the temperature, the part representing the lowest temperatures presents a flattened appearance when much dew falls, as compared with the part of the curve showing the highest temperatures. Thus, since the minimum temperature does not fall so low as

it otherwise would, the mean of the maximum and minimum temperatures gives a mean temperature a little higher than the true mean temperature of the day. In dry climates, where little or no dew falls, these two means may be expected to approach each other. This is the probable explanation of the small difference at Nertchinsk during summer, and at St Petersburg during winter. Again, in cloudy rainy weather, when the daily temperature falls less frequently to the dew-point, the difference between the two means may also be expected to be less. During the rainy season at Calcutta, which lasts from about the middle of May to October, the difference is less than during the dry season; the observations at Pekin, the climate of which resembles that of Calcutta, point in the same direction. At the Scottish stations, the smallest differences between the 9 A.M. and 9 P.M. and the maximum and minimum observations occur in the western and northern islands, where the climate is eminently cloudy and rainy. An examination of this whole question by observations of the *maximum daily relative humidity* would go far to settle the point.

155. The more this subject is considered, the more caution will one be inclined to use in applying "Corrections" (usually so called) of temperature, derived from the long averages of one place, to the long averages of another place, with the view of determining the true mean temperature. When this is attempted for averages of a few years, and *a fortiori* for averages of single months, it results in frequent error and confusion, and renders the examination of such "corrected" observations at best a very perplexing, and, in many cases, a hopeless inquiry. A few examples will illustrate this. At Calcutta the excess of the mean of the maximum and minimum temperatures was 1°.4 in January 1866, but in the same month in 1863 it was only 0°.7; in May 1864 it was 1°.6, in May of the following year it was only 0°.7. Hence, if the correction was applied for May 1864, the supposed true temperature would be 0°.6 above *the true* temperature, and in the following year it would be 0°.3 below it.

156.. At Dundee, in June 1867, the mean of the maximum and minimum temperatures for the month was 54°.8, and the mean of the 9 A.M. and 9 P.M. observations was 54°.4. Suppose now, we apply to these the Greenwich corrections, in order to arrive at the true mean temperature of the month: From the self-registering thermometers the mean temperature would be 53°.0; and from the 9 A.M. and 9 P.M. observations the mean temperature would be 54°.1; and, further, if we combine these two results, the mean temperature will be 53°.6. Is any one of these correct? The chances against it are at least as many as those for it. Judging from the greater prevalence than usual of cloud and east winds, and being guided by the figures in the table given above, the mean temperature was probably 54°.4. Owing to the uncertainty in which this question is at present involved, the Council of the Scottish Meteorological Society, in their abstracts of observations issued quarterly, publish the means without applying any corrections whatever to them—a practice which we think commends itself to meteorologists.

157. 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 which is 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. If meteorologists would investigate the drying qualities of the air in different parts of the same town when the east wind prevails, and the march of the temperature, also in different parts of the same town, when the weather is considered to be hurtful or beneficial to particular diseases; and if at the same time the physician would note the occurrence of particular diseases in his district, their commencement, culmination, and cessation,—solid contributions would be made to meteorology, which could not fail to result in alleviating suffering and prolonging life. It is in this direction that the question of local climate should be prosecuted.

158. *Value of Extreme Temperatures.*—Self-registering thermometers are of great practical value in recording the extreme temperatures, which in reference to their effects on health and vegetation must be regarded as 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 not 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 information 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.

159. *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 Menton 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 Menton it was only 77°.6; and during the coldest period of the night the temperature was 59°.5 at Madrid, whilst at Menton it was as high as 68°.0.

160. 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.

161. *Range of Temperature.*—This points out the import-

ance of considering the daily range of temperature, or the difference between the extreme day and night temperatures. Additional interest is added to the subject by the consideration that the rate of mortality is to a very large extent determined by the range of temperature of the climate. 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°.

162. 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. Owing to the restricted use of self-registering thermometers over the earth, the latter of these two is more widely known than the former.

163. 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 and 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; 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. It may be noticed here as remarkable, that in most of the above cases, though the range differs greatly, yet the mean annual temperature is found to be nearly the same. On considering these different conditions under which temperature may be observed, it is evident that if any of the above conditions were adopted as the standard the results could not be comparable. The arrangement least open to objection is that already recommended in par. 136 to 138, which has the great merit of being easily carried out in all places. An objection, sometimes urged against it, is this: The wood of the louvre-

boards being a bad conductor of heat retains during night part of the heat acquired during the day, and as a consequence the minimum thermometer does not fall so low during night as it otherwise would do. Grant there is something in this objection, the error must be small in the case of boxes in which the ventilation is so very complete, and which are largely protected from the sun's rays by a thick coating of white paint, and by a double system of louvre-boards. But since, as already stated, par. 136, *a perfectly unobjectionable arrangement is impossible*, the above is the least objectionable, and to be preferred to the practice of exposing the thermometers in a box open in one direction and placed against a wall. For, from experiments made with a number of boxes so constructed, the indications are found to vary with the amount of sky exposed to the thermometers, and their proximity to walls, trees, or other objects which radiate their heat to the thermometers; whereas with boxes louvre-boarded all round, such variation does not occur, or if it does, only to a very slight degree.

164. Of the daily registered highest and lowest temperatures, the following, for July 1866, is a specimen of the monthly abstract published by the Scottish Meteorological Society, as regards March Hall, Edinburgh :—

	Degrees.
Highest temperature in month, ...	82.7
Lowest do. in month, ...	45.0
Monthly range, ...	37.7
Greatest daily range, ...	29.7
Mean of all the highest, ...	65.5
Mean of all the lowest, ...	51.5
Mean daily range, ...	14.0
Mean temperature, ...	58.5

165. The above analysis, continued from month to month through a number of years, is sufficient as a basis on which this main element of climate may be established. But there are other points of the greatest practical importance in climate which require a more searching analysis for their elucidation, such as the frequency of occurrence, at different seasons, of

certain temperatures that exercise a powerful influence on vegetation and on health.

166. 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. 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 the staple products of the respective countries.

167. 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. Little has yet been done in preparing such tables, owing to the heavy tedious labour in compiling them. Perhaps Scotland is the only country whose climate has been thus examined; it is to be hoped that observers in other countries may be induced to analyse their observations and

publish the results. 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 enjoy the greatest safety or receive the greatest advantage that can be procured from a change of climate.

CHAPTER V.

TEMPERATURE—SOLAR AND TERRESTRIAL RADIATION.

168. The interchange of temperature among bodies takes place by conduction, convection, and radiation.

169. *Conduction.*—The communication of heat by *conduction* 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 the worst conductors.

170. 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. As regards the relative conducting powers of different substances, 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. From this it follows that 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, that frosts and extreme temperatures do not penetrate so far down into light soils as into heavy soils. In Scotland, during the past nine years, the

temperature at three inches below the surface has fallen to 26°.5 in loose sandy soils, and at a depth of twelve inches the freezing point has only once been observed. But in clay soils, at three inches the lowest is 28°, whilst at twelve inches the temperature often falls to freezing, and even at twenty-two inches 32° has once been recorded.

171. 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 are at the same temperature, because the heat is conveyed away from our bodies more rapidly. Thus at the breaking of the severe 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.

172. Snow being composed of crystals, with a very large quantity of air entangled among their interstices, is on that account one of the worst conductors of heat. It thus serves to protect 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.

173. *Convection.*—Though fluids and gases are bad conductors of heat, yet they may be quickly heated by a process of circulation of their particles called *convection*. When heat is applied to the bottom of a vessel containing water, the particles at the bottom, being heated, become lighter and rise to the surface, and other particles descend to take their place. Thus two currents are 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.

174. 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. We see it in the ascending and descending currents of the atmosphere everywhere, which are

caused by the daily fluctuations of temperature on 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 from the poles to the equator, giving rise to the polar and equatorial currents of the atmosphere. The same cause puts in circulation the waters of the ocean. The great and beneficial effect resulting from these currents is a more equal distribution of temperature, thereby mitigating the rigours of the polar cold, and moderating the scorching heat of the tropics.

175. *Radiation.*—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 at some distance from it. This mode by which heat is communicated is called *radiation.* Radiant heat proceeds in straight lines, diverging in all directions from its 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.

176. 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 colder bodies than it radiates to them, and consequently will become colder. 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.*

177. Solar Radiation.—(1.) *On Land.*—Of the solar heat which arrives at the surface of the earth, the part which falls on land is 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 downwards only by conduction. While the temperature of the surface increases, a wave of heat continues to be propagated downwards 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.

178. As regards the effect of the solar heat on the temperature of the air, it is the temperature of the extreme upper layer of the land which requires almost exclusively to be considered, seeing it is chiefly by contact with the surface that the temperature of the air is increased or diminished. Hence it is badly conducting surfaces which 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, 200°. When these hot particles of dust are lifting 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 and Arabia where the highest temperature on the globe occurs, their mean summer temperature ranging between 92° and 95°. The surface of loam and clay soils is not heated to 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.

179. When the earth 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 is not allowed to 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 superfluous heat; and heated air being lighter, it is constantly flowing off and giving way to colder air to supply its place. Hence one chief difference between the climates of two countries, the one covered with vegetation and the other not, consists in the heat being more distributed over the twenty-four hours in the former case, and being less intense during the hottest part of the day.

180. *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 illustrated in the case of forests. Trees are heated and cooled by solar and nocturnal radiation in the same manner as other bodies. They do not, however, acquire their maximum temperature till a little after sunset. This occurs in summer at 9 P.M., while in the air the maximum temperature occurs between 2 and 3 P.M. Hence trees may be conceived 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 very rapid. Hence the effect of forests on the daily temperature is to make the nights warmer and the days colder, or to give to the climate of countries clad with trees something of the character of an insular climate. Evaporation goes on slowly from damp ground under the 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, though exact observations are wanting to settle the question, it is probable that forests diminish the evaporation and increase the humidity. It also follows that forests lower the summer temperature, and maintain the winter temperature higher than it would otherwise be. This enables us to understand how forests increase the rainfall; for suppose an extensive forest to have its temperature 2° lower than that of the surrounding district, this lower temperature will have the same effect on the rain-bringing winds, as if a low range of hills opposed their course, and condensed their vapour into rain.

181. Thus it is evident that 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 will differ materially from each other. For the answer to this question, which affects to a great extent the interests of large sections of the human race, especially those dependent on the culture of the sugar-cane, it is to be regretted that there is little else than speculation to guide us. No trustworthy answer can be given till we have a series of hourly observations of the rainfall from two stations under similar meteorological conditions, except that the one is in the centre of an extensive wooded district, and the other in the centre of an extensive district which is clear, or nearly clear, of trees.

182. 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.

183. (2.) *On Water.*—When the solar heat falls on water, it is not, as in the case of land, arrested at the surface, but penetrates to a considerable depth below the surface. Also, 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 is diffused through a considerable depth of the water floating near the surface.

184. *Specific Heat of Water in relation to Climate.*—The specific heat of a substance is the number of units of heat required to raise the temperature of one pound of it by one degree. Thus 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, it 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 cases 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 chiefly due.

185. The temperature of the sea is also diminished by the process of evaporation constantly going on from its surface.

186. *Mode of Observing the Temperature of the Surface.*—It is necessary to distinguish between the amount of solar heat which arrives at the surface of the ground, and the tem-

perature to which the surface is raised by the heat which thus falls upon it. It is with the latter—viz., the temperature of the surface—that as practical meteorologists we have principally to do. In attempting to ascertain the effect of this element on the climate of such a country as Great Britain, which has so large a portion of its surface covered with grass or analogous plants, it is evident that it is to the temperature of grass that we should direct our attention. In vine-growing countries, where a great part of the surface of the soil is exposed to the sun, and in countries whose surfaces consist of rocks or tracts of sand destitute of vegetation, the temperature of the surface exposed to the solar heat will be very different from that of Great Britain. Care should be taken to place the thermometer in positions which will enable the observer to ascertain the temperature of the general surface. The temperature to which the leaves of plants, the ears of wheat, and other objects of agricultural and horticultural produce, are raised by the direct rays of the sun shining on them at different heights and in different climates, though a subject of great practical importance, has not yet been inquired into.

187. 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 shall shine directly on the bulb for as large a portion of the day as possible. This is best accomplished 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.

188. It frequently happens in cloudy weather, when there

is mist or drizzle, that these exposed black-bulbs register a lower temperature than thermometers in shade, being for the time almost under the conditions of the wet-bulb thermometer. But in such cases the difference is always small. Again, during calm, foggy, or dull weather, suddenly following cold, such as frost in winter, it often happens that the exposed maximum thermometer is several degrees lower than the protected one—a difference due to the proximity of the exposed thermometer to the cold ground, as compared with the protected thermometer four feet above it.

189. *Black-bulb thermometers* enclosed in thin glass tubes, hermetically sealed, are used for the purpose of ascertaining approximately the amount of the solar heat falling on the surface of the earth.

190. It would be interesting to inquire whether the heat received by the earth from the sun varies from year to year, and if so, to what extent. On account of the obstruction offered to the sun's rays by the vapour of water, and our necessarily imperfect knowledge of the varying quantity of vapour in the atmosphere interposed between the thermometer and the sun, it would be useless to conduct this inquiry at any place in Great Britain, or indeed anywhere except at some place within the tropics, and situated at a great height above the sea, where the amount of aqueous vapour is small and nearly constant. Perhaps the best situation would be Bogota, South America, lat. 4° 43′ N., and 8727 feet above the sea; or Quito. A black-bulb thermometer hermetically sealed would suit the purpose. From the importance of the inquiry, and from the simplicity of the required observations, which need not occupy more than one minute a-day, it is to be hoped some member of the medical profession, or some other person resident in Bogota, will undertake the observations.

191. 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 its own radiation into space that the earth parts with this

heat,—a process which is continued 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 falling more aslant, less heat begins to fall on the earth than is given off by 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. This mode of making up the loss lasts only 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. When the chilling of the surface goes on, it receives additions of heat from the air in immediate contact with it, and from the air above by radiation downwards from it. 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.

192. 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 is given out, as happens in every case when gaseous bodies are converted into fluids.

193. When the sky is wholly or partly covered with clouds, a large part of the heat radiated from the earth to the clouds is radiated back again by 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.

194. 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.

195. 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.

196. The degree to which the temperature of an object 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. The degree to which this remark holds is very striking when first brought under the notice of an observer. A sensitive mercurial thermometer will be seen to rise at once by the heat radiated from his person, as he approaches to examine it. Nay, even the holding up of the fragment of a wooden rail at a distance of some yards from the thermometer, has been observed perceptibly to raise its temperature. A cloud passing over raw wool much cooled by radiation, has been observed by Mr Glaisher to raise the temperature of the wool 1° per minute, and 15° in the quarter of an hour.

197. *Means of Measuring the Cold of Radiation.*—A thermometer is exposed in the focus of a concave mirror, polished within and without, with the concavity pointing upwards, in order to cut off all view of the earth. The only heat a thermometer placed in these circumstances can receive, is from the radiation of the air, and from the condensation of moisture. A thermometer so exposed always indicates a lower temperature than thermometers exposed on the surface of the earth.

198. But since it is the temperature of the surface of the earth which it is most important to know, owing to its intimate connection with the temperature of the air, a much simpler instrument is adopted. This is the ordinary *Minimum Black-bulb Thermometer*, which is a common minimum ther-

mometer with its bulb blackened. As in the case of the maximum black-bulb, it is laid on 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. The reason for these restrictions will soon appear.*

199. The degree to which the temperature falls depends on the radiating and conducting powers of the surface over which the thermometer is placed, being 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 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

200. 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

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* But it must be conceded that all the means yet proposed for determining solar and terrestrial radiation are only approximations to a solution of the problem, and that no satisfactory method has yet been devised.

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.

201. We thus see why it is that the temperature of grass and other plants falls during the night so much below that of garden mould, sand, and gravel. The great difference is not owing so much to different quantities of heat radiated into space, but to the ease or difficulty with which heat is conducted from the soil to the radiating surfaces so as to supply the loss sustained by radiation.

202. *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 water 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. 199, 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 the objects of the earth's surface which most require its refreshing influence. It is not deposited in cloudy weather, because clouds obstruct the escape of heat by radiation into space; 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. See par. 13.

203. *Effects of Radiation on Water.*—Water being a good radiant, heat is freely given off from its surface 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 occasioned 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.

204. The descent of the cold, and ascent of the warm, particles of water, is a much slower process than is generally supposed. From observations made by Captain Thomas, in the ocean west of Scotland, during September and October 1858 and 1859—that is, during the great annual fall of temperature—it was found that the mean temperature at a depth of 24 feet was 1° *warmer* than at 1 foot, and about 0°.8 warmer at 60 feet than at 6 feet. This is instructive, and shows the value of observation over theoretical deductions; for theory might have led us to suppose that the warmer water would have risen more readily to the surface. At this season the water of the sea is not in a state of equilibrium, a disturbing agent being at work (the cooling of the surface water), causing a continual descent of the colder and ascent of the warmer particles; and this process goes on as long as the surface is colder than any of the underlying watery strata. The difference between the temperature of the surface and that at several fathoms below the surface, shows, in a forcible manner, the length of time required to effect a complete

correspondence between the temperature of the sea and that of the air; for, being brought about by upward and downward currents, the difference of whose temperature is small, the motion of the currents and the interchange of temperature resulting therefrom proceed at a very slow rate.

205. The mean daily range of the temperature of the sea has been ascertained off the Scottish coast from Captain Thomas's observations, already referred to. 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 especially exceptional; whilst the temperature of the surface of the land varies not unfrequently as much as 100°. These figures present in perhaps the most striking light the conserving influence of the ocean on climate.

206. It is a well-known law of matter that bodies expand with heat and contract with cold; but to this law water is one of the remarkable exceptions. Water follows this natural 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 48°. 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, its maximum density would be at 27°.2, if it did not freeze before reaching that point.

207. 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 gets colder, 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 be reduced, 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 reduced.

208. *Difference of Shallow and Deep Lakes on Winter Climates.*—Owing to its great depth, Loch Ness, in 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; thus presenting so remarkable a contrast to the ice-bound streams on each side, that an oily element is vulgarly attributed to its water, preventing it from freezing. On the other hand, Loch Leven, in 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.

209. 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 displayed. Owing to the severity 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.

210. Advantage has been taken of terrestrial radiation *to secure the formation of ice* during the night in Bengal when the temperature of the air is above 32°. The process was first

described by Sir R. Barker, and afterwards by Mr Williams. It was a profitable business, and three hundred persons were employed in it. 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.

211. *Effects of Terrestrial Radiation on Land.*—One of the chief effects of terrestrial radiation on the air superincumbent 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 the variation on the sea.

212. *Increase of Temperature with the Height during Cold Weather.*—This 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 comparatively 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. Hence the necessity of having all thermometers in shade placed at the same height above the ground, for otherwise the results are not comparable. 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. Professor Wheatstone's thermometer, described by him at the meeting of the British Association held at Dundee in September 1867, by which the temperature at the bottom of the sea might be read continuously, might, by means of fixed or captive balloons, be turned to excellent account in solving the important problem of the decrease of temperature with the height.

213. 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 meteorological 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 slips down the slopes and accumulates in 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, because they are 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 of neighbouring heights. Hence low-lying places are peculiarly exposed to intense cold. Plains and table-lands are simply affected by their own radiation.

214. This explains why vapour becomes visible so frequently in low places, whilst adjoining eminences are clear; and 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 below a certain height were destroyed, but above that height they escaped; thus attesting, by unmistakable proof, to the great and rapid increase of the temperature with the height above the lower parts of the valleys.

215. *Distribution of Cold in Mountainous Countries during Winter.*—From the above remarks, 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. For the illustration of this point, it is fortunate that sixty-nine meteorological stations were established in Switzerland in 1863; and as one of the firstfruits of this Society, a paper has been

lately published by Professor E. Plantamour, on the Distribution of Temperature on the surface of Switzerland during the winter of 1863-64. Whenever the soil is colder than the air above it, the superficial layers become cold by contact, as already explained, and a system of descending air-currents sets in over the whole face of the country. The direction and intensity of these descending currents are modified by the irregularities of the ground, and, like currents of water, they tend to converge and become united in the gorges and ravines, down which they flow like rivers in their beds. These currents give rise to counter-currents flowing over them to supply their place.

216. 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 and ravines, are 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 upper regions of the atmosphere.

217. 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 defined, so that on rising above it in ascending the slope, an 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; and 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 to such gusts of cold wind as those referred to above.

218. *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 is exerted 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.

219. 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.

220. 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.

221. *Situations which afford the best protection against the Cold of Winter.*—In countries such as Great Britain, and, indeed, in most temperate countries, 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 from 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 the temperature many degrees higher than what prevails at lower situations near at hand—a difference which will frequently assuage suffering, and on certain occasions save life. The advantage will of course be the greater if the sleeping-apartments be in the higher flats of the house. The dwellings most 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. It is chiefly on account of these natural advantages that Bridge of Allan owes its popularity as a winter resort for invalids. It may not be irrelevant here to draw attention more particularly to the degrees of advantage held out by different sites in the same town or village—the low-lying being the coldest, and those on slopes and sheltered by trees being the mildest.

CHAPTER VI.

THE DISTRIBUTION OF TERRESTRIAL TEMPERATURE.

222. 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.

223. The most striking fact regarding the temperature of the sea, as ascertained by soundings, is that below a certain depth, dependent on the latitude, an invariable temperature of about 39° prevails. The depth at which this temperature is met with at the equator is about 7200 feet. On receding from the equator it becomes less, until about latitude 56° it reaches the surface, unless where superficial currents push it into higher or lower latitudes. From 56° lat. towards the poles this uniform temperature descends, till in 70° lat. it is 4500 feet below the surface.

224. Thus, then, the surface of the ocean is divided into three great regions—one surrounding each pole, where the temperature is below 39°, falling at the coldest parts to the freezing-point of sea-water; and the third, the zone between these two, the temperature of which is everywhere higher than 39°, rising at some places within the tropics to an annual mean of 85°.

225. How comes it that in the warmest parts of the globe, within the tropics, the temperature of the sea at all depths

below 7200 feet is invariably as low as 39°, and that by far the larger portion of the water of the ocean remains constantly at this low temperature? In the first place, it must be kept in mind that 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, in the second place, since sea-water contracts, and consequently gains in density, as it is cooled until it freezes, 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.* It is remarkable that this uniform temperature of 39° is the temperature at which pure water attains its maximum density. It may, however, be added, that this agreement is no more than a mere coincidence, there being no connection between the two facts.

226. *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 largest collection of facts bearing on the subject is in possession of the Board of Trade, consisting of about 550,000 different observations. In addition to these it is estimated that upwards of a million are still required before sufficient materials are obtained for solving the problem of the temperature of the sea. The British Government has taken steps to obtain the observations still desiderated, and to digest, tabulate, chart, and publish the results.

227. *Temperature of the Sea round Scotland.*—The part of the sea whose temperature is best known, is that portion surrounding the Scottish coast, from which, owing to the labours of the Scottish Meteorological Society, we have systematic observations during the last ten years. From these observations we learn that the mean annual 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 most apparent. 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. Richard Adie has observed the temperature of the sea in the shallow estuary of the Mersey as low as 29°; and during the severe frost of Christmas 1860, the Moray Firth was frozen to a considerable depth a mile seaward.

228. *Temperature of the Sea in different parts of the Globe.*—Among the papers left in an unfinished state by Admiral Fitzroy, was one on the temperature of the sea. This paper has since been published, and is accompanied by a chart, on which the surface of the globe is divided into spaces ranging between 80° N. lat., and 70° S. lat., and bounded by each tenth meridian and tenth parallel. Those spaces, in themselves of unequal areas, and of different shapes, are named ten-degree squares, because of their uniformly rectangular appearance in the charts drawn on Mercator's projection. The mean temperature is printed on these ten-degree squares. Partly owing to the fewness of the observations made in many of the squares, and partly to the method adopted in reducing the observations, this chart of sea temperatures cannot be considered otherwise than as a rude approximation to the real temperatures of many of the squares. In the square including Great Britain, the mean temperature of the sea is

stated to be 55°.8, which is, without a doubt, at least 3° or 4° too high; and in the adjoining square to the east, including the North Sea, the temperature of that sea is given as 50°.9, perhaps also a little too high. In spite, however, of this serious drawback, it is, and will be for some years to come, our best source of information regarding the temperature of the sea taken as a whole. On this ground we shall give some account of the temperatures as there laid down.

229. Owing to the small change of temperature within the tropics, the temperature of the sea in these parts is probably very near the truth. It is generally from 80° to 83°.5.

230. *Mean Temperatures of the different Oceans.*—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.

231. 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 three seas cannot but exercise a powerful influence on the climates of Palestine, Asia Minor, and adjacent countries.

232. 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.

233. *Abnormal Distribution of Temperature caused by Currents of the Sea.*—The following diagram gives the temperatures of the ten-degree squares as applicable to the North Atlantic:—

Long. West of Greenwich	80°	70°	60°	50°	40°	30°	20°	10°	0°
N. Lat. 70°									
	—	—	38.2	36.7	49.0	49.1	49.4	52.0	
” 60°									
	—	—	45.6	44.1	52.7	55.8	56.8	55.8	
” 50°									
	—	51.6	54.7	56.3	61.5	60.1	59.7	57.8	
” 40°									
	64.1	64.6	68.2	70.6	68.4	67.2	66.7	65.3	
” 30°									
	77.7	77.5	77.8	73.3	74.8	72.5	71.0	—	
” 20°									

From these figures it is evident that if a line be drawn from Cuba in the direction of the Faroe Isles, it will 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 the celebrated Gulf Stream, which, issuing from the Gulf of Mexico, 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 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.

234. 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.

235. South of Sierra Leone, the temperature of the Atlantic is only 75°, but from this westwards 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°.

236. 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 on the great bank of Newfoundland.

237. 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.

238. On the other hand, 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 thus 13°.5.

239. 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.

240. 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., and lower temperatures no doubt occur in higher latitudes.

241. 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.

242. It should be here remarked that the information gained from this chart, and from Maury's sailing directions regarding the currents of the sea, is in many cases of a very general character. The service already rendered to navigation

by the knowledge thus disseminated 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 Royal Society, 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.

243. 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.

244. As an example of what may be expected from a thorough examination of the ocean, we may mention that on a cruise from Gravesend to Farö during August 1865, Dr George Keith, Edinburgh, on the 7th, at 9 P.M., found the temperature of the sea, six miles off Whitby, to be 59°; on the following morning, twenty-five miles off Newcastle, it was only 52°; in the evening, when four miles off the Fern Islands, it was 54°; and on the morning of the 9th, five miles off St Abb's Head, it was 56°, at which point it remained till the latitude of the most northern point of Scotland was passed. Was the low temperature of the sea on the British coast from the Wash to Berwick, caused by a

cold current from the Baltic Sea (where the temperature had been unprecedentedly low during the summer) issuing through the Skager Rack, and thence spreading itself westward toward the opposite coast of England? and if so, was it merely a temporary current, or a permanent current, or a current flowing only during certain seasons of the year? The effect of such a current on the valuable fisheries of the North Sea, and on the climate of the north-east of England, especially when the wind is from the east, must be very great; but so meagre is our knowledge of the temperature of the North Sea, that no answer can be given to the above questions, though the success of the herring-fishings depends to a large extent on the possession of such knowledge.

245. *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 fresh water, which is considered as unity. The density is ascertained by means of the hydrometer, fig. 17, which is a glass vessel loaded with mercury or shot, and furnished with a scale. The zero point is found by floating it in pure water, at a temperature of 60°, and marking the point on the scale just where it meets the surface of the water.

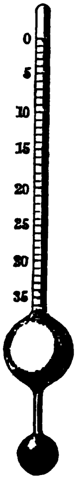

Fig. 17.

246. 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 At-

lantic 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.

247. 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 in 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 of any lake known, containing 32 per cent of saline matters; the Dead Sea, 24 per cent; and the Salt Lake of Utah, 22 per cent.

248. 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.

249. 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, the density being 1.0000. 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.

250. 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 the 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.

251. *Currents caused by the different Specific Gravities of the Sea.*—If we except such partial currents as those caused by the tides and the winds, all the currents of the ocean are produced by the different density of the water of the sea at one place as compared with that at another, whether it arises from different degrees of saltness or of temperature. Thus the seas of the two polar basins being about 50° colder than the sea within the tropics, their specific gravity is much greater. To restore the equilibrium, the warmer, and therefore lighter, water of the equatorial regions flows towards the poles, and the colder and denser water of the polar regions towards the equator. If the whole globe was covered with water of the same saltness throughout, the equatorial current would be seen everywhere flowing towards the poles as a surface-current, and the polar current could be detected by soundings flowing everywhere towards the equator as an under-current. But owing to the obstructions offered by the land, and by the inequalities of

the bed of the ocean, and to the different degrees of saltness and therefore of density prevailing in different parts of the sea, these two great currents are broken up into the innumerable currents and counter-currents which diversify the face of the ocean and mark out the highways of commerce.

THE TEMPERATURE OF THE LAND.

252. 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 in countries 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.

253. *Influence of Snow on the Mean Temperature of the Soil.*—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. It is in Russia and Siberia that the greatest divergence between the curves of these two temperatures is observed to take place. 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 Semipolatinsk, 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.

254. The daily changes of temperature do not affect the soil to greater depths than 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.

255. 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.

256. 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 down-

wards to 24 feet, the latter depth being fully a degree above the former. At 3 feet the mean temperature is 45°.83; at 6 feet, 46°.07; at 12 feet, 46°.36; and at 24 feet, 46°.88.

257. 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 annual mean 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 proved 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 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. The mean rate of increase over the globe is probably 1° of increase of temperature for every 50 English feet of descent.

258. 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 important 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 under ground 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.

259. The distribution of heat over the surface of the globe is best represented by isothermal lines, or lines drawn through all places having the same mean temperature. The mean temperature of the warmest month in the northern hemisphere, July, is shown by the isothermal lines in Plate IV.; of the coldest month, January, in Plate V.; and of the year in Plate VI. These systems of lines are sometimes called *isotherals*, or lines of equal summer temperature; *isochimenals*, or lines of equal winter temperature; and *isothermals*, or lines of equal mean annual temperature.

260. In all the charts the part of the earth's surface where the highest temperature prevails forms an irregularly-shaped belt lying within the tropics, and 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 deviations brought about by disturbing causes too important to be overlooked. 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), the prevailing winds; and (5), mountain-ranges.

261. The influence of an oceanic current on climate depends on the temperature of the place it leaves, and that of the place toward 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 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.

262. *Gulf Stream.*—Of these currents the most important as well as the most marked is the Gulf Stream, 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 V., receives striking illustration from the charts. If no more heat is 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 37°—Shetland being thus benefited 36° and London 20° 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 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.

263. *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 winter, fig. 18, 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, we should expect a different arrangement of the lines of equal temperature.

264. 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.

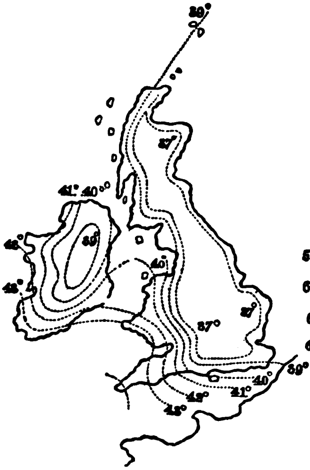

Fig. 18.

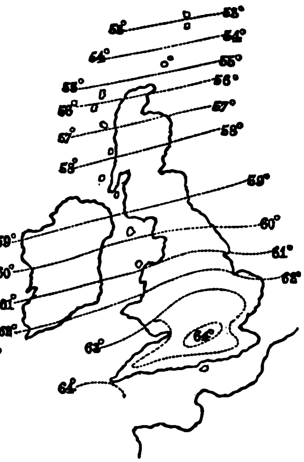

Fig. 19.

265. 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 by the west coast of America, depressing the temperature, especially the summer temperature, of these parts, Plate IV. 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 V., 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.

266. In all cases the influence of these currents is most distinctly marked in January and July, the months of extreme temperatures. Thus the warm current of the Gulf Stream is most felt in January, when several of the *isochimenals*, 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 that month, the distance being about 1300 miles nearer the equator. About the most remarkable lowering of the isothermals occurs on the Labrador and Newfoundland coasts during May and June, being caused by the icebergs which then descend on these coasts through Davis Strait.

267. The great fresh-water lakes of North America—Lakes Superior, Huron, Erie, Michigan, Ontario, Bear Lake, &c.—exercise 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, which is 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 32°, 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 all round its coasts would have been much milder.

268. Since winds bring with them the temperature of the regions they have traversed, the equatorial current is a warm wind, and the polar current a cold wind. 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 during the year as winds from a continent. As an atmosphere loaded with vapour obstructs both solar and terrestrial radiation, moist winds blowing 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 the polar 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 polar and continental current.

269. 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 lie perpendicular to the course of the wind, and are at the same time of great 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°.3, the difference between those of Söndmör in the same latitude, but on the other side of the Dovréfeld Mountains on the coast, is only 33°.8. In the British Islands, the same differences between the east and west are considerable; thus, on the coast of Essex, the difference is 26°, whilst in Kerry it is only 18°. A large part of this difference is due to the great dryness of the air in the east as compared with the west.

270. These considerations explain the position of the isothermals in the north temperate zone, where the prevailing wind is the S.W. or anti-trade. In January, as shown on Plate V., 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 getting colder and drier as they advance, 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 as a consequence the temperature rapidly falls. In the interior of Siberia, the January temperature falls to –40°, which is 9°

colder than the coldest part of the American continent. 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.

271. On the other hand, the interior of continents is much hotter in summer than their western parts, 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.

272. Hence the countries in the interior and in the east of Asia and America are characterised by extreme climates, and the countries in the west by equable climates. Thus at Yakutsk, in Siberia, the temperature in July is 62°.2, and in January −43°.8; whereas at Dublin these are respectively 59°.8 and 41°.0. Thus the difference between the summer and winter temperature at Yakutsk is 106°.0, whilst at Dublin it is only 18°.8. The temperature of New Archangel, in Sitka, in the west of North America, is 55°.6 in July, and 32°.4 in January; whereas at Fort York, on Hudson Bay, in the same latitude, the July temperature is 60°.0, and the January −5°.1, thus giving a difference of only 23°.2 between the summer and winter temperature on the coast of the Pacific, but of 65°.1 in the interior of the continent.

273. Fig. 19, 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. Great Britain owes more to Ireland than is generally supposed.

274. It is this which makes the most important distinction among climates, both as respects animal and vegetable life. On man especially the effect is very great. The severity of the strain of extreme climates on his system is shown in a striking manner by the rapidly increasing death-rate accord-

ing 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 found on advancing into the continent of Europe, that the more extreme the climate becomes, so much the more is the death-rate increased.

275. The combined effect of the disturbing causes is seen at once if we compare the observed temperature with the *normal temperature*—that is, the temperature due to a locality in respect of its latitude alone. Dové has published an elaborate set of maps, constructed on this principle, in which he shows by a system of *Thermic Isabnormals* the deviations from the mean of each month, and of the year, in the different parts of the globe. Those maps show that in January, in the northern hemisphere, the sea and the western parts of the continents are in excess of their normal temperature, but that elsewhere there is a deficiency. There are two centres of excess—one to the north-east of Iceland, amounting to 41° of excess; the other in Russian America, amounting only to 18°. On the other hand, there are two centres where the temperature is deficient—one at Irkutsk, amounting to 41°; and the other west of Hudson Bay, amounting to 27°. In July, the United States of America, Europe, Asia, the Indian Ocean, the north of Africa, and the extreme north of South America, have their temperature in excess, while elsewhere it is deficient. The centres of greatest excess are the north of Siberia, 13°.5 of excess; the Red Sea, 11°; and the north-west of the United States, 4°.5. The centres of greatest defect of temperature are the entrance to Hudson Bay and the Aleutian Islands, the defect in each case being 11°.

276. 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 no doubt 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 it is in January.

277. *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 keep the aërial particles further asunder, 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. This supposition is confirmed by the circumstance that the low mean temperatures which universally prevail in high places are chiefly caused by the low temperature during the nights, and during the winter season when terrestrial radiation is the main influence at work modifying the temperature. 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.

278. From what has been here advanced, it is plain that 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. Accordingly, much diversity of opinion exists regarding the rate of decrease to be allowed in reducing temperature observations to sea-level. For the five years ending with December 1861, the mean annual temperature of Montrose, Forfarshire, 14 feet above the sea, was 47°.2, and of Braemar, Aberdeenshire, 1110 feet high, 43°.5. This gives the rate of decrease, 1° to every 296 feet, or nearly 1° for every 300 feet, the rate of decrease most generally adopted. But the law, through its different variations, requires yet to be stated.

CHAPTER VII.

TEMPERATURE—ITS RELATION TO ATMOSPHERIC PRESSURE.

279. The relation which exists between the temperature of a portion of the earth's surface and the atmospheric pressure at that place 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. The examples will be taken from the recent numbers of the Journal of the Scottish Meteorological Society, and almost all of them will be selected from the weather of 1867—a year so remarkable for illustrations of violent alternations of heat and cold, drought and rain, brilliant sunshine and the dullest weather, as well as for the many great storms which have swept all parts of the globe, that it may well be regarded as the *annus mirabilis* of meteorology.

280. *Examples* 1 *and* 2.—During the severe frost which prevailed in Great Britain from the 1st to the 21st of January 1867, the following are the mean pressures, reduced to 32° and sea-level, at different places from the English Channel to Iceland for these three weeks:—

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

Now, since air flows from the region of high to that of low pressure, these figures show at a glance the immediate cause of the singularly low temperature which prevailed; for it is plain that Great Britain was then in the stream of a powerful polar current descending from Iceland over Western Europe. The geographical distribution of the cold is instructive. Thus 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 nearer the source of the cold suffered a greater depression of temperature than places further south. The wind during the time blew from the N., N.E., and E. ten days more than the average of the month. The same principle is illustrated by the equally severe weather of March 1867. From the 15th to the 18th, during which the severity of the cold was greatest, the pressure in Iceland was 30.191 inches; in the south of Norway, 29.941 inches; in Orkney, 29.943 inches; and at Brest, in France, 29.619 inches; and as a consequence, the mean temperature of Scotland fell to 29°.7, being about 11° below the average temperature of the season—a degree of cold which, in our equable climate, is happily of rare occurrence in this or any other season.

281. *Example* 3.—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

Thus during the month there prevailed over this part of Europe a remarkably strong equatorial current, bringing over Great Britain the warmth of southern latitudes. The mean temperature of Scotland for the month rose to 4° above the average, being absolutely the highest mean temperature for

February hitherto recorded. The winds, it need scarcely be added, were almost wholly from the S., S.W., and W. 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 all the more remarkable from its being immediately preceded and followed by the almost unprecedentedly cold weather already described.

282. *Example* 4.—During 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. To the north, the temperature was below the average, to the extent of 5° in Iceland, and 2° at Farö; whereas to 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 under such circumstances that long-continued rains take place—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.

283. *Examples* 5 *and* 6.—*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.
Reykjavik, Iceland,	29.957	...
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, the 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 gradual movement of the whole 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, no doubt, 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 actually took place during September 1865 (see the above barometric readings). 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.

284. An important and vital distinction must be here drawn. 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

high pressures increase 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 got higher—severe frosts would no doubt have been the consequence.

285. It is the general relation of the barometric 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 on examining Plates I. and II., from which the south-westerly direction of the winds which prevail in these months is the natural consequence, as well as the peculiar distribution of the temperature as figured on the small charts on page 121. In addition to the examples already adduced, I shall give other two instances which place in a remarkably strong light the intimate connection between these two important meteorological elements.

286. *Example 7.—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 isobarometric curves for Europe and Western Asia for each of these nine days. The general result is shown by a chart showing the average pressures during these nine days. These I have calculated for a large number of places, and thence drawn the isobarometric lines on the accompanying chart (fig. 20), in which the solid lines show a pressure of 30 inches and upwards, and the dotted lines a pressure of less than 30 inches. The mean direction of the wind during the time is represented by arrows. Compare this chart of the pressure with Plate II., 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 isobarometric 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, though in a modified degree, into Northern and Eastern Europe, while at the same time

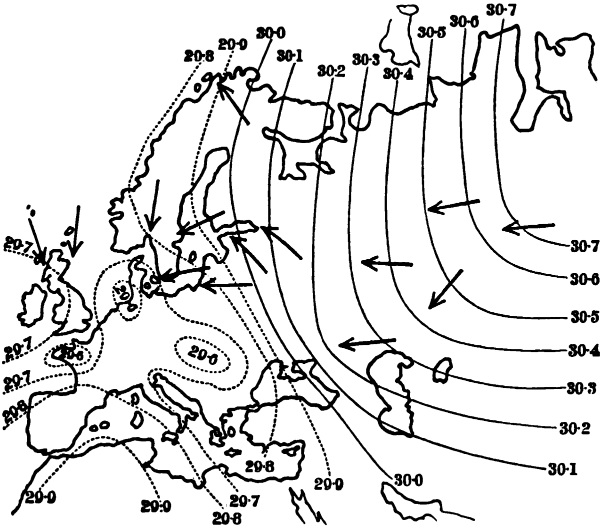

Fig. 20.

the pressure was low over the rest of Europe and in the north of Africa. At Tobolsk the mean pressure at 32° and sea-level was 30.685 inches, being fully an inch higher than that of Western Europe. On one day it rose at Tobolsk above 31 inches. Now it was by the enormous drawing force which the widespread low pressure prevailing 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 westwards 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 time comparatively small, light winds and calms prevailed. This desiccated air permitted the process of terrestrial radiation to proceed almost unimpeded; the thick covering of snow (which is a bad conductor of heat) checked the descent of the cold downwards 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 was permitted to accumulate 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. It is doubtless under circumstances similar to these that great frosts have occurred, such as that experienced in Flanders in 1544, when, according to Mézerai, wine froze in the casks, and was cut by hatchets, and sold by the pound weight. When the causes conspiring to bring about frosts so intense as that of Christmas 1860 are considered,—viz., an extraordinary distribution of pressure similar to that exhibited in fig. 20, 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.

287. In Scotland, the barometer continued to fall with the falling temperature till the 25th, which was nearly the period of greatest cold, after which it rose steadily with the temperature and with westerly winds until the 28th. According to the rule usually given in books, this was in both respects anomalous, since we are thereby taught to expect a rising barometer with cold easterly winds, and a falling barometer with warm westerly winds. The exception shows the arbitrary character of the rule. Fig. 20 not only gives an intelligible explanation of this great cold, but it points out the proper method of inquiry into the causes of weather-changes. This

great frost could not, it is evident, have been satisfactorily explained by observations limited to the British Islands and parts of the Continent adjoining, or even by observations from all Europe, excluding Russia; but the extension of the field of observation so as to embrace Russia, Western Asia, and Northern Africa, was necessary in order to arrive at the explanation.

288. 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 happens when cholera or any other pestilence stalks over the land. With a more extended field for our 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 measures in time to secure for his patients, who might require it, an artificial atmosphere of warmer and moister air, and thus extend the sphere of his usefulness in assuaging suffering and prolonging life.

289. *Example* 8.—*The Cold Weather of July* 1867.—This month was particularly cold and ungenial, but it was from the 18th July to the 1st August that the temperature was most deficient. The following figures indicate in inches the mean pressure during these two weeks:—Iceland, 29.928; Farö, 29.906; Shetland, 29.816; Orkney, 29.892; Hebrides, 29.896; Ross-shire, 29.868; Aberdeen, 29.825; Islay, 29.850; Liverpool, 29.831; Haddingtonshire, 29.821; Jersey, 29.882; Paris, 29.941; Vienna, 29.950; Brussels, 29.849; Riga, 29.658; St Petersburg, 29.670; Stockholm, 29.607; Mandal, south of Norway, 29.570; Christiania, 29.532; Hernösand, 29.552; Haparanda, 29.595; Vardö, north of Norway, 29.725. The pressure being low in Norway and countries surrounding the Baltic, and high in Iceland, Scotland was thus placed in the cold arctic current which set in from Iceland towards the Baltic. A comparison of the above pressures

with the mean pressure for July, of this part of the earth's surface (Plate I.), will show how completely the usual summer pressure in Scotland was reversed at the time, in consequence of which cold northerly winds (N.E., N., N.W.) took the place of the warm breezes from the south. The influence of this anomalous distribution of the pressure on the temperature is graphically exhibited in the two accompanying charts of the British Islands. The mean July temperature, fig. 21, is what occurs when the pressure is the average as in Plate I. Fig. 22 shows the mean pressure which occurred from 19th July to 1st August 1867, when the pressure was as detailed above. At Muthill, Perthshire, the mean temperature from the 22d to the 26th was only 48°.0, being 10° below the average, and during these five days the temperature did not rise above 54°.0. On the 23d frost occurred at Sandwick which injured potatoes and dahlias growing in low-lying situations—an

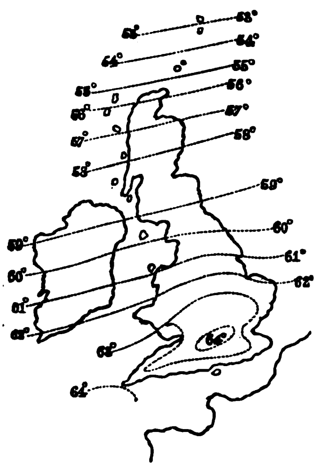

Fig. 21.

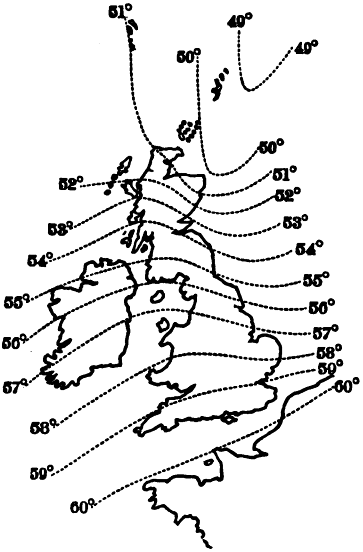

Fig. 22.

unusual occurrence at this season, particularly in Orkney. In Scotland, mist and fogs accompanied this period of low temperature, and as a consequence, the deficiency of temperature was greatest during the day.

290. Hence its disastrous effects on the harvest. It has been proved that in Scotland a temperature of at least 56°, with the average amount of sunshine, is required to ripen wheat and barley properly. But during this period the temperature was far below 56°, and the sunshine was at the same time very deficient; and hence, though the temperature sufficed for the growth of straw, it was altogether inadequate to carry on the functions which are concerned in maturing and ripening the kernel of the seeds, upon which the quality of the grain depends. Many of the wheat and barley flowers never ripened into seeds; and of those which ripened, the tough outer covering of the seed, usually thin, was large and abnormally developed, and the white kernel, usually large, was small and deteriorated.

291. It is evident from these remarks that, if we would understand aright the weather of Great Britain at any time, it is absolutely indispensable to have before us at least the barometric pressure, the temperature, and the winds, from at least the greater part of Europe. Another remark may be added. Though all meteorologists now agree in thinking that daily telegrams of the weather should not be attempted, yet a great deal not merely of negative information (such as the non-occurrence of storms), but also of positive information regarding the suitableness of the coming weather for travelling, farming operations, the growth and ripening of the crops, and for other objects and purposes of human life, may be most certainly concluded from daily weather-telegrams received from a wide field of observation. There is another use to which daily weather-telegrams may be put. It will be evident, from these illustrations of the relations of the pressure and temperature of the atmosphere and of the winds, that daily observations, particularly barometric, from a number of well-selected points in Europe, would supply sufficient data

from which really trustworthy conclusions could be drawn regarding the weather from day to day over any part of Europe in which for the time we might take an interest. And who is not so interested at the critical seasons in summer and early autumn, when the weather which then prevails over Europe really determines the state of the markets for the next year? If Mr Reuter would add to his daily telegrams a note of the weather, as suggested in par. 25, and if buyers and sellers would take the trouble to make a private note of these weather-telegrams from day to day, and gave a little attention to understand the principles of meteorology, they could not fail to arrive at a tolerably accurate estimate of the probable productiveness of the harvest in grain-producing countries. In this way they would be less in the power of the heartless spirit of speculation, which for its selfish ends too often succeeds by false representations in raising and depressing prices.

292. Some time ago I examined the mean temperature of Europe for each week of the year, beginning 1st April 1865, and ending 31st March 1866,* from observations made at sixty-three places as well distributed as possible over the Continent; and having calculated the excess or defect of each week's mean from the average of the week, constructed fifty-two charts, which exhibited by shadings of red and blue where and to what degree the heat and cold of each week was distributed. Among many points of interest which the charts brought into prominence, perhaps the most interesting was the relation between the pressure and the temperature of the atmosphere which they were found to illustrate in every case in which such relation was made the subject of examination. When a high pressure appeared in the N.E., N., or N.W., and pushed its way southwards or westwards over the Continent, its march was marked by a falling temperature, and the degree of the accompanying cold was generally proportioned to

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* See Journal of Scottish Meteorological Society, New Series, Nos. ix. and xi.

the difference between the pressures in the N. as compared with the pressures in the S. On the other hand, when a high pressure emerged from the S. or S.W., and thence spread itself over Europe, a rising temperature followed in its train, generally proportioned to the extent and volume of the equatorial current. These waves of temperature and pressure were frequently so vast that the whole of Europe could exhibit no more at one time than what seemed to be the merest fragment of one of them.

293. 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. But it might be supposed, 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. Now, the results of all observations hitherto made are unanimous in telling that this 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 speed. These interruptions are noticed here because they illustrate the connection between the pressure and temperature of the atmosphere.

294. 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 notice. 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 strong 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.*

295. I have examined the temperature of Scotland for a number of years, and have shown † that the following interruptions occur from year to year, with very rare exceptions, in the annual march of the Scottish 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.

296. The interruptions which take place in July, August, November, and December have been particularly examined; but since the same conclusions have been arrived at for them all, it will be enough to state the results of the examination of the November and December interruptions. The cold

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* For an account of the cold week of May, see a paper of great elegance and learning read by Dr Arthur Mitchell at a meeting of the Scottish Meteorological Society, and since published in 'Good Words,' May 1866.

† Journal of Scottish Meteorological Society, Nos. xiii., xiv., and xvi.

weather in the beginning of November is accompanied by an unusual prevalence of N. and N.W. winds, and by calms; by a diminution of the amount of the invisible vapour of the atmosphere; an increase in the rainfall, both as regards amount and frequency; and a more frequent occurrence of fogs. On the other hand, the mild weather of December is accompanied by an extraordinary predominance of southerly winds, and an almost total absence of northerly winds; an increase in the amount of the aqueous vapour, and a considerable increase in the rainfall, both in amount and frequency.

297. Hence, then, as regards the causes of the interruptions in the regular annual march of the temperature, we are led to one conclusion—viz., *that they are determined and regulated by the wind.* Nothing could present this in a clearer light than the winds which are found to occur during the November and December periods. Thus, during the cold period of November, winds from the N.E., N., and N.W. were in the proportion of 35 per cent, while winds from the S.E., S., and S.W. were 29 per cent. On the other hand, during the mild period of December, winds from the S.E., S., and S.W. were in the proportion of 69 per cent, while winds from the N.E., N., and N.W. were only 5 per cent.

298. But since the wind is only an effect or consequence resulting from differences between the atmospheric pressure in Scotland and that of neighbouring regions, we must look to the atmospheric pressure for an explanation of the interruptions of temperature. The pressure was examined with this view, and it was found to hold universally during the cold periods that pressure was higher to the north of Scotland and lower to the south, thus drawing over Scotland the polar current, and thereby depressing the temperature; and during the warm periods, that pressure was 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 have, so far as examined, been proved to depend on the relations of the polar and equatorial currents to each other. The circumstance that one of these great atmospheric currents, and not the other, prevails 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.

299. The commencement of each of these more 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 a well-known anomaly which occurs in the latter end of January and earlier part of February. In regard to this anomaly Principal Forbes, in his paper "On the Climate of Edinburgh," remarks: "In most European instances it affects materially the mean temperature of February, which is very commonly far too high when contrasted with the general sweep of the annual curve. At Brussels, M. Quetelet finds an excess in the temperature of February above the general curve of at least 1°.5. The same peculiarity may be noticed in the annual curves of London, Prague, St Petersburg, Vienna, and many other places, including the Great St Bernard." It is probable that a careful examination of the monthly isobarometric curves will lead to a better knowledge of so important an anomaly, and of the causes of its occurrence when the region over which it spreads has been accurately defined.

300. From the principles enunciated it is plain that the climate of Scotland is ruled and determined by the relations which most commonly exist between its atmospheric pressure and the pressure of surrounding regions. Since the same principles are applicable to the whole atmosphere, it also follows that mean monthly isobarometric charts furnish us

with 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 determined by the regions from which they blow. This subject will be more fully stated in the chapter on WINDS.

CHAPTER VIII.

THE MOISTURE OF THE ATMOSPHERE.

301. *The Two Atmospheres of Air and Vapour.*—The gaseous envelope surrounding 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 is 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.

302. According to the strength of the force of cohesion drawing the particles of matter together, as compared with the repulsive energy of heat driving 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. It is the absence of cohesion which is the distinctive characteristic of gases and vapours. 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 vessel in which they are, showing that, instead of cohesion, there is a mutual repulsion among their particles. Since, then, the particles constantly tend to recede from each other, it follows that they will exert an outward pressure on the sides of the vessel, and that the amount of this pressure will be proportioned to the repulsive force, or to the elasticity of the gas.

303. From the circumstance that a gas completely fills the vessel which contains it, it will be seen 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. It is generally known as Marriotte's law, and 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. But by doubling the pressure we double the elasticity.

304. This law is true for air at all pressures and temperatures which have hitherto been tried; but it does not hold good for the vapour of water, either as respects pressure or temperature. Under low pressures the vapour of water follows the law; but under high pressures the space occupied is less than would have been if the law had been observed, because part of the vapour then passes into the liquid state, thus occupying less space.

305. Since it is the repulsive force of heat which drives the particles of bodies asunder, it is evident that 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, it follows that 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.

306. 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 accord-

ing 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.

307. If the vapour of water remained permanently in the atmosphere—that is, was not liable to be withdrawn from it by being condensed into rain—the mixture would be as complete and uniform as that of the oxygen with the nitrogen. But the equilibrium 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. And since the independent and equal diffusion of the dry air and the vapour is, owing to these disturbing causes, never reached, it follows that the observations of the hygrometer only indicate local humidity. Hence they should never be regarded as anything more than approximations to a correct indication of the quantity of vapour in the atmosphere over the place of

observation. It should, however, be added, that though in exceptional cases the amount of vapour indicated may be wide of the mark, yet, in long averages, a very close approximation will be obtained, except in confined localities which are exceptionally damp or exceptionally dry.

308. Vapour is continually passing into the air from the surface of water and moist surfaces at all temperatures by the silent process of *evaporation.* Evaporation also takes place from the surface of snow and ice. In evaporation the vapour is supplied only from the surface of the water; hence the extent of surface in contact with the air greatly influences 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 when the air is perfectly dry or free from vapour. Since currents of air remove the saturated air and substitute dried 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.

309. *Evapometer.*—The instrument for measuring the quantity of water which the atmosphere can take up from the surface of water in the form of vapour in a given time is called an *Evapometer.* 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. The best evapometer is one invented by Dr Arthur Mitchell. It consists of an evaporating dish, the losses in which are supplied as they occur from a reservoir, whose area is ten times, or any number of times, less than that of the evaporating dish, the principle being the same as that involved in the fountain inkstand, or the fountain drinking-cup of the bird's cage. The water in the dish is thus always kept at the same level, and any rain that falls is at once carried off by an overflow pipe, so constructed as to prevent any error arising from the wavelets raised by the wind on the surface of the evaporating dish. The advantages of this instrument consist in the rain and dew being at once conveyed away, and the facility with which minute quantities can be read off. As the reservoir is liable to be broken in the time of frost, a modification of this evapometer has been devised by Mr James Procter, Barry, one of the ablest observers of the Scottish Meteorological Society. His evapometer presents a surface of 10 inches square, with an overflow pipe at the level of the zero line. The small quantity daily evaporated is measured by a scale of brass divided into 10 equal parts placed diagonally in the evaporation-vessel, so that during the evaporation of one inch of water, *the line of contact of the surface of the water with the diagonal scale will traverse the whole length of the scale.* Since each of the 10 parts may be subdivided by the eye into 10 parts, the 100th part of an inch may be easily read on the scale.

310. There is another evapometer, or *Atmometer*, fig. 23, which from its simple construction will be found to possess 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.

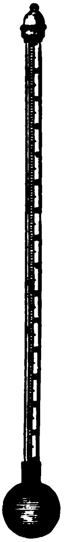

Fig. 23.

311. There is no class of observations which show such diversity, we may almost say such contrariety, of results, as those made by different observers on evaporation. This arises from the different methods employed. The object sought to be obtained is the *drying power* of the atmosphere, a question of prime importance in its relations to the animal and vegetable kingdoms. And since none of the ordinary meteorological observations enable us to arrive at this element with any approach to exactness, it is hoped that some one evapometer, such as Dr Mitchell's, will come to be generally used among observers.

312. *Loss of Heat by Evaporation.*—One of the most important consequences of evaporation is the loss of heat which accompanies it. During the conversion of a liquid into the gaseous form, a very large quantity of heat disappears; and since it becomes imperceptible to the senses or to the thermometer as long as the gaseous state is retained, the heat is said to become *latent.* It must be kept in mind that the heat which thus appears to be lost, is not destroyed, but may be recovered or made evident at pleasure 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 they were in the liquid state, and hence the thermometer is not affected by it. The

change of water to vapour by evaporation being thus productive of cold, and the conversion of vapour to water productive of heat, one or two important 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.

313. *Effect of Drainage on the Temperature of the Soil.* —Theory should lead us to suppose that the temperature of drained land would be higher than that of undrained land, because, being drier, less heat is lost by evaporation. In order to bring this supposition to the test of experiment, the Marquess of Tweeddale in 1862 offered prizes to the amount of £80 for sets of observations on the temperature of drained and undrained land on mountain pastures, and on arable land under crops of turnips, wheat, and ryegrass. Two sets of observations, each extending over a year, were made, one at Otter House in Argyle, on arable land under a ryegrass crop, the soil being light and sandy and sloping 1 in 40 feet; and the other set at North Esk Reservoir, Pentland Hills, on hill pasture, the soil being clay mixed with decayed moss. From these valuable observations the following results were drawn: 1. The mean annual temperature of the arable land was raised nearly a degree (0°.8) by drainage. 2. The temperature of the hill pasture was 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 was under a covering of snow, the cold passed more quickly and completely through undrained than through drained land. 4. When the temperature of the air was higher than that of the soil, drained land received more benefit from the higher temperature than undrained land, less of its heat being lost by evaporation. 5. Since, when

rain or sleet fell, the superfluous moisture soon flowed away from the drained land (it being sandy and the slope considerable), drainage tended to maintain in the soil a comparatively equable temperature; whereas the undrained land was liable to considerable fluctuation, for when soaked with warm rain-water its temperature was temporarily raised, and when soaked with melted snow it was temporarily lowered. On one occasion sleet showers lowered the drained land 2° and the undrained land 4°. 6. The temperature of drained land was 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.

314. Since these different temperatures are chiefly caused by the different amounts of water evaporated from the land, it is evident that different results will be obtained from different soils, with different crops, and with different slopes and exposures.

315. In 1847 Professor James Elliot made a number of experiments which shed some light on this extensive subject. He found that peat-moss can absorb 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 $\frac{2}{3}$ 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.

316. Three 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.

317. From these experiments a few practical conclusions may be drawn. 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 sooner than common mould, common mould sooner than clay, and clay sooner than peat-moss. In respect of evaporation, drainage affects the temperature of the soil in two ways: (1) By keeping the soil drier, and thus diminishing the evaporation, it maintains a higher temperature. (2) Since a dry soil is more friable than a wet soil, and thus presents more evaporating points, it is probable that on soils bare or nearly bare of vegetation, and therefore freely exposed to the influence of the weather, the effect of drainage will be to lower the temperature for some time after rain, or as long as the evaporation exceeds that of undrained land. It is evident that when the soil is covered with vegetation this peculiarity can only obtain to a very limited degree.

318. In regard to the experiments with moss, and grassy turf which resembles moss, and their bearing on the important question of climate, Professor Elliot remarks: "We cannot doubt that the destruction of the moss adds not only

to the productive quality of the soil, but also raises the temperature of the air around it. For moss can retain five times its own weight of water on the surface of the soil always prepared for evaporation, and prepared in the manner that it can most readily evaporate. No one need be astonished at the coldness of our hills and the dampness of our mountain climate, when they consider that the entire surface of the soil is either covered with moss or grassy turf. This moss or turf retains most of the water that falls from the clouds, permitting little, except in very wet weather, to enter the soil; this water is almost immediately evaporated, and the turf prepared to receive other supplies. The coldness caused by evaporation must therefore be very great." It follows from this, that 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.

319. *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 are full of vapour, the air is said to be saturated. Professor J. D. Everett constructed a hygrometer (Dry-and-Wet-bulb) with the degrees on a large scale and carefully compared with a standard, and found that instances of exact correspondence of the two thermometers, which happen when the air is perfectly saturated, are events of as rare occurrence as eclipses of the sun or moon. Thus, then, though every time dew is formed the air in contact with the ground must be brought to the point of saturation, and every time cloud is formed and rain falls the point of saturation is also reached where the condensation takes place, yet the air a few feet above the ground is seldom perfectly saturated.

320. 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.

321. *Hygrometer.* — The instrument for ascertaining the amount of vapour in the atmosphere is called a *hygrometer.* 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. 24), 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 little or no scientific value, yet it may be turned to good account in the sick-room or in conservatories.

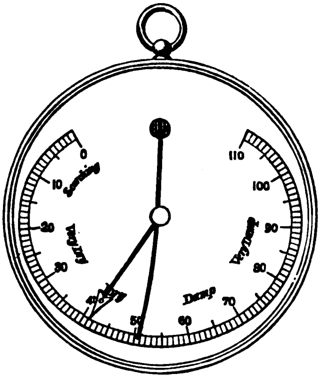

Fig. 24.

322. It is this property of substances to be changed in bulk in attracting moisture from the atmosphere, or in parting with it, which explains a large number of popular prognostics of the weather, especially such as refer to the feelings and con-

duct of animals, the opening and closing of flowers, and the lengthening and shortening of strings, cordage, and other materials.

323. 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 are subject to great change. 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 now cooled down 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.

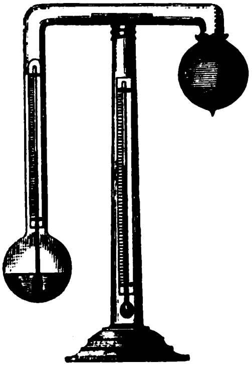

Fig. 25.

324. Daniell's and Regnault's hygrometers are constructed on the principle of this simple phenomenon, having only superadded to them various contrivances for reducing the temperature quickly to any point that may be desired, and for observing the temperature at which dew is formed with precision. Daniell's hygrometer (fig. 25) 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 is plunged the ball of a delicate thermometer. 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. In consequence of this the ether inside the other bulb evaporates,

and its temperature 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. At the same time 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.*

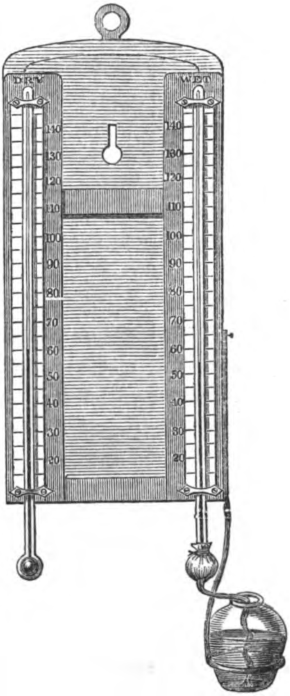

Fig. 26.

325. This hygrometer (fig. 26) consists of two mercurial thermometers, which, being placed side by side, would indicate the same temperature. The dry-bulb is a common thermometer, intended 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. But 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.

326. 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 is 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 time 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.

327. To keep this instrument in working order one or two things require special attention. 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 thereby 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, as far removed as possible from the dry-bulb.

If these directions, trivial though some of them may appear, be not attended to, the observations will lose their value.

328. 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.

329. By means of 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.

330. 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 VII. From this table, f is found; and d and h being obtained by observation, F is calculated. From F *the dew-point* is found 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°.

331. 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.

332. *Relative Humidity.*—In calculating the relative humidity, saturation is assumed as 100, and perfectly dry air as 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°.

333. 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 practical meteorologist. We shall conclude this chapter with a few remarks on the dew-point, elastic force, and relative humidity.

334. *Dew-point.*—The ascertaining of the dew-point is of great practical importance, particularly to horticulturists, since

it shows 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.

335. This suggests an important practical use of the hygrometer. If the dew-point be ascertained by it, 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 at that season. If, on the other hand, with a sky quite as clear, the dry-bulb was 50° and the wet 47°; the dew-point being thus 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 the predictions founded on the hygrometer.

336. *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. Hence the elastic force of aqueous vapour would be the pressure of the whole vapour in the atmosphere over the place of observation; this 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 aqueous vapour .450 inch of mercury. Thus, then, the elastic force may be regarded as representing the absolute quantity of vapour suspended in the atmosphere subject to the modification stated in par. 303. 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 oceans, 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 aëronauts have thrown some light on the question. But the number of ascents are by far too few to warrant the drawing of general conclusions as to the *mean rate* of the decrease. The chief point established is, that on 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.

337. *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 essential and 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 at 9 A.M. and 9 P.M., when the temperature is about the average of the day, is 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. Thus, during May 1866, at Corrimony, in Inverness-shire, the dry-bulb at 9 A.M. on the 21st was 65°, and the wet 47°, thus giving a humidity of 29, perhaps as low a humidity as has hitherto been observed in the British Islands; and of course later in the day this extraordinary dryness must have been still further increased.

338. In the ocean, at a distance from the land, the humidity is always 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 yet begun perceptibly to fall.

339. Now, between the vapour present in the air and the temperature of the air there is a vital and all-important connection, which recent experiments and researches have done much to elucidate.

340. *Diathermancy of the Air.*—Bodies possess perfect diathermancy when they allow rays of heat to pass through them freely and unimpeded, or when they absorb none of the rays of heat which fall on them as they pass through them. Thus perfectly dry air 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, which presents an obstruction to the free passage of the heat of solar and terrestrial radiation much in the same way as stones in

the channel of a river oppose its course. This is undoubtedly one of the most important and conservative functions of the invisible 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 the 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."

341. 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.

342. Lieutenant-Colonel Strachey has examined the Madras Meteorological Observations of several years, and compared the elastic force or tension of the vapour with the number of degrees the temperature was reduced by radiation from 6.40 P.M. to 5.40 A.M. In all the cases examined, the sky was either quite, or all but quite, free from clouds. During 1844, when the tension was 1.00 inch, the temperature fell 2°.7; when the tension was between 1.00 and .90, the temperature fell 4°.5; between .90 and .80, 5°.4; between .80 and .70, 6°.9; and between .70 and .60, 8°.3. A tract of remarkably clear weather occurred from the 4th to the 25th March 1850, during which there were great differences in the tension of vapour. The following results exhibit the dependence of the temperature on the vapour in a clear light:—

TERRESTRIAL RADIATION.

Tension of vapour,	.888	.849	.805	.749	.708	.659	.605	.554	.455
Fall of temp. from 6.40 P.M. to 5.40 A.M.,	6°.0	7°.1	8°.3	8°.5	10°.3	12°.6	12°.1	13°.1	16°.5

Solar Radiation.

Tension of vapour, . . .	.824	.737	.670	.576	.511	.394
Rise of temp. from 5.40 A.M. to 1.40 P.M., . .	12°.4	15°.1	19°.3	22°.2	24°.3	27°.0

Hence, then, 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. Also when the quantity of vapour is great, since less of the sun's heat reaches the earth's surface, 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. From the above examples, when the tension of vapour was about .840 inch, the daily range of temperature was 19°.5; but when the tension was only about .400 inch, the daily range was 43°.5. Since the temperature is hottest during the day, when the air is driest, and evaporation consequently greatest, it is evident that the extent to which the temperature falls during dry nights owing to the evaporation is comparatively small, and that the cause of night cold is radiation. Further, from observations made at Melbourne, M. Neumayer concludes that the absolute quantity of aqueous vapour in the air is in itself alone not sufficient as a criterion for the degree of radiation; but that the absolute quantity of aqueous vapour, together with a certain temperature—in other words, the relative humidity of the air—influences terrestrial radiation in such a manner that the greater the degree of relative humidity the less is the effect of radiation. In connection with this view, the effect of the dew-point in arresting the descent of the temperature must not be forgotten (par. 330).

343. In mountainous countries, where, on account of their height, much less aqueous vapour is interposed between them and the cold regions of space, radiation, both solar and terrestrial, is least obstructed. 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 his ship exposed to the sun, while ice was rapidly generated at the other side.

344. When observations with black-bulb thermometers, showing the force of solar radiation in different parts of the world, are stated, they appear at first sight absurd, if not contradictory. Thus at Port Louis, Mauritius, in lat. 29° 9′ 56″ south, the highest reading of the black-bulb *in vacuo* was 125° in 1864, and 130° in 1865. Now in Scotland, a thermometer placed in these circumstances, particularly in the eastern districts, would register higher temperatures than those, during at least four months of the year; and in the case recorded by Captain Scoresby, the heat of the sun's rays in melting the pitch must have been about 130°, that is, as high as occurred in the Mauritius during two whole years. An interesting collection of facts of solar radiation in different latitudes and at different elevations is given in Daniell's 'Essays' (2d ed., p. 208 *et seq.*) From the facts adduced, the conclusion is drawn that the *power of solar radiation in the atmosphere increases from the equator to the poles, and from below upwards*,—a result which these remarks on the vapour of the atmosphere explain. It follows that hygrometric observations ought to accompany all observations on solar radiation, in order to render them intelligible.

345. 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 summer.*

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* In the above remarks on the diathermancy of the atmosphere in reference to the influence of its moisture on solar and terrestrial radiation, I have used the word "vapour" to include all states of the moisture which are, in a popular sense, invisible—in other words, as inclusive of every form in which water may be suspended in the air, except those of mist, fog, cloud, and rain-drops. In 1862, Professor Tyndall made experiments on the vapour of water, from which it was concluded, that while the dry air of the atmosphere was diathermanous, the pure vapour was not so. As this result seemed to give a very satisfactory explanation of the observed effects of solar and terrestrial radiation, it was very generally adopted by meteorologists. In the first edition of this work it was assumed throughout.

But in June 1867, Professor Magnus of Berlin published a more extensive series of experiments, by which it was shown that the results obtained differ not according as the air which is forced through the tubes is moist or dry, but according to the condition of the sides of the tube through which the currents of dry air and moist air are forced. Hence, while Professor Tyndall's experiments, so far as they go, are good, they do not warrant the conclusion which was drawn from them, since the results are shown to be due to the condition of the sides of the tubes used, and not to any diathermical difference between moist air and dry air. Others have confirmed Professor Magnus's experiments.

The observations of solar and terrestrial radiation in relation to the moisture of the atmosphere are probably to be accounted for by the presence of moisture in states other than that of pure vapour, which are imperfectly diathermanous,—such as moisture in a vesicular state, and at the same time invisible, and in states intermediate between the vesicular and that of pure vapour. The conditions under which atmospheric moisture may be formed and maintained in these states, so as to account for the varied and often surprising phenomena of radiation, are very imperfectly known, and some of them perhaps not even yet suspected.

CHAPTER IX.

MISTS, FOGS, AND CLOUDS.

346. 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.

347. During a calm clear night, when the air over a level country has been cooled by radiation, and dew begun to be deposited, the portion of the air in contact with the ground is lowered to the dew-point, and thus 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, must necessarily flow down and fill the lower grounds; and since it is colder than the saturated air which it meets with in its course, it will reduce its temperature considerably below the point of saturation, and thus produce mist, or *radiation fog*, as it is sometimes termed. When a lake, river, or marsh fills up the valley, the air, being thereby more saturated, often gives rise to denser fogs; and, on the other hand, when the low grounds are sandy or dry, mist is less frequently produced.

348. When an oceanic 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. 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 whose temperature is lower than that of the air. Thus the waters of the Swiss rivers which issue from the cold glaciers have a temperature considerably lower than that of the air; consequently they cool the air in contact with them below the point of saturation, and mist is thereby often 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 fogs.

349. When rivers are considerably warmer than the air, they give rise to fogs, because the more rapid evaporation from the warm water pours more vapour into the atmosphere than it can hold suspended in an invisible state, and 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.

350. The densest fogs occur during the cold months in large towns built on rivers,—the causes which produce fogs being then at the maximum. The denseness of the London November fogs is notorious, giving significance to a capital sketch in 'Punch,' which represented a street-boy springing into the air, exclaiming, "I am monarch of all I survey." Their peculiar denseness is caused by the warmth of the river-bed, and it is increased by the sources of artificial heat which London affords; and from the circumstance that the temperature is falling everywhere, and the humidity being then great, the vapour of the atmosphere is quickly and

copiously condensed by the gently-flowing cold easterly winds which generally prevail in November.

351. 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 originated under different meteorological conditions. Fogs often accompany the breaking-up of frosts in winter. For when the humid south-west wind has gained the ascendancy, 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.

352. Mountains are frequently covered with mist. Since the pressure and consequently 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. 180), forests have a marked effect on the 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. Mists also 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 be-

neath 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.

353. I am informed by the Rev. J. Farquharson, Selkirk, that when the atmosphere is very moist and the south-west wind is blowing strongly, a mist or cloud is sometimes seen to settle over Bowhill, which is situated at the junction of the classic Yarrow and Ettrick; and that the cloud thus formed is subject to great and rapid changes, both as regards its outline and its size. This is a highly instructive observation, considered with reference to the causes which produce the phenomenon. Both valleys lie nearly in the direction of the south-west wind, but the Vale of Ettrick is the more highly wooded of the two; hence the temperature of the two valleys will, from what has been stated above, be generally different the one from the other. Now, when a steady humid south-west wind is blowing, each will acquire the temperature of the valley down which it has flowed, and be at the same time at or near the point of saturation; and at Bowhill, where the two aërial currents meet and mix together, cloud will be formed, in accordance with the well-known law by which two volumes of air, each saturated but of different temperatures, can when mixed no longer hold all the vapour in suspension; consequently part is condensed into cloud or rain. The same phenomenon is stated by Dr James Bryce, in his 'Arran,' to occur occasionally at Brodick, at the point where Glens Rosa and Shiraig meet. The explanation is the same as that of the cloud formed at Bowhill.

354. Extensive fogs also prevail where great differences occur in the temperature of contiguous regions. Thus promontories running out into the sea are frequently enveloped in mist; for since land is generally warmer than the sea in summer and colder in winter, the difference of temperature is generally sufficient to cause mists with the veerings of the

wind landward or seaward. The same cause explains the mists and fogs which frequently prevail on the coast. These mists generally occur in the morning and evening, seldom advance far inland, and usually accompany fine weather. There is a weather prognostic current in Elie, Fifeshire, as follows:—

> "When Kellie Law gets on his cap,
> Largo Law may laugh at that;
> When Largo Law puts on his hat,
> Let Kellie Law beware of that."

Kellie Law, the lower of the two hills, lies to the north-east of Elie, and Largo Law to the north-west. Hence the mist, which covers Kellie Law only, is brought by a local, temporary, and superficial sea-breeze from the east, which does not advance so far to the westward as Largo Law; but when Largo Law is involved in clouds while Kellie Law is yet clear, we may be sure that the south-westerly current, laden with moisture, has already reached that hill, and consequently will speedily advance on Kellie Law and pour down its rain over the district.

355. 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 polar current. The high temperature of the stream, which is often from 16° to 18°, and sometimes 30°, higher than that part of the sea past which it flows, fully explains the denseness and persistency of these fogs.

356. 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, still

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

apparently motionless and unchanged. This phenomenon is instructive, and 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.

357. 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 considerable importance in meteorology. It would appear to originate from the juxtaposition of the polar and equatorial currents. When these currents flow side by side, fog frequently fills up the comparatively calm space intervening between them. It results from the mixing together of the two currents, the cold of the polar current condensing the vapours of the south-west wind. 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 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 humid equatorial current overlaps the polar current, and the fog which prevails is due to the mixing of the two currents. Hence, in discussing storms, fogs constitute one of the most important elements which require consideration, and they supply valuable help towards the foretelling of storms.

CLOUDS.

358. Clouds are visible vapours floating in the air at a considerable height; thus differing from mists and fogs, which float near the surface. Both arise from the same causes.

359. 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 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. The whole of this process is frequently seen on a warm summer day. In the morning the sky is cloudless, or nearly so; as the heat becomes greater, clouds begin to form before noon and increase in numbers and size, often presenting scenes of unparalleled beauty as, lighted up by the sun into dazzling brilliance, they sail slowly and smoothly across the blue sky; but as the heat diminishes, they contract their dimensions, and gather round the setting sun, lit up with the fiery splendours of his beams. In a short time they disappear, and the stars come out, shining in a cloudless sky.

360. The balloon ascents of Mr Glaisher and other aëronauts, as well as observations of the clouds, show us that the whole atmosphere, to a great height, is constantly traversed by many aërial currents superimposed on each other and flowing in different and 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.

361. 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 wedgeways 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 the cold heavy east wind, or polar current, thrusts 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.

362. 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.

363. A very natural inquiry is, 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. 356) suggests an explanation. The cloud itself may appear stationary or suspended, but the particles of which it is composed are undergoing constant renewal or change. The particles are upheld by the force of the ascending current in 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.

364. When a cloud overspreads the sky, its lower surface is for the most part horizontal, or more generally it seems as if it was an 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 below its level.

365. 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.

366. The gorgeous appearance clouds occasionally present in balloon ascents, is thus graphically told by Mr Glaisher in describing his ascent from Mill Hill, near Hendon, on 21st August 1862: "Twenty-seven minutes after leaving the earth, a white mist enveloped the balloon; the temperatures of the air and dew-point were alike, indicating complete saturation. The light rapidly increased, and, gradually emerging from the dense cloud into a basin surrounded by immense black mountains of cloud rising far above us, shortly afterwards there were deep ravines of grand proportion beneath open to the view. The sky immediately overhead was dotted with cirrus clouds. As the balloon ascended, the tops of the mountain-like clouds were tinged with silver and gold. On reaching their level, the sun appeared flooding with light all that could be seen both right and left, tinting with orange and silver all the remaining space. It was a glorious sight. The ascent still continued, but more quickly as the sun's rays fell upon the balloon, each instant opening to view deep ravines and a wonderful sea of clouds. Here arose shining masses of cloud in mountain-ranges, some rising perpendicularly from the plains with summits of dazzling brightness, some pyramidal, others undulatory. Nor was the scene wanting in light and shade; each large mass of cloud cast a shadow, thereby increasing the number of tints and beauty of the scene."

367. *Height of Clouds.*—Kaemtz has collected the results arrived at by many distinguished 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.

368. Since clouds are subject to certain distinct modifications from the same causes which produce the 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 order to predict the coming weather. It is to this chiefly that the weatherwise sailor and the farmer still look in foretelling the weather; and their predictions are frequently more correct than are those 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 universally adopted is that proposed by Luke Howard, and published by him in 1803.

369. By this nomenclature clouds are divided into seven kinds; three being simple, the *cirrus*, the *cumulus*, and the *stratus;* and four intermediate or compound, the *cirro-cumulus*, the *cirro-stratus*, the *cumulo-stratus*, and the *cumulo-cirro-stratus* or *nimbus.*

370. *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.

371. 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.

372. 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.

373. 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. When the storm seems past and the sky has cleared, should a few fine cirrus clouds be seen slightly blown back at their eastern extremities, the storm has in all likelihood really past, and fair weather may with some confidence be expected, since the dry polar current has already begun to prevail overhead.

374. 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.

375. *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 the ascending currents of warm air which rise from the heated ground. Its beginning is the little cloud not bigger than a man's hand, which is 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.

376. 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.

377. 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, the rain is near at hand.

378. *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 the 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.

379. When the sun has risen and begun 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 begins to rise from the ground. As the heat increases it continues to ascend, and becomes broken up into detached masses, and soon disappears altogether. These appearances indicate a continuance of the finest and serenest weather.

380. *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.

381. 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. But in this case the cirro-cumulus will be found wanting in the settled order which it wears in fine weather.

382. *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.

383. 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.

384. 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* or mock-suns, *Paraselenæ* or mock-moons, *Coronæ,* and *Solar* and *Lunar Halos.*

385. *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. Tennyson has finely described it as it rises in the west:—

> "The wild unrest that lives in woe
> Would dote and pore on yonder cloud,
> That rises upward always higher,
> And onward drags a labouring breast,
> And topples round the dreary west,
> A looming bastion fringed with fire."

386. *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.

387. 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 the windward; these rapidly increasing unite at all points, forming one continuous grey mass, from which the rain falls. It is evident from this that the whole body of air under the upper sheet of cloud into which the clouds drift must be completely saturated. The breaking-up of the lower grey mass indicates that the rain will soon cease.

388. 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.

389. *Observing Clouds.*—In observing clouds, the kind, 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 that is half covered, and 10 that it is wholly obscured.

390. 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 month most free of clouds is May, owing to the rising temperature and the dry east winds which then prevail. The cloudiest month is December, when the temperature is rapidly falling, and the south-west wind attains its maximum frequency.

391. *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. One day in the beginning of May 1867, happening to be on the top of Corstorphine Hill, near Edinburgh, I made some observations on the motion of the clouds. The occasion was very favourable, inasmuch as a storm which had prevailed during the previous night was breaking up, and the clouds had separated into large cumulus masses, which drifted with great apparent leisureliness across the otherwise clear sky in the direction of Donaldson's Hospital, a prominent object in the landscape. The number of seconds which elapsed between the times of the shadows of four clouds touching the top of the hill, and the same shadows touching the hospital, was noted; and the exact distance of the two places being known from the map of the Ordnance Survey, the velocity of the clouds was found to be at the rate of 72 miles an hour. At the same time the force of the wind on the surface of the earth was estimated at 3 in the scale 0 to

6—being about the rate of 42 miles an hour. Henry Stephens informs me that, in an earlier part of the same day, when the force of the wind was greater, he made similar observations at Redbraes Cottage, near Edinburgh, on the rate of motion of the clouds, which he determined, from twenty observations, to be at the rate of 109 miles an hour. And as the velocity did not even in this case appear to be at all striking, or greater than is often seen, it cannot be doubted that the rate of motion of the upper currents of the atmosphere far transcends the limits usually assigned to them.

CHAPTER X.

RAIN, SNOW, AND HAIL.

392. Whatever lowers the temperature of the air may be considered as a cause of rain. Various causes may conspire to effect this object, 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 wedgeways 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 forced up their slopes is cooled, and its vapour condensed into showers of rain or snow. Moist air-currents are also drawn up into the higher regions of the atmosphere over the area of least pressure at the centre of storms; and in such cases the rainfall is generally very heavy. The temperature of the air is lowered, and the amount of the rainfall increased by those winds which convey the air to higher latitudes. This occurs in temperate regions, or in those tracts traversed by the return trade-winds, which in the north temperate zone blow from the south-west, and in the south temperate zone from the north-west. The meeting and mixing of winds of different temperatures is also 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.

393. The rain-cloud has been already generally described in paragraphs 385, 386; but the more specific conditions under which rain is precipitated are the following, as 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. The geographical distribution of rain over the globe is proportioned to the temperature, the humidity, the mean depression of the barometer, the fluctuations in the temperature, and the configuration of the earth's surface.

394. Rain sometimes falls from a cloudless sky, and is then called *Serein.* Sir J. C. Ross thus describes a case which occurred near Trinidad 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.

395. 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. 27. 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. 28, 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 gauge, fig. 29, commonly known as Fleming's gauge, which is used extensively in Scotland. Since this gauge does not admit of very nice measurement, another sort 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 de-

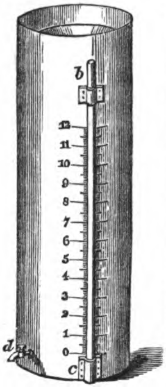

Fig. 27.

Fig. 28.

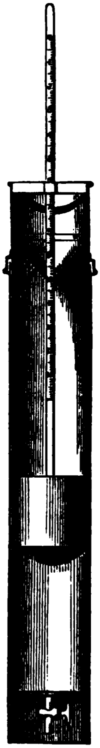

Fig. 29.

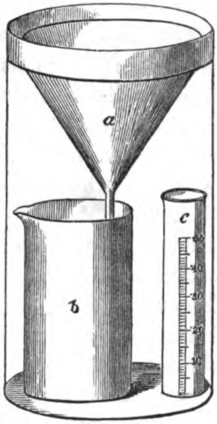

Fig. 30.

sired. A good specimen of this class is the gauge recommended by G. J. Symons, London, fig. 30, 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 Rao, a wealthy zemindar of Vizagapatam, proposed a gauge (fig. 31) in the form of a funnel, having a diameter of 4.697 inches, or 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 and Crosley; but, being too expensive for general use, they need not be described here.

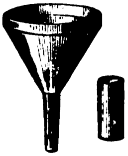

Fig. 31.

396. As regards the size of the receiving surface of a rain-gauge, or its diameter, series of observations, with gauges of different diameters, have been conducted since the beginning of 1864 by Colonel Ward, Castle House, Calne, Wilts, and by the Rev. J. Chadwick Bates, Catleton Moor, Manchester. Mr Symons has discussed these three years' observations in his 'British Rainfall, 1866,' and drawn the conclusion that "so far as size is concerned, no difference exceeding 1 or 2 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. The 3-inch gauge is not included in the list, which is an unfortunate oversight, considering its extensive use in certain parts of Great Britain; but, judging from the returns of the other sizes, it is probable that it would have measured about the same amount as the larger gauges. We may therefore conclude 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.

397. A most important point requiring attention in the position of the rain-gauge is its height above the ground. Mr 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; 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. The Castleton observations give at 1 foot 1.00; 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; 5 feet, .94; 10 feet, .91; 15 feet, .90; 20 feet, .89; and 25 feet, .88.

398. 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. The minute watery globules drawn gradually down from the rain-cloud in the train of the falling drops, and the downward course becoming horizontal as they near the surface, the greatest accumulation of such globules is near the surface, where, therefore, they coalesce in greatest numbers into drops heavy enough to fall into, instead of floating past, the gauge; the eddies and currents which prevail most and strongest around isolated objects raised above the ground; the rebound of the finer particles into which many of the drops break as they strike with violence on the ground; and the condensing of the vapour of the atmosphere on the rain-drops as they fall through it,—to a large extent account for the phenomenon. The first of these theories, which has been proposed by

James Dalmahoy, Edinburgh, would appear to account for the greater part of the excess of rain collected in gauges nearest the surface. The last of the theories, being that proposed by Dr Franklin, and long accepted as sufficient, can only, according to Sir John Herschel, account for one-seventeenth part of the observed excess. The eddy theory advocated by Mr Jevons is interesting, as affording an explanation of many of the anomalous results which have been obtained; while the remaining theory serves to explain the greater part of the excess observed from one foot downwards to the surface. Since no gauge can ever be constructed and placed so as to measure with perfect accuracy the quantity of rain which falls on the ground, it is only necessary to secure, as far as possible, that all gauges be similarly constructed and placed in positions similar to each other.

399. Rain is the most capricious of all the meteorological phenomena, both as regards its frequency and the amount which falls in a given time. It rarely or never falls in certain places, which are on that account denominated 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.

400. 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, there fell at Portree, in Skye, 12½ inches in 13 hours, during which a continuous cataract appeared to fall from the roofs of the houses; and on the same day 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.

401. *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.

402. *Rainfall within the Tropics.*—At places within the tropics where the trade-winds are blowing regularly and steadily, the rainfall is small, because, these winds coming from higher latitudes, the temperature is increasing, and they are thus rather in the condition of taking up moisture than of parting with it; and the return trades, which blow above them in the opposite direction, having discharged the greater part of their moisture in the region of calms, are also dry and cloudless. Where, however, the trade-winds are forced up the slopes of mountain-ranges lying in their course, as on the east of Hindostan, they bring rain in copious showers.

403. *The Region of Calms* is a broad intertropical belt about 5° in breadth, where the north-east and south-east trades meeting, mutually destroy each other, and thus produce a calm. This is the region of constant rains. Here the sun almost invariably rises in a clear sky; but about midday 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 belt 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 extreme 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.

404. This state of things is only strictly applicable to the Pacific Ocean, whose expanse of water, presenting a uniformly radiating and absorbing surface, is sufficiently broad to allow the law to take full effect. But over a great part of the tropics disturbing influences draw the trade-winds out of their normal 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.

405. 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, 55 inches, but Seringapatam only 24 inches; at Bombay, 75 inches; among the West Ghauts, at Uttra-Mullay, 263 inches; and at Mahabuleshwar, 254 inches; while at Poonah, more inland, it is only 24 inches. In Mauritius, for the four years ending 1865, the average rainfall at Gros Cailloux was 29.84 inches, whereas at Cluny, only about 16 miles distant, it amounted to 146.17 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."

406. The south-west monsoon discharges from 60 to 80 inches of rain over the parts of Hindostan not bounded by high mountains to the west, before reaching the Himalayas, after which it discharges the greater part of its remaining moisture, 120 to 140 inches, on the outer Himalaya range, at elevations of 4000 to 8000 feet. Thus four times less rain falls annually on the Himalayas, as compared with the Khasia Hills, because (1) they present a less abrupt face to the south, and (2) are separated from the ocean by a sandy burning district, raising the temperature of the air above the dew-point, or by hilly ground, which drains the winds of much of their moisture as they pass.

407. The following are a few of the more interesting annual rainfalls in the tropics:—Singapore, 97 inches; Canton, 78 inches; St Benoit, Isle of Bourbon, 163 inches; Sierra Leone, 87 inches; Caraccas, 155 inches; Pernambuco, 106 inches; Rio Janeiro, 59 inches; Georgetown, 100 inches; Barbadoes, 72 inches; St Domingo, 107 inches; Bahamas, 52 inches; Vera Cruz, 183 inches; and 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; thus, as already stated, the fall at Poonah is only 24 inches.

408. *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 falls generally 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.

409. 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 south-west 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 Norway, Ireland, the west of Great Britain 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.

410. 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; and at the Stye, 224½ inches in 1866. At Bergen, in Norway, the rainfall is 89 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 France the average is 30 inches; and in the plains of Germany and Russia, 20 inches; while in some parts of Sweden and Russia, it is as low as 15 inches. 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, 104.35 inches.

411. 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 rather greater than in winter. This peculiarity is shown by the east and west sides of Great Britain. It is probably owing 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; but in summer, the clouds, being high, pass above and discharge their moisture in the interior.* For every 10 inches of rain which fall at the following places in winter, there fall in summer respectively, 8½ inches in the west of Great Britain, 11 inches in the east of Great Britain and in west of France, 15 inches in the east of France, 20 inches in Germany, and 27 inches in the north and east of Russia.

412. 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 and southerly 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 this examination 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. It will be necessary to make an important distinction here—viz., this large rainfall, which is deposited by easterly winds, is not brought by the polar currents, which the mere direction of the wind might indicate; but the moisture is originally brought by the southwest wind, which, prevailing first in the higher regions of the atmosphere, as the direction of the cirrus cloud and other high

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* For a first instalment of an able and thorough discussion of this question by Frederic Gaster, see Symons's 'British Rainfall, 1867,' p. 33.

clouds some time before the breaking out of the storm clearly proves, and then gradually descending, saturates the air with the vapour which it brings from the ocean. Thus, then, 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.

413. The peculiarity of the rainfall of the basin of the Mediterranean 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 get wetter, and north winds get drier as they proceed on their course. Along the Syrian and North African coasts it rarely rains in summer, but frequently in winter. 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.

414. *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 westerly winds blow. In North America the yearly amount increases as we proceed northward; thus at San Francisco it is 22 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.

415. 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 in Central America plays an important part in the rainfall. In the northern parts they drain westerly winds of their moisture as they cross them. Further south they present a barrier to the passage of the easterly winds which blow across the Gulf of Mexico, which are, partly on this account, and partly on account of the heated plains of the States, turned or drawn to the northward, and spread themselves over the States, especially over the low basin of the Mississippi. Thus, then, the greatest part of the moisture will be drawn into the valleys where the heat is greatest, and the least part into the high mountainous regions, where respectively it will be disengaged and fall in rain. If this be the case, then the greatest quantity will fall in the valleys, and the least on the higher grounds—a mode of distribution the opposite of what obtains in Europe. That such is the case the following remarks by Blodget on the rainfall of America, given in the 'Army Meteorological Register,' will show :—"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.

416. 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.

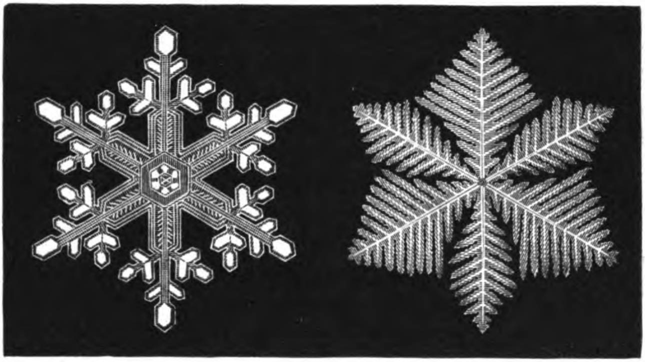
SNOW.

417. *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 class—comprising several hundred forms of the rarest and most exquisite beauty (figs. 32 to 38).

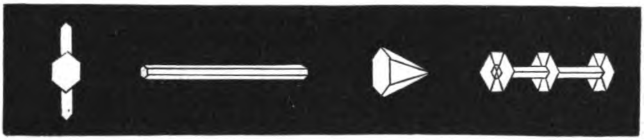
Figs. 32 33 34 35 36

2. A spherical nucleus or plane figure, studded with needle-shaped crystals (fig. 39). 3. Six or more rarely three-sided pris-

matic crystals (fig. 40). 4. Pyramids of six sides (fig. 41). 5. Prismatic crystals, having at the ends and middle thin plates perpendicular to their length (fig. 42). 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. 37 38



Figs. 39 40 41 42

418. The crystals of hoar-frost being formed on the leaves of trees and other substances which greatly modify the temperature, are on this account not so regularly formed, and are more opaque. During the great frost of Christmas 1860, Henry Stephens made the observation, that each tree or shrub was covered with crystals peculiar to itself.

419. Since the capacity of air for retaining its vapour is diminished as the temperature sinks, it follows that the aque-

ous precipitation, snow or rain, is much less in polar than in temperate regions.

420. 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 V.), because 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.

421. The *white colour* of snow is caused by the combining 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 ordinary crystal gasaliers; but when a mass of snow is looked at, the different colours blend into homogeneous white. Pounded glass and foam may be cited 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.

422. *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.

423. 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.

424. 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, the rule commonly adopted 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.

425. On the 5th March 1862, about 9 P.M., the Rev. Dr Charles Clouston, Sandwick, Orkney, observed the snow which was then covering the ground to be rolled up by the wind into masses increasing in size as they moved before it, which were blown backwards and forwards in the eddy-wind of the house. The same phenomenon had occurred in February 1847, and was then described by him in the following terms: "On examination, the masses were all found to be cylindrical, like hollow fluted rollers, or ladies' swan-down muffs, of which the smaller ones reminded me, from their lightness and purity, but most of them were of much greater dimensions and weight than any lady would choose to carry, the largest measured being 3½ feet long and 7 feet in circumference. The weight, however, was not so great as might have been expected from the bulk; so loose was the texture, that one 3 feet long and 6½ feet in circumference was found, on being weighed, to be only 64 lb.; the centre was not quite

hollow, but in all there was a deep conical cavity at each end, and in many there was a small opening through which one could see, and by placing the head in this cavity in the bright sun, the concentric structure of the cylinder was quite apparent. They might occupy 400 acres, and I counted 133 cylinders in one acre. A combination of favourable circumstances is required for their formation,—viz., a recent fall of loose snow-flakes in calm weather, as took place on the day previous; a temperature near the freezing-point, so as to give adhesion to the snow, while it is not so warm as to thaw it; and a good breeze of wind to spring up when the other circumstances are favourable to their formation."

426. 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, and is very rarely an accompaniment of storms.

427. *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 different 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

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.

428. 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 Tibet, 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.

429. 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.

430. 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.

431. 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.

432. 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.

433. 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. 43 and 44). The interior occasionally contains several nuclei, in which cases the hailstones appear to be a conglomeration of several hailstones, as in fig. 45, 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.

434. 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 Maga 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.

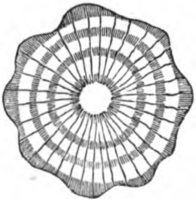


Fig. 43.

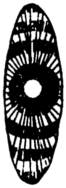


Fig. 44.


Fig. 45.

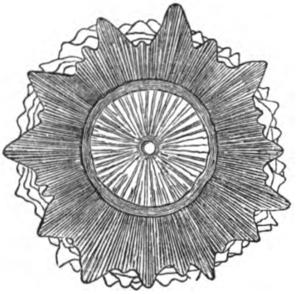


Fig. 46.

435. A hailstone (fig. 46) 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. Further particulars regarding these and other meteors will be found in Thomson's 'Introduction to Meteorology,'—a work replete with exact, learned, and curious information of every sort in the different departments of the science.

436. 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°.

437. 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.

438. 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.

439. **Wind** is air in motion. The speed of the wind varies, from the lightest breath that scarcely stirs the leaf on its branch, to the hurricane which, sweeping on in its fury, lashes the ocean into a tempest, strikes down the stateliest trees of the forest, and levels even substantially-built houses with the ground.

440. 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*, generally called Robinson's Anemometer, fig. 47. It 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 the upright axis, which are read off 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.

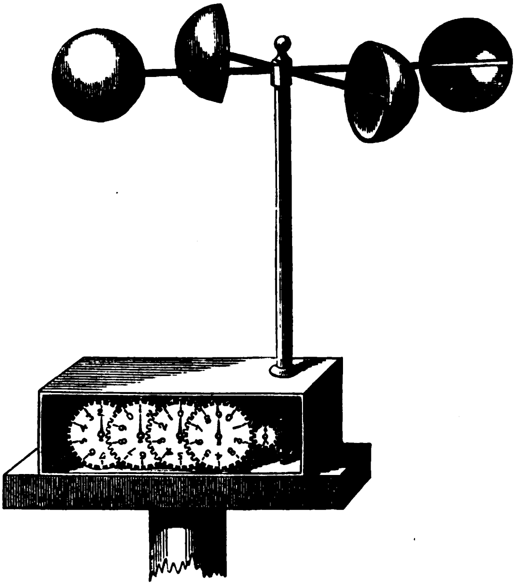


Fig. 47.

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.

441. In this form the anemometer only gives the whole velocity between two observations; it does not register the velocity at any moment. To effect continuous registration an elaborate machinery is required—too complicated to be here described—by which the result is transferred to paper by a pencil, or by photography.

442. 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.

443. The pressure is also measured by Lind's wind-gauge, fig. 48, which consists of a tube 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.

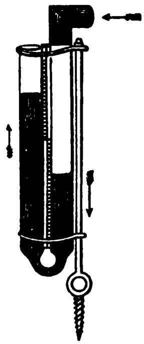


Fig. 48.

444. Many observers who have no wind-gauge give the force of the wind by estimation. The scale generally adopted in this country is 0 to 6,—0 representing 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. Observations on this scale are, of course, reduced to the preceding scale by dividing by 2. In Sweden,

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* In most European countries the force of the wind is given in kilogrammes on the square metre; and since a kilogramme equals 2.2046 lb. avoir., and a square metre 10.76 square feet, a pressure of one lb. on the square foot is equivalent to 4.88 kilogrammes on the square metre.

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 & T.G. Sails.
3.5	12.25	49.5	7	Moderate gale,		Double Reefs & 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 Foresail.	
5.5	30.25	77.8	11	Storm,	Under Storm Staysails or Try-sails.	
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.

445. But a more important observation of the wind is the direction from which it comes. 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 of the above two. 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.

446. All winds are directly caused by differences of atmospheric pressure. The wind blows from a region of higher to a region of lower pressure, 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 Howson's or King's.

447. 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, from any cause, come 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; and these currents will continue to flow till the equilibrium is restored. 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 incumbent air, 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.

448. 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 the maximum force when they blow from the N. and S., and falling to the minimum in the E. and W.

449. 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 on that account lighter will 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.

450. Winds are classified into CONSTANT, PERIODICAL, and PREVAILING WINDS.

CONSTANT, PERIODICAL, AND PREVAILING WINDS.

451. *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, a surface wind will set in towards the equator from both sides; these having united, will ascend, and then separating, flow as upper currents in opposite

directions. Hence a surface current will flow from the higher latitudes towards the equator, and an upper current from the equator in the direction of the poles. If then the earth were at rest, a north wind would prevail in the northern half of the torrid zone, and a south wind in the southern half. But these directions are modified by another cause—viz., 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, as it were, come up against it; in other words, an east wind will prevail there. Since, then, the wind north of the equator is under the influence of two forces—one drawing it south, the other drawing it west—it will, by the law of the composition of forces, take an intermediate direction, and blow from the north-east to the south-west. Similarly, south of the equator, the wind will blow from the south-east to the north-west. All observation confirms this reasoning. From the great service these winds render to navigation on account of their steadiness and constancy, they are called the *Trade-Winds.*

452. 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° north and 22° south, and in the Pacific between latitudes 4° north and 23½° south. These limits are, however, not stationary, but follow the sun, advancing northwards from January to June, and retreating southwards from July to December.

453. *Region of Calms.*—The region of calms is a belt of about 4° or 5° in breadth, stretching across the Atlantic and the Pacific, 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 severe thunderstorms. The position of the calms varies with the sun, reaching its most northern limit, 25° N. lat., in July, and its most southern, 25° S. lat., in January. It is greatly modified by proximity to the continents; in the Indian Ocean it wholly disappears during the S.W. monsoon.

454. There are two other regions or belts of calms at the limits of the north and south trades. Except in the Pacific Ocean, this belt of calms is either broken up, so as to appear only in patches, or is 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. This is the region of the Sargasso Sea, which is thus characterised not only by its still waters, but also by its still atmosphere. A similar region of calms exists in the South Atlantic. These calms are well known to sailors. The isobarometric charts suggest valuable hints how to steer clear of them.

455. It is clearly established by numerous observations, that while the surface wind within the tropics is directed toward the equator or region of calms, the prevailing direction of the winds of the north temperate zone are S.W. or W.S.W., and of the south temperate zone, N.W. or W.N.W. The *westing* of these two great equatorial currents is brought about by 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 blows over these places as a west wind, and this, combined with its original south direction, produces the S.W. wind. In the same way the direction of the equatorial current in the south temperate zone is N.W.

456. But though the mean direction of the winds has been calculated from long series of observations made at many places in Europe and North America, and the general prevalence of S.W. winds, or the equatorial current, has been clearly 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, 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 S.W. A complete examination of the observations of the winds in the different parts of the globe through the months of the year would perhaps be the most tedious, as it would certainly be the most laborious, problem in science. To work it out fully would require the labour of at least twenty years, and the assistance of a large staff of computers. The most extensive collection of facts yet brought together is contained in Professor James H. Coffin's 'Winds of the Northern Hemisphere,' a work of immense labour and research. It requires, however, to be used critically, since the means given for many places are for too small a number of years to be regarded as trustworthy. Since in January 1864 the wind in Scotland blew from N.W., N., N.E., and E. on five days, and in the same month in 1867 on seventeen days, it is evident that a considerable number of years are required to give the true mean of this month for Scotland. I shall content myself here with comparing the winds with the isobarometric lines, so that, the relation between these two meteorological elements being stated, a tolerably correct conception of the prevailing winds in different parts of the earth for the months of January and July, and for the year, may be arrived at.

457. *Winds in the North Atlantic and adjoining Regions in January.*—On examining Plate II., which shows the isobarometric 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 singular 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 a table is subjoined, giving the mean directions of the wind in January calculated for a number of years at places situated in different parts of this region.

TABLE SHOWING THE MEAN DIRECTION OF THE WIND IN JANUARY.

	No. of Years.	Days each Wind prevails.								
		N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm or Var.
Reykjavik, Iceland,	10	4	4	5	4	3	5	1	1	4
Upernivik, Greenland,	8	8	4	10	1	0	3	1	0	1
Jakobshavn, Greenland,	12	2	1	17	1	2	3	0	0	5
Godthaab, Greenland,	5	2	9	9	2	0	5	1	2	1
Norway House, Hudson Bay Ter.,	7	3	4	1	3	4	3	3	7	3
St John's, Newfoundland,	6	2	2	1	2	1	6	7	10	0
Eastport, Maine,	5	6	3	2	0	2	3	8	7	0
New Bedford, Massachusetts,	16	2	3	2	2	2	5	3	12	0
Washington, U.S.,	6	6	3	1	2	4	4	5	6	0
Trenton, New Jersey,	6	2	4	1	2	3	8	3	8	0
N. Atlantic (50° to 55° N. lat.),	2	3	2	3	4	5	4	5	4	1
Dublin,	10	1	1	2	3	3	10	8	1	2
Ahun, France,	28	3	4	3	2	4	9	4	2	0
Greenwich,	20	3	3	1	2	4	10	3	2	3
Stonyhurst,	14	5	5	2	2	5	8	4	0	0
Sandwich, Orkney,	10	2	1	2	6	5	6	5	3	1
East Linton, East Lothian,	10	1	1	2	2	2	12	10	1	0
Brussels,	20	2	3	3	2	4	9	5	3	0
Copenhagen,	9	2	1	4	2	7	6	5	2	1
St Petersburg,	10	2	1	2	4	4	4	6	2	6
Kostroma,	10	2	1	3	5	8	4	4	2	2
Hammerfest,	10	2	1	3	12	9	0	2	1	1

458. 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 it is S.S.W.; at St Petersburg and Kostroma, situated a little to the eastward, it is nearly S.; and at Hammerfest, near the North Cape in Norway, it is S.S.E. Let these directions be laid down on the isobarometric chart for January, and their relation to the iso-

barometric lines will be seen at once. The relation is this: All the prevailing winds in January over this extensive region are the simple expression of the difference of barometric pressure which prevails in the different parts of the region. The whole of the atmosphere flows in towards and upon the region of low pressure round Iceland,—not directly towards the region of lowest pressure, but in a direction a little to the right of it.

459. At Reykjavik, in Iceland, there is no particular direction observed, the only noticeable point being a remarkable deficiency of W. and N.W. winds. At Upernivik, Jakobshavn, and Godthaab, in West Greenland, it is N.E. and E. At Jakobshavn there are more east winds than all other winds put together, and this relation was constant during each of the twelve years. It is therefore probable that the very high pressure which prevails in the north of Asia at this season is extended in a modified form across the north pole, and terminates in the north of Greenland. And if so, the high winter pressure of Siberia will exercise an important influence over the weather of Great Britain, especially during the winter and spring months; for when low pressures prevail in middle and Southern Europe, a strong polar current will be drawn southwards over the British Islands.

460. Thus, then, it is to the low atmospheric pressure in the North Atlantic that we must chiefly look as the immediate cause of the winds which prevail in winter over America N. of lat. 40°, and over Western and Northern Europe. It is instructive to mark that from this cause N.W. winds are the prevailing winds in North America, but in Greenland and in Western and Northern Europe these winds are reduced to a minimum, being in truth the least frequent of all the winds. In Europe, they seldom occur except near the termination of gales and storms, and when the wind shifts round to that quarter a lull almost invariably follows. This fact is popularly recognised in Scotland, and finds a place among the weather prognostics current in the country, especially in the north. "The N.W. wind is a gentleman, and goes to bed;" that is, when the wind veers to the N.W., a

calm generally follows. The reason for this is evident from the chart, which shows that there is ordinarily little or nothing the wind can draw from in that quarter.

461. 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 the S.W. winds from the warm waters of the Atlantic that we owe, almost wholly, our mild, open, and, 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 a slow, steady air-current from the cold règions of Northern Asia is drawn westwards 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 V.) Finally, the same low pressure draws over British America and the United States by the N.W. wind, the cold, dry currents of the polar regions. In the State of Maine the mean January temperature is about 23°, whilst on the coast of England, 10° farther north, it is as high as 40°.

462. *Winds of Asia in January.*—These are explained by the extraordinary high pressures which prevail in the interior of the continent, and which gradually diminish on all sides on approaching the coast (Plate II.) The following are the directions of the winds at a few points :—

	No. of Years.	DAYS DIFFERENT WINDS PREVAILED FROM								
		N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
Yakutsk, . .	10	9	2	0	1	2	1	1	1	14
Bogoslovsk, .	10	1	1	1	1	1	5	1	1	19
Calcutta, . .	5	11	1	2	1	3	2	3	2	0
Ceylon, . . .	6	5	14	1	1	0	1	0	2	1
Hong-Kong, .	6	3	7	14	2	0	0	2	1	2
Pekin, . . .	6	5	1	0	1	3	1	2	11	7
Chacodate, . .	3	2	0	1	0	0	0	14	12	2
Sitka, . . .	9	1	3	8	6	1	2	1	2	8

All these represent the winds as flowing out of this region of high pressure. At Calcutta the prevailing winds in winter are N.; at Hong-Kong, E.N.E.; at Pekin, N.W.; at Chacodate, in Japan (lat. 41° 48′ N., long. 140° 47′ W.), W.N.W.; and at Bogoslovsk, Ural Mountains, S.W.; and at Yakutsk, N.; but at both these last places the atmosphere is generally calm, and the winds light. The influence of the low pressure in the North Pacific must not be lost sight of here. It will be seen that the E.S.E. direction of the wind at Sitka is in accordance with this low pressure, the wind there blowing in towards it in the manner already described.

463. 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 everywhere 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. Owing to the general direction of the winds in the north-west of America, resulting from the low pressure in that region, the rainfall from Vancouver Island northwards is greatest at this season.

464. The influence 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 −43°.8 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 every direction, 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 25°.2, whereas in Minorca, lat. 40° N., it is 53°.4. 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.

465. *Winds of Asia in July.*—The following table gives the mean direction of the wind at different points in Asia during July, when the central parts of the continent are highly heated by the summer sun, and atmospheric pressure is very low, being at least 0.400 inch lower than on the seaboard of the continent (Plate I.):—

TABLE OF PREVAILING WINDS IN ASIA DURING JULY

	No. of Years.	DAYS DIFFERENT WINDS PREVAILED FROM								
		N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
Bogoslovsk, .	10	2	5	1	2	1	4	3	4	9
Jerusalem, . .	3	2	1	0	1	0	2	8	18	0
Ooromiah, . .	2	1	0	2	6	2	2	12	5	1
Ceylon, . . .	6	0	0	0	0	1	16	9	1	0
Calcutta, . .	5	1	1	4	6	11	4	1	0	0
Hong-Kong, .	6	1	2	7	8	2	6	1	2	1
Pekin, . . .	6	4	2	2	5	8	1	0	1	8
Chacodate, . .	3	1	0	9	9	3	5	1	0	3
Yakutsk, . .	9	4	3	3	2	5	1	3	3	6

Here, then, we have 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, S.S.E.; and at Chacodate, in Japan, nearly S.E. Hence the particular course taken by the winds is a flowing in towards the centre 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.

466. *Monsoons.*—The term *monsoon,* derived from the Arabic word *mausim,* a set time or season of the year, has been long applied to the prevailing winds in the Indian Ocean, which blow 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 monsoons are thus caused by the inequality of heat, and thence of pressure, at different places, and the earth's rotation on its axis. If the equatorial regions had been entirely covered with water, the trade-winds would have blown from the N.E. all the year round. During the summer half of the year, when the sun is north of the equator, the continent of Asia becomes heated to a much greater degree than the Indian Ocean, which in its turn is warmer than Australia and South Africa. Hence, as the heated air of Southern Asia expands and rises, and the pressure is thereby reduced nearly half an inch below the average, colder air from the S. flows in to take its place, and thus a general movement of the atmosphere of the Indian Ocean sets in towards the N., giving a *southerly* direction to the wind. But as the wind comes from parts of the globe which revolve quicker to those which revolve more slowly, a westerly direction is communicated to it. The combination of these two directions results in the S.W. monsoon, which accordingly prevails there in summer. Since, during winter, as already explained, when the sun is south of the equator, Asia is colder than the Indian Ocean, and the pressure being thereby increased nearly half an inch above the average, a general movement of the atmosphere sets in towards the S. and W. As this is the same direction as the ordinary trade-wind, the result during winter is not to change the normal direction of that wind, but only to increase its velocity. Thus, while south of the equator, owing to the absence of sufficiently large tracts of land, the S.E. trades prevail throughout

the year, on the north of the equator, in the east we find the S.W. monsoon in summer and the N.E. in winter, it being only in summer and north of the equator that great changes are effected in the direction of the trade-winds.

467. Similar, though less strongly marked, monsoons prevail off the coasts of Upper Guinea in Africa, and Mexico in America. The E. and W. direction of the shores of these countries, or the large heated surfaces to the N. of the seas which wash their coasts, produce, precisely as in the case of South Asia, a S.W. monsoon in summer. The S.W. monsoon which blows off the coast of Africa is of great service to sailing vessels, since, by taking advantage of it, sailors are enabled to cross the latitudes of the Doldrums, or the region of calms, in the Atlantic. As might have been expected, the trade-winds off the coast of Mozambique are diverted more towards the E., and those off the coast of West Australia into a north-westerly direction. They are also in some degree turned out of their normal direction on the coasts of Brazil, Peru, Lower Guinea, and a few other places. Since these winds veer only through a few points of the compass, they are not true monsoons—the term being strictly applied only to those winds which change their direction so as to blow from opposite quarters at different seasons.

468. Some time in March the N.E. monsoon changes into the S.W., 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 in the south of Asia till the middle of May, it is not till this month that the S.W. monsoon acquires its full strength, and the heavy rains which accompany it fairly set in. In October the S.W. monsoon changes into the N.E., when the rain ceases and the dry season begins. These times depending on the sun's course, and consequently 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.

469. 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. The full advantages they bring with them are not seen until we consider them in their relations to the rainfall of Southern Asia. The fertility of the greater part of this fine region is entirely due to the S.W. monsoon, for if the N.E. trade-wind had prevailed there throughout the year, Central and Western India, and many other regions, would have remained scorched and barren saharas. The rainfall of China is also regulated by the same cause. When the wind blows from the continent on account of the high pressure there, little or no rain falls in China; but when the pressure of Central Asia is diminished, the wind begins to flow from the sea to the land, and the rainy season commences. Thus, at Canton the rainfall during the three winter months is only 3.34 inches, but in the three months May, June, and July, it amounts to 37.70.

470. It is under precisely similar circumstances that the annual inundation of the Nile has its origin. Though observations from the interior of Africa are wanting, yet from the direction of the winds round the coast, and from the analogy of the other continents when heated by the sun, there can be no doubt that during the summer months the interior of North Africa has a low atmospheric pressure, and that this low pressure follows the sun northward till July. As soon as the region of least pressure has advanced nearly as far north as Abyssinia, the air-current from the Indian Ocean, and consequently heavily charged with vapour, begins to flow across that mountainous region as it is drawn in towards the low pressure to the west or north-west of it. Hence the deluges of rain which begin to fall in June, the flooding of the White Nile and its tributaries, and the inundation of the Nile, with which Sir S. W. Baker has just made us all so familiar. When the region of least pressure following the sun has retreated into latitudes south of these mountains, then a dry hot current from Arabia is drawn over Abyssinia

southward towards the low pressure, in consequence of which the rain ceases, and everything is quickly parched up. Since to latitudes a little to the south the region of low pressure brings an atmospheric current from the Indian Ocean during almost the whole year, we have an explanation of the almost ceaseless rains of those hapless regions, where the mountains, obstructing the onward course of the vapour-laden wind, condense it into torrents of rain. The heavy rains in the north of South America, which Humboldt described so graphically, are explained in the same way.

471. From the relation of the United States in summer to the high pressure prevailing over the Atlantic at this season, the winds on the eastern seaboard are generally S. and S.W.; and hence the rainfall there is greater in summer than during any of the other three seasons. Since the British Islands are situated between the high pressure (30.348 inches) of the Atlantic and the low pressure (29.700 inches) in the northern portion of this ocean, the prevailing winds in summer are S.W. Hence the moderated heat of our summers, the comparatively large rainfall, the refreshing greenness of our landscapes, and the exquisite beauty or overpowering grandeur of the summer skies of the Scottish Highlands.

472. Owing to the almost invariably low atmospheric pressure of the Antarctic regions, the winds there may be regarded as blowing constantly from the N.W. This is one of the chief reasons why ships sailing from Europe to Australia and New Zealand round the Cape of Good Hope, and thence proceed eastward; and make the return voyage by Cape Horn; for thus they secure a westerly wind a great part of the way. It is scarcely necessary to point out how important it is to keep in mind these facts regarding the pressure of the atmosphere in southern latitudes, it being evident that a pressure of 29.4 inches to the south of Cape Horn, being the mean pressure there, indicates settled weather —a pressure which in the North Atlantic, and in most parts of the globe, would portend broken weather and stormy winds.

473. We sometimes see it stated that the general direction

of the wind in the Arctic regions is N.E. or N. The data on which this supposition has been based, have been obtained exclusively from observations made in Greenland, in ships employed in Arctic exploration or in the Greenland fisheries, and at the more northern of the Hudson Bay Company's stations. Now, the N.E., N., and N.N.W. winds prevalent in these regions are exactly the directions we should expect from the low pressures in the north of the Atlantic and Pacific Oceans. At Hammerfest and Archangel, in the north of Europe, the prevailing winds in winter are southerly. In Asia there are no observations of the winds in winter farther north than lat. 62°, consequently the direction of the wind in the northern parts of Asia is not known from observation. From the isobarometric lines it is highly probable that in winter the winds of the Arctic regions of the eastern hemisphere blow in directions which are determined by the high pressure in Asia, and by the low pressures in the North Atlantic and the North Pacific. There can be little doubt that these low pressures are the centres towards which they flow in a spiral direction, and not towards the North Pole, as Maury has supposed. The prevailing winds in the north of Asia in summer are most probably from the north (N.W., N., and N.E.), being drawn southwards towards the low pressure in the interior of the continent.

474. With regard to the manner in which the wind flows from the region of high towards that of low pressure, it will be observed that it does not blow directly towards the region of low pressure, but that it has the area of lowest pressure to the left hand of the direction towards which it is blowing. Thus in winter, the lowest pressure being in Iceland, the direction of the wind is N.W. in North America, W.S.W. and S.W. in Great Britain, and S.S.E. in Norway. In summer, the least pressure being in the centre of Asia, the wind is N. at Bogoslovsk, N.W. at Jerusalem, W. in Persia, S.W. in Arabia, W.S.W. in Ceylon, S.S.E. in Pekin, and S.E. in Japan. It will be shown in the chapter ON STORMS that this is the manner in which air-currents flow in upon

the areas of lowest pressure which accompany storms. Dr Buys Ballot has long urged this law, by which the course of the winds is regulated, upon the attention of meteorologists, especially in its important practical bearings on the notification of wind-direction in storms, and has based his system of signalling storms upon it. It is extremely interesting to observe that the same law which regulates the direction of the wind over comparatively limited regions during storms, is as conspicuously displayed in the mean direction of the wind over the globe, taken in connection with the mean barometric pressures.

475. A similar course is observed by the winds of Asia in winter (Plate II.), which flow from the region of high pressure in the interior towards the regions of low pressure which surround it. Referring to the table on page 219, it is seen that the wind does not flow directly out of this region of high pressure toward the low pressure, but takes a direction exactly the reverse of what it would take if the pressure was low instead of high. Thus, if the pressure in Asia at this time were low, we should expect the direction of the wind at Hong-Kong to be S.W.; but as the pressure in the interior of Asia is higher than on the coast, the wind at Hong-Kong is from the direction opposite to S.W., or it is N.E. I have often, in charting the weather of Europe, observed similar areas of high pressure out of which the wind flows on all sides. Francis Galton was the first to point these out to meteorologists in his 'Meteorographica.' They were called by him *anticyclones*, from the circumstance that the wind blows on these occasions in a manner exactly opposite to what it does when it blows round and in upon the centre of least pressure in cyclones or storms.

476. Another illustration of the same law is shown by the winds in summer on the north-west coast of Africa, between lat. 35° and 29° N., considered as an outflow from the high pressure in the Atlantic in the west towards the low pressure in the interior of the continent (Plate I.) Suppose the system of pressures in the Atlantic to be low instead of high,

then the mean direction of the wind on this part of the African coast would have been S.S.W.; but the pressures being high, the wind is from the opposite direction to S.S.W., —in other words, it is N.N.E.*

477. An important consequence follows from these results which seems to suggest the explanation of the great movements of the atmosphere. It has been partly referred to in Chapter III. Since the winds flow round and in upon the centres of least pressure, it follows that enormous quantities of air are being constantly poured all round into the areas of least pressure; and since, notwithstanding these accessions tending to increase the pressure, the pressure is not thereby increased, we are compelled to draw the conclusion that from the regions of low pressure vast columns of air ascend to the upper regions of the atmosphere, and thence flow away into neighbouring regions. Again, since where the pressure is high the winds all appear flowing out of it, and since, notwithstanding this draining away of the air tending to diminish the pressure, the pressure is not diminished, but remains high, it follows that the high pressure must necessarily be maintained by upper currents. This has been long given and accepted as the explanation of the low pressure of the region of calms in the tropics, and of the constant high pressures which bound it on each side. It may also be applied to the explanation of the high and the low pressures in other parts of the world.

478. In the North Atlantic, in January (Plate II.), the air is moist and warm, and the pressure consequently low. Towards what directions will the ascending current which rises

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* For this direction of the wind, see an interesting article in the 'Philosophical Magazine' for December 1867, *on the Natural Forces that produce the Permanent and Periodic Winds*, by J. Knox Laughton, R.N. In this article, too exclusive stress is laid on the condensation of aqueous vapour as the cause of winds. Compare the winds in Africa and Arabia in the table given by him at page 444 with the isobarometric lines on Plate I. at the end of this book, and they will appear as the simple result of differences of pressure, whether such differences arise from high temperatures, or from the presence of aqueous vapour or from its condensation.

from this region flow? Since it will flow in those directions where, at a great height, the density of the air is least, and since this happens where the mean temperature of the lower beds of the atmosphere is least (par. 98), an answer to the question will be given by the chart of the isothermals for January (Plate V.) Indeed, taken in a very general sense, these isothermal lines may be regarded as isobarometric for the upper currents of the atmosphere. If this be the case, we should expect the upper currents of Western Europe to be for the most part westerly (including N.W., W., and S.W.) It may be here remarked that the same reasoning is applicable as regards Western Europe to the isobarometric and isothermal charts for the year (Plates III. and VI.)

479. Now the only knowledge we can have from observation of these upper currents is from the appearances and motions of the cirrus cloud. This cloud has unfortunately been little observed, and the few observations which have been made of it have not received the attention which their great importance in meteorology entitles them to receive. William Stevenson, well known as an accurate observer and enthusiastic meteorologist, observed the cirrus cloud at Dunse, in Berwickshire, for eight years, beginning with 1840, and published an account of his observations in the 'Edinburgh Philosophical Magazine' for July 1853. The following is his summary of the directions of the motions of all the cirri observed by him, together with the mean direction of the winds at the surface of the earth for the same years:—

	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.
Direction of motion of cirri, .	77	16	3	49	92	256	222	243
Mean direction of winds at surface of the earth, . . .	46	31	35	19	26	85	71	33

Thus the most frequent direction of the cirrus cloud during these years was from the S.W.; the N.W. was nearly as frequent; the W. only a little less so; and any one of these three directions was about equal to all the other five directions taken together. The most instructive of these is the N.W. direction, as compared with the surface winds; for whilst the N.W. wind is one of the less frequent of the winds, the motion of the cirrus cloud from the N.W. is nearly as frequent as that from the S.W.,—a result quite in accordance with what we should expect from the position of the lines of equal mean pressure and mean temperature. It may be added that as the N.W. upper current advances into southern latitudes, the increasing heat of the sun will tend to dissolve the cirri which mark its course; and as the S.W. upper current advances into northern latitudes, the cirri accompanying it are much less liable to be dissipated; and hence it is probable that the N.W. upper current is the most prevalent in Great Britain, since being more frequently unaccompanied with clouds than the S.W. current, it has been less frequently observed. The *black showers* which occasionally fall in Scotland are in all likelihood the dust or scoriæ from the volcanoes of Iceland transported southwards by this N.W. upper current.

480. Hence, in the northern hemisphere in winter, we should expect the pressure of the atmosphere to be greatest in that region in which the temperature is lowest, and which is at the same time most completely surrounded by regions where the temperature is higher and the pressure low. The centre of Asia most completely fulfils these conditions, having a very low temperature, and being bounded immediately on the east, west, and south by regions where the pressure is considerably less. On the other hand, since in summer the ascending currents are chiefly those of heated air, the highest pressures are over that ocean (when the temperature is lower than that of the land) which is most completely surrounded by heated land; and, as already shown (par. 99), the Atlantic Ocean, between Africa and the United States, which most fully fulfils those conditions, shows the greatest excess of pressure.

481. From these considerations it may be concluded that

the winds at the surface of the earth are approximately known from the isobarometric lines—the direction being from the regions of high to those of low pressure, subject to the change produced by the earth's rotation; and that the upper currents of the atmosphere may be inferred from the isobarometric 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 part 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.

VARIABLE WINDS.

482. 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 movement of the atmosphere over a large part of the earth's surface. 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 prevail there in all their force. But in temperate regions, owing to the larger and more frequent departures of atmospheric pressure from the mean, the winds are often variable, and they are thereby also more under the influence of local causes. It is beyond the scope of this work to show the peculiar modifications to which the permanent atmospheric currents are subject from local influences in different countries, the question belonging rather to discussions of the climates of different countries. The most interesting of these winds are those which prevail in countries bordering on the Mediterranean

Sea, the Black Sea, the Caspian Sea, and also to some extent the Baltic and adjoining Seas. An inquiry into the disturbing influences caused by the evaporation and unequal temperature as compared with the surrounding land, would be a valuable contribution to meteorology,—such, for example, as a statement of the local and other causes by which the mean direction of the wind in January is N.E. at Christiania, whilst at Skudesnes, Christiansund, and Hammerfest, on the west coast of Norway, the mean direction is S.S.E.

483. 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., E., S.E., S., S.W., W., and N.W., to N. This follows in consequence of the influence of the earth's rotation in changing the direction of the wind. Dové has the merit of having, from Hadley's principle, propounded the *law of rotation of the wind*, and proved that the whole system of atmospheric currents, the permanent, periodical, and variable winds, obey the influence of the earth's rotation.

484. 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 versa*. 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 :—

485. *Puna Winds.*—To the east of Arequipa in Peru there is a barren table-land, high up among the mountains, called the Puna, which for four months of the year is swept by cold arid winds. These winds are part of the outflow from the high pressure in the South Atlantic towards the lower

pressures in the Pacific near the equator (Plate I.) After having crossed the lofty range of the Cordilleras, they are parched to a degree that has perhaps no parallel in any other country in the world. 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. It was in this district that the ancient inhabitants of Peru preserved their dead.

486. *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, 37, and even 29, 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.

487. Since these winds are simply the flowing away of the air from a higher to a lower pressure, it is only necessary, in explaining them, to show why, during that season, atmospheric pressure is more frequently higher to the north-east of Great Britain than during the other seasons. From September to March, when the sun is south of the equator, the air of the southern hemisphere, being warmer than that of the northern, expands, and by reason of its expansion part flows over into the northern hemisphere; hence there is a greater accumulation of dry air north of the equator in winter than in summer. The excess of air is greatest in regions such as the north of Russia, where the greatest degree of cold is experienced in winter, because the air, becoming denser on account of its low temperature, tends to settle there (Plate II.) If we consider only the dry air of the atmosphere, the mean pressure at St Petersburg in winter is 29.840 inches, and in summer 29.512 inches. There is thus a difference of

0.328 inch between the winter and summer pressure at St Petersburg. In Western Asia the difference is very much greater. This fact may be made more impressive by saying that there is conveyed away from St Petersburg during summer a stratum of air about 320 feet in thickness. When the sun has begun markedly to heat the air in the northern hemisphere in spring, part flows back into the southern hemisphere. But what influences the east winds more immediately is the heating of the north of Africa and south of Europe and Asia, by which the superincumbent air expanding flows upwards, *thus setting in motion an indraught of air from the north of Russia to take its place.* This northerly current marked out by a high atmospheric pressure generally holds its course through the centre of Europe; and it is a tributary, so to speak, from this current, pouring its dry pestiferous air westward over Great Britain, which constitutes the east wind.

488. The Isobarometric Charts of Europe for the spring months exhibit a smaller difference of mean pressure between Great Britain and the north of Europe, than during the other months, except November, when east winds also to some extent prevail. This smaller difference arises from the more frequent occurrence during these months of higher pressures to the north and north-east of Great Britain than in Great Britain itself; and it is from the repeated occurrence of these throughout the year that next to the S.W. or W.S.W. the N.E. wind is 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 polar 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 polar 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."

489. *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* (Ar. 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.

490. 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, the superficial layers of sand in the deserts of Africa and Arabia often 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 it possesses, that its destructive effects on animal life are to be ascribed.

491. 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 red 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 these mounds of sand, large caravans are frequently 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.

492. Hot winds from Africa 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 Sicily, South Italy, and adjoining districts. 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. The wind 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 withers and dries up, and thousands of cattle are cut off. It is called the *Samiel* in Turkey, from its reputed poisonous qualities.

493. 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."

494. The *Harmattan* of Guinea and Senegambia belongs to the same class of winds. It is a periodical wind blowing from the dry desert of Africa to the Atlantic, from N. lat. 15° to S. lat. 1°, during December, January, and February. It blows with moderate force, is often highly charged with fine particles of dust, and since under its influence no dew falls, vegetation grows languid and withers.

495. The *Pampero* is a wind which blows chiefly in the summer season from the Andes across the pampas of Buenos Ayres to the sea-coast. It is thus a north-west wind, or part of the anti-trade of the southern hemisphere, and in this respect it is analogous to the stormy winds which sweep over Europe from the south-west. But since it blows from the Andes over the South American continent, it is a dry wind, frequently darkening the sky with clouds of dust, and drying

up the vegetation of the pampas. The cause of its prevalence in the summer season will be evident on examining the isobarometric lines on Plate II.

496. 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 (Plate II.) 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 almost unknown in Great Britain.

497. In the south of Europe north winds are notorious for their violence. The great differences of the temperature of the Alps, the Mediterranean, and Africa explain them; and when the polar current, with a high atmospheric pressure accompanying it, is descending at the same time over Europe, the effect is greatly heightened. Of these 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 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 very high 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 last 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 shores of the Mediterranean the polar current in its full strength, which became still colder and drier in crossing the Alps in its southward course. Atmospheric pressure was at the same time high in Scotland, but as this country lay to the west of, and beyond, the cold polar current which set in from Russia towards the Mediterranean, the temperature was only slightly under the average of the season; in other words, no unusual cold occurred in Scotland. 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 XII.

STORMS.

498. 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. There is, perhaps, no question in physical science in which there has been so large an admixture of speculation with fact as in attempts made to reduce the phenomena attendant on storms to general laws; the reason being, that meteorological observations were, for long, too few in number, and too far apart, to enable any one to give the atmospheric pressure, the general course of the winds, the temperature, and the rainfall, without drawing largely on conjecture. Now, however, owing to the growing popularity of meteorology, and the countenance happily given to it by most civilised nations, sufficient data may be obtained for a fuller and more satisfactory statement of the question. I shall first state the chief facts of observation regarding storms as obtained from synchronous 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. The Scottish Meteorological Society has been for some time in a very favourable position for examining the storms of Europe. The sources of information are the following:—Observations (1) from the Society's stations on the mainland and in the outlying islands;

(2) from Farö and Iceland; (3) from several places in Norway, from Christiania round the coast to Vardo, east of the North Cape, sent monthly by Professor Mohn; (4) from sixteen places in Austria sent monthly by Dr Carl Jelinek; to which may be added (5) the daily Weather-Telegrams published in 'The Times;' and (6) the Observations and Chart published daily in the 'Bulletin International.' Through the courtesy of Dr Buys Ballot, any of the observations published in the 'Jaarboek' are available when required in particular discussions. There are thus ample materials for investigating European storms. The most valuable of these observations are those from Iceland, Farö, Scotland, and Norway; indeed, without these, most European storms could not be satisfactorily investigated, since the position, extent, and nature of the area of least pressure, and hence the drawing force of the storm, could not be certainly known.

499. In discussing storms, the most important by far of all the observations are those made by the barometer. Three different methods have been adopted to represent the relations of atmospheric pressure to storms:—*First Method.* By isobarometric lines drawn through places of equal pressure, for every tenth or two tenths of an inch of pressure. Lines for every two tenths are very suitable, since the disturbing force is sufficiently represented by them, and the eye is not distracted by the overcrowding of lines, which would be the result were smaller differences represented on the charts. This method of charting the barometric observations really leaves nothing to be desired, and no doubt it will soon be the only method used in investigating storms.

500. *Second Method.*—In place of lines of equal barometric pressure, some Continental meteorologists draw lines of equal barometric disturbance—that is, the difference between the barometer on the particular day, and the mean height of the barometer for the place and season. As this method can only suit a limited space of the earth's surface, it ought to be discarded. Thus, suppose on the 15th January the barometer in Western Europe was the average of the month—viz.,

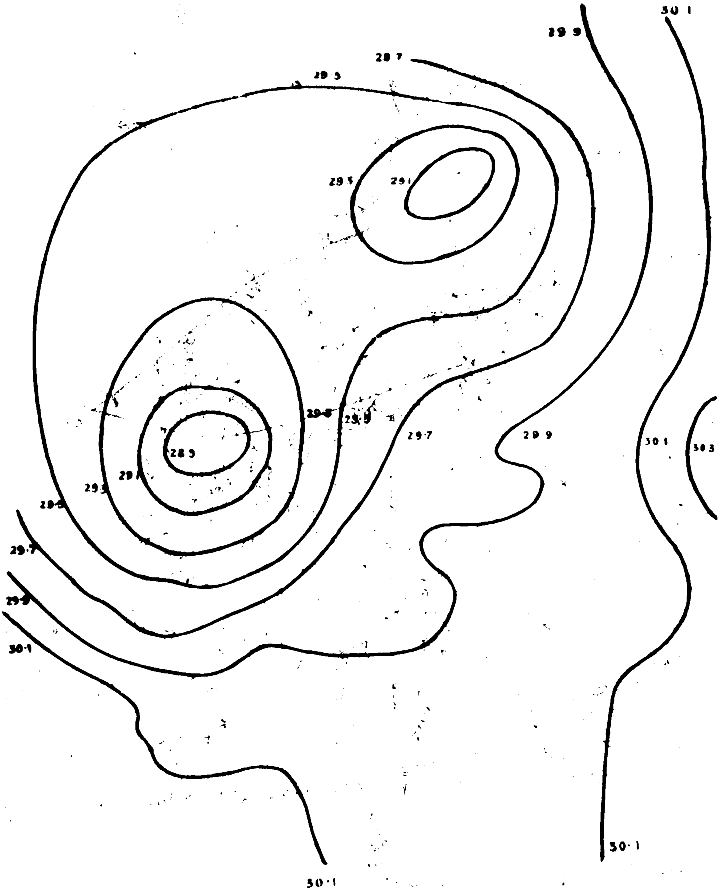
in Iceland, 29.510 inches; at Aberdeen, 29.737 inches; in London, 29.956; at Algiers, 30.119 inches, &c.; in other words, suppose the pressure to be exactly the mean of January, as represented in Plate II., then, by the method of equal barometric differences, these pressures would all be reckoned as 0—that is, no barometric disturbance would be indicated. But under such circumstances there *would be considerable barometric disturbance, which would occasion a general flow of the atmosphere from the very south of Europe northward towards Iceland.* Hence no method but that of reduction of barometric observations to sea-level represents *the whole of the disturbing force* at any time prevailing over wide areas. Except at very great heights, reductions to sea-level by the usual methods may be accepted as close approximations. The pressures which prevail at great heights must not be mixed up with pressures which prevail at lower levels in examining storms. The only use to which pressures at great heights can be legitimately put is in their relation to the upper currents, or to the winds which prevail at these heights, and not to the winds which blow on the earth's surface. On this point R. Russell, in his 'Climate of America,' has made some ingenious and valuable remarks.

501. *Third Method.*—By this method account is taken only of the line of minimum and the line of maximum barometer; in other words, a line is drawn through all places at which at the moment the barometer has fallen to the lowest point, but has not yet begun to rise; and another line through all places where the barometer has risen to the highest point. By this method only one feature of the pressure is given, which is included in the first method. It needs scarcely be said that this method is very defective, since by it no information can be got as to where the greatest differences of pressure are,—the most essential element of the storm, as pointing out where the wind is strongest,—the shape and position of the storm as defined by differences of pressure, and the exact direction towards which the body of the storm is moving. This is the method which was

adopted by Espy in examining the storms of America, and it is at present advocated by Signor Matteucci and R. Russell.

STORMS OF EUROPE.

502. I have charted a very large number of European storms, laying down in all cases the isobarometric lines, or lines of equal atmospheric pressure, and the direction and force of the winds; and, in a great many instances, the lines of equal thermometric disturbance, and the rainfall, cloud, and clear sky. I have also completed many of the daily charts of the weather published in the 'Bulletin International,' by filling in the observations from Iceland, Farö, Norway, Scotland, England, Austria, and other places. Hence the results which will be stated as applicable to the storms of Europe are based on a sufficiently large number of instances. Plate VII. is given as illustrative of the general features of these storms. It is a synchronous or synoptic Chart of Europe, giving, from observations made at about one hundred and forty places scattered over this continent, the atmospheric pressure and 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 isobarometric lines, or lines showing where at that hour the height of the barometer reduced to 32° and the level of the sea, was the same, are given 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 the utmost importance in its relation to the force of the wind. The force of the wind is shown by arrows represented as 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 ⤞,


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

which represents 6, a violent storm or hurricane. This arrow ⟼ indicates that the force of the wind is not known; and ⊙ represents a calm.*

503. The average atmospheric pressure over Europe at the level of the sea may be stated roughly at 29.9 inches. When, therefore, the barometer falls below 29.9, the equilibrium of the atmosphere is more or less disturbed in proportion to the extent of the fall, and it is within this *area of low barometer* that storms occur. Hence, by tracing these low pressures as they advance over the earth's surface from day to day, we trace at the same time the progress of the storms.

504. *Form and Extent of Storms.*—The curved isobarometric lines on the chart represent the shape storms generally assume. The area of European storms is generally either circular or elliptical, and when elliptical, the major axis of the ellipse seldom exceeds twice the length of the minor axis. Rarely in Europe, though less rarely in America and 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 be found to have parted into two, or more rarely three, distinct storms, which remain separate for some time, and afterwards reunite; sometimes, however, they continue separate, and diverge, one taking one direction, the other a different. The irregular shape of the isobarometric 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.

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* I have been enabled to make this Chart more complete than in the first edition,—to make it indeed one of the most complete Synoptic Weather-Charts of Europe hitherto published,—through the courtesy of Professor Mohn, Norway, Dr C. Jelinek, Austria, and A. O. Thorlacius, Stykkisholm, Iceland, in sending me observations made in these respective countries. The Russian observations since published are also added.

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 that time its centre at Liverpool, 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 space 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. 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 Liverpool 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.

505. *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 could be adduced as having advanced on Great Britain from N.W.; still more which 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 given only as conjectural, or as the impression left on my mind from the examination of a very large number of storms, and from the examination of the monthly schedules of the observers of the Scottish Meteorological Society for upwards of seven years, before sending them to be reduced to the Royal Observatory, Edinburgh. Before the proportions could be stated numerically, or before positive statements should be ventured, at least a thousand weather-charts would require to be constructed, showing the progressive movements, from day to day, of all storms that have passed over Europe during, say, the last six years; and such examination should include, if possible, observations from Iceland, the Azores, and the east coast of the United States of America. In Plate VII. the two blue lines represent the tract 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 Liverpool 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. Some storms, however, travel towards the south-east, over Great Britain, Austria, and the Black Sea, into Asia; of this class was the disastrous storm of November 1854, which inflicted so much damage on the British and French fleets during the Crimean war. Others descend over the North Sea, Germany, Austria, and Italy, thus following a course from north to south. From the 27th to the 30th March 1864 a storm passed successively over the Bay of Biscay, Gulf of Lyons, Corsica, Croatia, the valley of the Theiss, Warsaw, Dantzic, and the south of Sweden; its track being thus nearly semicircular. These two directions are of comparatively rare occurrence.

506. The least common, or rather rarest, direction in which storms travel, is toward some westerly point. The great snowstorm which occurred in Europe in January 1836, and which has been admirably traced and described by Professor Loomis, America, began, as the barometric curves conclusively 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. Hence, then, though the weather-changes of Europe generally advance from west to east, it is a mistake to suppose that this is always the case; and weather-prediction proceeding on this assumption must occasionally lead to error. Further, all the weather-changes which conspire to produce the dry east winds in the British Islands are instances of weather-changes advancing in a westerly direction.

507. 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, including, if possible, Archangel. For 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 a low pressure in the Baltic or Gulf of Bothnia, either stationary or having advanced thither from the east, influences the winds at the sea-ports of Great Britain by giving to them a westerly direction. It is during the occurrence of these storms in Russia and Sweden that strong 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 Russia that warning of such gales can be sent to seamen about to navigate the dangerous waters of the Pentland Firth. And since similar heavy 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 as applicable to Great Britain, will readily appear. Hence forecasts made of British weather without weather-telegrams from these localities must occasionally lead to inaccuracies, and give an empirical look to any system of forecasting, if these omissions in the weather-telegrams be not allowed for.

508. 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, thus giving evidence of the descent of a polar current of dry heavy air over central Europe. In passing through Russia storms frequently have a more contracted area than they had in passing over western Europe—*a remark of general application to storms in passing from a wet into a dry climate.* Observations show that the two storms on the chart, Plate VII., died out, the one in Finland and the other in the Baltic.

509. The storms on the coasts of the Mediterranean follow a different course. Some proceed from the north to the south, influenced probably by the heated air rising from the Sahara; a number appear to come from the east, and pass in the direction of N.W. over Greece and Italy towards the Alps, where their onward course is arrested; while others travel in an easterly direction,—some passing from the Bay

of Biscay up the valley of the Garonne, down upon the Gulf of Lyons, and thence to the east; and others passing south of Spain and then pursuing an easterly course.

510. *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, 0 miles, or stationary; whilst on rare occasions it is as great as 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.

511. 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, of barometric and wind observations made every hour in the extreme west of Ireland. 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. It need scarcely be pointed out that this frequent transmission of observations from Ireland to London is not called for unless when a storm is expected.

Let the instruments there be in charge of one who has some knowledge of weather-changes,—of the bearings of the cirrus cloud, the direction of the wind, and the fluctuations of the barometer, in their relations to storms. Then, if everything appear settled, no additional telegraphic despatch is required; but, if the usual premonitions of a storm show themselves, he should at once telegraph the fact to London, and continue to do so from time to time as already indicated.

512. *General Path of Storms over Europe.*—This is a feature of storms which has not yet been investigated. To do so properly would require an examination of many storms at all times of the year, to show the influence of season, if any, in changing the line of the general route; and, from that examination, to lay down on maps lines similar to the blue lines on Plate VII. From those I have examined, I am inclined to think that the two blue lines show not only the two most general directions in which storms travel, but also the average position of the line of the routes—the track north of Great Britain being the more common. I have calculated the mean monthly range of the barometer at about eighty places in Europe, for the eight years beginning with 1859. The lines of equal annual disturbance lie in a direc- from W.S.W. to E.N.E., of which the following indicate the position of a few:—

	Inch.		Inch.
Bayonne,	.746	Kremsmünster (Austria),	.721
Brest,	1.005	Warsaw,	.920
Bristol,	1.138	Dorpat (Russia),	1.132
Galway,	1.215	Christiania,	1.229
Stornoway,	1.355	Shetland,	1.304

In July these lines lie from south-west to north-east; but in winter the direction is nearly due east and west, the mean monthly barometric range in Orkney being 1.712 inches, and at St Petersburg, 1.797; at Dublin, 1.421, and at Königsberg, 1.474; and at Bayonne, .926, and at Trieste, .033.*

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* As connected with this subject, see an interesting paper by Joseph Baxendell, Manchester, on the Periodic Disturbances of Atmospheric Pressure in Europe and Northern Asia. (Mem. Lit. and Phil. Soc. of Manchester, 1860-61).

513. *Relations of the Temperature and the Dew-point to Storms.*—The temperature increases a few degrees at places towards which, and over which, the front part of the storm is advancing, and falls at those places over which the front part 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 in advance of the storm, it may still be above the average when the storm has passed, though lower than it was before. 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.

514. *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.

515. *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 least atmospheric pressure was in the central districts of England, from which it rose to some extent all round. The arrows, representing the winds exactly 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 least pressure.

516. Again, if the direction of the wind be referred to the region where the pressure was least—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 isobarometric lines, which are coloured red on the chart, 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.

517. This relation is what is known as Buys Ballot's "Law of the Winds." According to this distinguished meteorologist, if a line be drawn in the direction of the wind, and

another from the place of observation to that of least pressure, the angle is generally from 60 to 80 degrees. This is unquestionably the general direction of the wind in storms, but the angle is frequently as small as 45 degrees, especially where the winds become lighter on approaching the central space of least pressure, and on rare and peculiar occasions it exceeds 80 degrees.* 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. In reference to these two storms, the winds in the south of Norway and in Denmark are very interesting.

518. 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 I have yet examined; and it should be

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* Of these rare occasions, the storms of 6th February 1867 and 1st December 1867 are illustrations. In the former case the direction of the wind at places on the Channel and in the north of France, and in the latter case on the east coast of Scotland, as far as the north of Shetland, formed angles from 90° to 100°; in other words, the winds followed the isobarometric curves, or even to a slight degree crossed them. In every one of the occasions in which I have observed this peculiarity, the barometric lines were disposed in lines nearly straight, were closely crowded together, and the anomalous direction of the wind was strictly confined to a very small portion of the storm. Elsewhere, the winds were in accordance with Buys Ballot's law, and the storm, taken as a whole, was consequently in agreement with it.

particularly noted that it is no mere theory or opinion, but a simple statement of what has been constantly observed.

519. Professor Taylor first applied Dové's law of rotation to explain the direction of the rotation of storms round their centre. This may be illustrated by referring to the storm of the 2d November. On that morning, the pressure over England being much less than in surrounding countries, if the earth had been at rest, it is 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 to the north, would, on account of its greater initial velocity, blow when it arrived at Paris, no longer directly towards the north, but to a point a little to the east of north; in other words, it would be no longer 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, had changed from a north to a north-east wind. Similarly the north-west current changed to a north, the south-west to a west, &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, as may be expected, flows 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 baro-

metric differences are greater,—the whole phenomena being, as it were, condensed into smaller space.

520. *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 the fishermen and sailors in the west of Scotland. In inland situations, the influence of hills and valleys in changing the direction of the wind is everywhere recognised.

521. (2.) The irregular outlines of some of the isobarometric 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, the pressure in the valley of the Clyde was a little less than what prevailed to the east, south, and west, as well as to the north of it. The following will show, in inches, the nature of this depression: Glasgow, 29.053; Douglas Castle, 29.072; Girvan, 29.092; Paisley and Balloch Castle, 29.148; Oban, 29.175; and Edinburgh, 29.192. The influence of this small local depression is seen in diverting from the normal directions the wind at Aberdeen, in East Lothian, and at Glasgow. At the same time the pressure on the coast of the Gulf of Genoa was lower than it was elsewhere in the vicinity; and the influence of this small local disturbance is plainly seen in the direction of the wind at Marseilles, Toulon, Leghorn, Venice, Milan, and Turin, these all being seen to flow round and in upon this patch of less pressure. Similar areas of small local disturbances in the pressure occurred near Geneva, in the north-east of Austria, and near Odessa in the Black Sea, and at all of these places corresponding deviations of the wind may be ob-

served. These local disturbances are thus noticed by Francis Galton in his 'Meteorographica,' page 7: "In addition to the great barometric fluctuations, there are numerous smaller ones, and it occasionally happens that the barometric readings have a widely-spread tendency to show marked though minor irregularities in adjacent places; or, to use an intelligible though inaccurate metaphor, they are violent ripples on the great barometric waves." If the expression "or eddies" be inserted after ripples in the above extract, these smaller barometric disturbances would be more completely described.*

522. (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 legitimately be referred to isobarometric lines showing the pressure at the level of the sea. It is thus we explain the anomalous direction of the wind as not unfrequently observed at Madrid, and at the higher of the stations in Austria. The value of observations from such high stations, as previously stated, lies 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. In critically examining Buys Ballot's law of the winds, it is indispensable that these three classes of apparent exceptions be taken into account. From the very extensive examination of the law which I have made, I am convinced that if all apparent deviations from it be examined they will turn out, if the critic has the whole facts before him, to be only strong confirmations of its correctness.

523. This view, which considers the direction of the wind as brought about by the drawing force arising from differences of atmospheric pressure, together with the influence of the earth's rotation on its axis, is sometimes objected to as insufficient—it being urged that the rotation of the earth is inadequate to

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* This interesting feature of storms can only be properly investigated when observations from numerous stations are available.

produce so large an angle as 60 or 80 degrees. But storms cover a large portion of the earth's surface, and since the part of the earth's atmosphere involved in the storm is simultaneously moved as one mass by the difference 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 action in this 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, resulting in whirling currents which flow 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 exerted by the air-currents themselves 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 these 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 exceed, 90°.

524. *The Force 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 isobarometric lines are far apart; and it will be observed in the other parts of Europe where these lines are far apart, that there the wind did not reach the force of a gale.

525. In the south of Scotland, the north of England, and in Ireland, where the isobarometric 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 barometric 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), it being there where, at the time, the violence of the wind was most felt.

526. Near the centres of the isobarometric lines which mark the position of the storms in England and in the north of Sweden, calms and light winds prevail. At Christiania, between the two storms, and where the pressure was about the same as at places near it, a calm 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. We thus see that, as the wind comes near the centre of the storm, it gradually turns round and blows more in the direction of the centre; and that at the same time it abates in force and then sinks to a lull or calm. Since at this time 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. It is also seen from the winds in the east of Russia that calms and light winds prevail along the ridge of high barometer, or the region where the barometer is highest, and in receding from which it falls 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 the pressure is less.

527. The storm on the 6th February 1867 may be adduced as an excellent illustration of the same principle which rules the force of the wind in storms. On that morning the barometer was 28.422 inches at Christiansund, and 28.375 inches at Skudesnes, both in Norway; 28.254 inches at Kirkwall,

28.335 inches at Nairn, and 28.540 inches at Scarborough and Isle of Man. Hence the differences of pressure being small over that wide region, the winds were everywhere light; but much rain and snow fell. But, south of Scarborough, the pressure rapidly increased to 28.776 at Yarmouth, 28.859 at Greenwich, 29.607 at Paris, 30.079 at Bayonne, and 30.420 at Lisbon; and consequently, over the whole region, from Yorkshire to the north of Spain, high winds and stormy weather prevailed—the anemometer at Lloyd's registering a pressure of 35 lb. to the square foot, or a velocity of 84 miles an hour. Since this storm passed eastward—the central depression, while passing, being in the extreme north of Scotland—and for some days was preceded by low pressures, it happened that, though in the centre of greatest depression, no stormy weather occurred in North Britain. From this it is evident that a storm is not most violent where the pressure falls to the greatest extent, but at those places which, during the course of the storm, may at any time happen to lie in a position between much higher and much lower pressures; such places being in the line of the course down which the air rushes impetuously from the high to the low barometer to restore the equilibrium.

528. *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 29.5 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 aërial rapids of the storm between the high and the low barometer. In forecasting the weather, this consideration ought not to be lost sight of. 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 our best defence.

529. *Velocity of the Wind.*—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 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. Mr Hartnup informs me that 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.

530. Since all examinations of storms uniformly show that where the isobarometric 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.* Hence, then, 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.

531. Thomas Stevenson, C.E., has proposed to express the numerical intensities of storms by what he calls the *barometric gradient*, which is obtained by the simple arith-

metic 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. The great hurricane which swept over Scotland on the 24th January 1868 is an excellent illustration in point. At 9 A.M. the barometer at Hawick was 29.985 inches, and at Auchendrane House, near Ayr, 29.835 inches, thus giving a gradient[†] at the rate of 1 inch in 407 miles. In the district between these two places the wind at the time did not reach the force of a gale. But at Callton Mor, near the Crinan Canal, the barometer was 29.535 inches, and hence the gradient between this place and Auchendrane, distant 54 miles, was 1 inch in 191 miles. The state of the weather over the intervening space may be seen from the circumstance that, at 10.20 A.M., the Rothesay and Wemyss Bay steamer Victory, ran in to Greenock harbour to shelter, having taken about two hours to cross from Rothesay, which is usually done in half an hour.

532. But it was at Edinburgh that the force of this hurricane was most severely felt. From observations made simultaneously at Thirlestane Castle, near Lauder, and at Edinburgh, I have calculated the following gradients, with which are given the times at which masonry was thrown down, as detailed by Mr Stevenson in 'Good Words' for June 1868:—

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[*] See 'Journal of the Scottish Meteorological Society.' New series, No. XVII.

[†] In these gradients the lines joining the places referred to were nearly at right angles to the *lie* of the isobarometric lines at the time.

Hour.	Barometric Gradient.	Damage.
9 A.M.	1 inch in 606 miles.	None reported.
12 noon.	,, 108 ,,	Morningside Church gable, 12.15; Queensferry Street, 12.50; North Castle Street, 12.50; Bristo Street, 12.55; 252 Cowgate, 1.10; 10 Duke Street, 1.20; 53 Frederick Street, 1.30; 64 East Crosscauseway, 1.30; 102 Pleasance, 1.45.
2 P.M.	,, 72 ,,	7 North Frederick Street, 2.0; two trees broken, 2.10; Queen Street, 2.15; Hope Street, 2.15; 5 Roxburgh Terrace, 2.20; 2 Potterrow, 2.45.
3 ,,	,, 76 ,,	5 Roxburgh Terrace, 3.30; Holyrood Palace, 3.30; 26 Potterrow, 3.30.
4 ,,	,, 95 ,,	Park Street, 4.0; North Richmond Street, 4.30; 29 Frederick Street, 4.30.
8 ,,	,, 164 ,,	None reported after 4.30.
9 ,,	,, 267 ,,	

533. In addition to these effects produced by the hurricane, I may give three illustrations of the great force of the wind on this occasion. I happened to be at the Royal Observatory, Calton Hill, between 2 and 3 P.M., at which time the gravel on the platform facing the south was being blown off and about like hailstones in a shower of hail. Next morning every loose stone (several of them weighing 2 oz.) had been swept off this platform by the wind—a circumstance which is not known to have occurred before at the Observatory. Many cabs were blown down, with the horses; in one case the horse had somehow got disentangled from the tracings, and was seen standing quietly beside the cab, when on a sudden it was blown to the ground—not even staggering as it fell, but falling just as if it had been a jointless piece of wood. While walking quickly against the wind, estimated at about 50 miles an hour, I was instantaneously brought to a stand by a gust so strong that the feeling produced was the same as if I had unwittingly walked up against something solid, such as a shut door.

534. There was unfortunately no anemometer in working order in Edinburgh at the time, to record the velocity or pressure of the wind. At Glasgow, where the storm was less violent than at Edinburgh, complete observations of the velocity and pressure of the wind were made, copies of which have been kindly forwarded by Professor Grant. The maximum velocity occurred from 1.15 P.M. to 1.30 P.M.; in these 15 minutes 21 miles of wind passed over the Observatory, being at the rate of 84 miles an hour. During several of the short-continued gusts which occurred, the force exceeded this high rate. The strongest of these gusts, as registered by the pressure anemometer, occurred between 1 and 2 P.M., and the pressure recorded was 42 lb. to the square foot.*

535. *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 calm which marks 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 a considerable number of 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.

536. 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

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* For the details of this storm see 'Jour. Scot. Met. Soc.,' No. XVIII.

charts. This storm extended from north to south 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.

537. I have examined the storm which passed over the United States from the 13th to the 16th March 1859, laying down, on seven synchronous charts, the barometers at sea-level and the winds, from the copious materials which have been prepared by Professor Coffin, and published by the Smithsonian Institution. In all these charts the isobarometric lines are 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 isobarometric 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. The storm, as marked out by the area of low pressures referred to, travelled from Texas towards Newfoundland, or it pursued a course from S.W. to N.E., or from W.S.W. to E.N.E.

538. In the 'Fourth Meteorological Report' issued by the Senate of the United States, Professor J. P. Espy gives 58 synchronous charts illustrating the storms which occurred in America from 1st January 1851 to 8th June 1852. These charts have one very serious defect—viz., the isobarometric lines are not drawn on them; but, instead of these, two hypothetical lines, referred to in paragraph 501. This mode of representation, it need scarcely be said, is very defective. It makes hypothetical barometric lines usurp the place of

lines representing actual observations; and it gives no clue whatever to find the position of the area of least pressure, the shape of that area, and the depth of the barometric depression—the essential elements of storms, to which all others are subordinate, inasmuch as the strength of the wind is proportioned to the difference of pressure. Since, however, the winds and rainfall supply very trustworthy information regarding the position of storms, and their translation from place to place, an examination of these fifty-eight charts leads to the following results: The storms of America seem to take their rise in the vast plain which lies immediately to the east of the Rocky Mountains, and thence advance, generally in an east-north-easterly direction, across the United States. The other features of storms—the in-moving spiral course of the winds round and in upon the centre, the high temperature and dew-point in front, and the low temperature and dew-point in rear of storms, the rainfall, cloud, and clear sky—differ in no respect from the storms of Europe. A noteworthy difference which exists between the storms of the two continents is, that in America they appear in many cases to have a more elongated form, and to advance towards the east sideways—that is, the longest diameter is at right angles to the onward course of the storm.*

539. But 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

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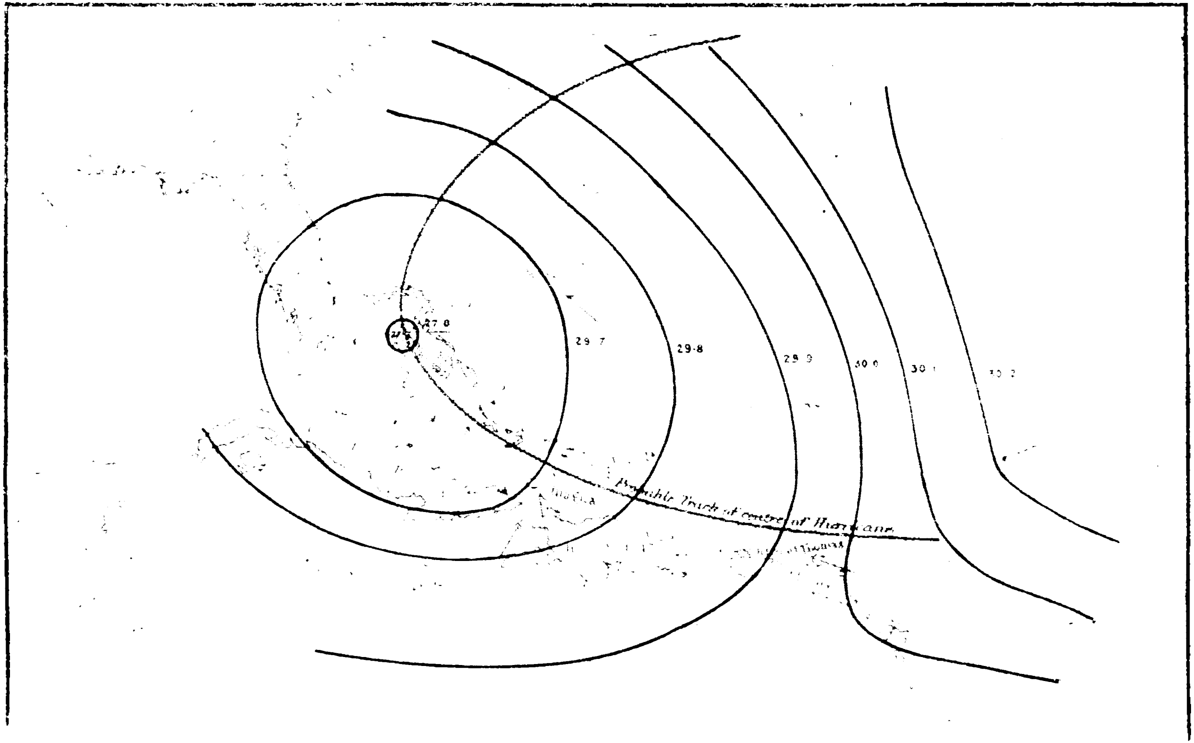
* From their method of examining storms, Professor Espy and R. Russell have concluded that the direction in which they travel in winter is from W. to E.; and perhaps as regards the more elongated storms this is not far from the truth.


27.8
29.7
29.8
29.9
30.0
30.1
30.2
Probable Track of centre of Hurricane

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 having 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 Botanic Gardens, 35 of these being spring flowers; and the strange spectacle was seen of Sweet Peas and Hepaticas blooming together.* Now in America storms are almost invariably succeeded, or rather terminated, by intense cold. It occasionally happens, however, that intensely cold winds terminate British storms, and in these cases it has been invariably observed that barometric pressure is very high in Iceland. The storm of the 1st and 2d December 1867 was of this sort. In this storm the wind suddenly veered to N.W., N., or N.E., suddenly rose from a light air to a storm, the barometer rapidly rose, and the temperature fell everywhere to the extent of 20° or 30°. The northerly gale was felt first at North Unst, in Shetland, from which it proceeded towards the south-east, advancing with an extended front many hundreds of miles in length. At Brussels, which was south of the area of lowest pressure accompanying this storm, no sudden change of the wind took place, but it veered successively through S.S.E., S., S.W., and W. to N.W.

STORMS OR HURRICANES OF THE TROPICS.

540. THE BAHAMA HURRICANE OF OCTOBER 1866.†—On

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* See a paper by Professor Balfour on "The State of Vegetation in the Royal Botanic Gardens, Edinburgh, in the end of December 1863," in 'Proceedings of the Royal Society of Edinburgh,' Session 1863-64.

† The data of this hurricane have been obtained from Commander A. J. Chatfield's Record Chart of the storm; Governor Rawson's Report of the Hurricane; and observations received from Mr Andrew Lang, St Croix; the Royal Mail Steam Packet Company; the Director-General of Hospitals, &c.

Plate VIII. are exhibited the barometric pressure 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 the storm was at Nassau. At this instant the barometer was 27.7 inches at Nassau, 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 extraordinary fluctuations of the barometer as never occur beyond the tropics. In Great Britain the fall of one-tenth of an inch of barometric pressure 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 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 lasted from 7.20 P.M. to 8.50, we learn, 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 isobarometric 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. Barometric differences much greater than these have been observed. Thus, during the hurricane which devastated Guadaloupe on the 6th September 1865, it is stated in the 'Bulletin International' that the barometer at Marie Galante, a neighbouring island, was 29.929 inches at 4 A.M., 29.646 at 6.30 A.M., 29.174 at 6.47 A.M., and

27.953 at 7.40 A.M., having thus fallen 1.693 inches in one hour and ten minutes!

541. *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 the 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.

542. *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 instance did the winds blow directly to the centre of least pressure at Nassau, or blow round the area of low pressure in circles returning on themselves; but that in every instance they blew in a direction intermediate between these two directions. Hence the storm was rotatory, and, as the direction of the arrows show, it revolved in a direction contrary to the hands of a watch; and within the area of rotation the winds approached the centre by spirally in-moving currents of air. It will be observed that the winds nearest the centre blew more directly towards it than those at a greater distance from it. In this respect this hurricane resembled every European and American storm

which I have hitherto examined from actual observations laid down on synchronous charts.

543. *Connection between the Direction of the Wind and the Centre of the Storm.*—Standing back to the wind, the centre lies to the left hand of the direction in which the wind is blowing. This holds in all places north of the equator, and it furnishes the rule which must be observed by ships in steering out of the course of the storm. From this relation of the winds to the pressure is also deduced the rule for predicting the direction of the wind at particular seaports during storms. Thus, suppose at 9 A.M. it be required to know the direction in which the wind will blow in London at 9 P.M., a storm being observed advancing from Ireland towards the east. Information being had through the telegraph of the course the storm is taking, and an inference being drawn from that observed course that at 9 P.M. its centre will be near Liverpool, then at that hour the gale may be expected at London from S.S.W.

544. The only exceptions to the rule, shown by the winds on Plate VIII., are the winds at St Thomas and St Croix. But it must be considered that the storm had already passed these places; the winds were therefore light, and were now beginning to yield to the influence of the high barometer which prevailed at that time to the east and north-east.

545. *Probable Track of the Centre of the Storm.*—From observations received, the position of the centre was determined at seven points, which were then connected together by the hacked line on the chart. It will be observed that it began to the north-east 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. This is the track usually followed by West Indian hurricanes.

546. *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 not on the velocity of translation of the whole body of the storm, but 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 hurricance.

547. The barometric differences determining the force of the wind must have been very great. Since the pressure at Nassau at 8 P.M. was 27.70 inches, and 286 miles distant it was 29.70 inches, the mean barometric gradient for the distance was 1 inch to 143 miles. But since the barometer did not fall uniformly over the intervening space, much steeper gradients must have taken place. The following barometric observations were made by Captain Chatfield, R.N., at Nassau on the 1st :—

Hour.	Inches.	Hour.	Inches.	Hour.	Inches.
8 A.M.	29.82	4 P.M.	29.20	8 P.M.	27.70
10 ,,	29.72	5 ,,	28.50	9 ,,	27.86
noon.	29.50	6 ,,	28.14	10 ,,	28.44
2 P.M.	29.33	7 ,,	27.90	midnight.	28.78

Now since the onward course of the storm as it neared Nassau was at the rate of fifteen miles an hour, after which it increased gradually to thirty miles,—suppose that between 4 and 5 P.M. it advanced twenty miles, then there probably occurred at 4 P.M. a difference of 0.700 inch of pressure between Nassau and places twenty miles to the south-east, which would give a gradient of 1 inch to about twenty-nine miles. Colonel Sykes has recorded a still more remarkable case of great difference of pressure. During a cyclone off the

Malabar coast, the barometer on board a ship read 28 inches, whilst the barometer at Ootacamund, 100 miles distant, reduced to sea-level, stood at 30, thus showing a difference of 2 inches in 100 miles. If there had been observations at intermediate points, it is probable that steeper gradients would have been observed than at the rate of 1 inch in 29 miles.

548. *Veering of the Wind during the Storm.*—At St Croix, situated in the south or left-hand side of the storm's track, the veering of the wind, as recorded by Mr Andrew Lang, who has paid much attention to these West Indian hurricanes for the last fifty years, was as follows: On the morning of 28th September the wind was N.E. (the usual trade-wind); at 4 P.M., N.; on the 29th, at 6 A.M., W.; at 10 A.M., W.S.W.; on the 30th, at 6 A.M., S.; on the 1st, at 6 A.M., S.E. It then shifted to the east, and on the afternoon of the 2d to E.N.E. Observations from other six places, or ships, on the left-hand side of the track of the storm all show that the wind veered in precisely the same way—viz., from N.E. to N., W., S., E. The ship Mexican, whose course during the storm was from 200 to 300 miles north-east of Nassau, recorded the following veerings of the wind: On 1st October, at 6 A.M., E.; at 6 P.M., E.S.E.; on 2d, at 6 A.M., S.S.E.; at noon, S.; and at midnight, S.S.W.; on the 3d, at 6 A.M., S.W.; at noon, W.S.W.; and at 6 P.M., W. Observations from other five places, or from ships, on the right-hand side of the storm's track show that the wind veered in the same direction—viz., from N.E. to E., S., W., and N. 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 by 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. These facts regarding the veering of the wind are a simple consequence of the revolving character of the storm, and its progressive motion over that part of the earth's surface.

549. I constructed other eight synchronous charts of this storm at different points of its course, and they all agreed in the essential features portrayed on the chart, Plate VIII. I have also constructed similar charts of the storms described by Redfield and Reid, and have not found them to differ in any essential point from the Bahama hurricane of October 1866. All are revolving storms showing the wind blowing round and in upon the centre of least atmospheric pressure when the barometric depression at the centre was known; and when not, they were observed blowing round and in upon a centre presumed, from the general direction of the winds, to be that of least pressure. None of those examined showed the winds blowing directly towards the centre of least pressure; though in some instances, when observations were had from points in the immediate neighbourhood of the centre, there was a tendency in the winds to turn further round so as to approximate to the centripetal direction. None of the storms, at any hour at which they were charted, exhibited the winds whirling round the centre in perfect circles, but all were "vorticose," to use Sir John Herschel's expression—that is, they were formed of spirally in-moving currents of air.

550. At Nassau the calm at the centre of the storm lasted an hour and a half, from 7.20 to 8.50 P.M. While the vortex of the storm was passing over the harbour, 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 heavy dense 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.

551. The 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 splendid 'Physical Atlas.'

STORMS OF SOUTHERN ASIA.

552. *Typhoons.*—The name typhoon is applied to the storms which occur at certain seasons in the north of the Indian Ocean and in the Chinese Sea. As regards their form, the sudden barometric changes accompanying them, and the blowing of the winds round and in upon the centre, where the pressure generally falls to 28 inches, and even on rare occasions as low as 27 inches, 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; and hence 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 monsoons. Here, then, are two great atmos-

pheric currents—the S.W. monsoon, prevailing over southern Asia, and the ordinary N.E. trade-wind in the Pacific Ocean to the east—flowing side by side, but in opposite directions (see isobarometric lines for July, Plate I.) On this account, an examination of these storms from observations made in China and on the ocean and islands to the east and south of it would possess considerable interest to meteorologists, since from this peculiarity typhoons are well fitted to throw light on inquiries affecting the origin and tracks of storms.

553. 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. Since the formation of this Society in 1851, it has devoted a large share of its attention to the collecting of Meteorological Statistics of the Indian Ocean, and the tabulating of them in chronological order. Upwards of 500 synchronous weather-charts have been constructed under the direction of its able and energetic secretary, Charles Meldrum. I have, through his courtesy, examined a considerable number of these charts, which, if the isobarometric lines were filled in, would leave nothing to be desired. At the meeting of the British Association held in Dundee in 1867, Mr Meldrum gave an account of these storms; and it is chiefly from this paper, a copy of which he has kindly sent me, that the following facts regarding them have been taken. Of these storms there are two sorts—viz., tropical and extratropical storms.

554. *Tropical Storms.*—The tropical storms occur only from November to May inclusive. They originate between the parallels of 6° and 14° lats., and thence proceed in the direction of W.S.W., and afterwards, though not always, their course curves round and turns towards the S. or S.E. The winds invariably move 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 the winds in storms of the southern hemisphere. 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.

555. 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. As already stated, Mr Meldrum has shown 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 chart (Plate II.) giving the isobarometric curves for January be examined, it will be seen that the N.W. monsoon, which prevails in the northern part of the Indian Ocean at this season, is fed by the region of extraordinarily high pressure which overspreads the Asiatic continent; consequently, this atmospheric 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 the precipitation proceeds, the pressure is diminished, and the N.W. monsoon advances sometimes along its whole extent 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 oscil-

late 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.

556. The monsoon does not always advance equally along its whole extent, 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.

557. 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 seasons. As regards the form of these storms, it varies, and Mr Meldrum is of opinion that it is not so circular as is usually supposed; but in regard to this point no satisfactory opinion can be formed till the isobarometric lines be drawn.

558. In applying the knowledge thus acquired regarding these storms to purposes of navigation, Mr Meldrum makes the following excellent 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 roadsteads of Reunion 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 May 1863, for instance, of twelve homeward-bound vessels which had got involved in a storm by running to the southward with increasing winds, falling barometer, and threatening weather, two had to be abandoned at sea, and the others were so disabled that on arriving at Port Louis some of them were condemned and some detained for two or three months undergoing repairs. The loss on that single occasion must have amounted to at least £60,000, and there is not the slightest doubt that it would have been avoided if the vessels had kept back for a day or two, and not run headlong into the storm. *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.*"

559. *Extratropical Storms.*—These 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 invariably 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.

560. Mr Meldrum is of opinion that they are not revolving gales, like the storms which take place in the tropics—an opinion with which I am not prepared to concur, for the following reasons: The data from which the charts have been constructed are, with the exception of the observations taken at Mauritius, exclusively sea observations. It is probable from an examination of the charts that the northern portion of the storm stretches for some distance into Africa, and then, as it advances, it passes over those parts of the ocean seldom traversed by ships touching at Mauritius; and since its southern termination is beyond the region usually traversed by ships, it follows that in almost all the storms charted, only the middle portion of the storm is represented—its northern and southern limits being beyond the field of observation.

In one or two cases I examined, in which ships were at or near the northern limit of the storm, the shifts of the wind were not sudden from N.E. to S.W., but passed regularly from E. to N.E., N., N.W., W., and finally to S.W. I would suggest, in prosecuting the investigation of these storms, that means be used to procure the observations made at the meteorological stations established some years since in Cape Colony and Natal, which will definitely decide the point under discussion.

561. 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. When a storm with its low pressures is passing to the south of Africa, a hot wind from the N.W. prevails in Natal and South Africa, bringing with it a temperature rising to from 90° to 97°, and a dryness which withers vegetation, and causes the furniture of houses to crack with loud explosions. This connection between the low pressures accompanying storms, and hot winds from the interior of Africa, has been stated by Dr Mann in a singularly lucid and able paper on the 'Atmospheric Pressure in Natal, South Africa.' *

562. It may be suggested that the great differences between these two classes of storms in passing from the tropical to the south temperate zone, should be made a subject of constant observation, and of most earnest study by seamen who navigate these waters in the passage from China or India to England, or *vice versâ*.

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* Proceedings of the Meteorological Society of England, vol. iii. p. 340, *et seq.*

563. 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.

564. On the storm-charts given in the works of Reid, Dové, and some other writers, the arrows representing the direction of the wind are invariably drawn as flying round the circular area of the storm in perfect circles returning on themselves. These arrows, it is unnecessary to say, in no case represent any winds actually observed at a particular hour, but are in every instance representative of a hypothesis in the mind of the writer at the time—viz., a particular rotatory theory of storms. They serve the purpose for which they were intended; for by shifting the circles with the arrows drawn on them over the space passed over by the storm, and

comparing it with the observations at each place as it is passed over, it is proved beyond a doubt that all these storms turn round upon a centre. But the kind of the rotation is not proved—that is, it is not proved whether the winds blow round the centre in perfect circles, modified only by the progressive motion of the storm, the ideal of the cyclone; or whether they blow round and in upon the centre. I have examined many, especially tropical storms, by synchronous charts, in the hope of lighting on some one that might illustrate the purely cyclonic behaviour of the winds round the centre, but have not yet found one. On the contrary, every storm examined in Europe, in America, or within the tropics, shows beyond a doubt that storms are vorticose. This, be it noted, is not a mere opinion, but the simple statement of the position of the winds in storms as shown by synchronous charts on which the winds are entered exactly as observed at each place. It is therefore a statement unassailable by argument, and must be accepted as the law in accordance with which the course of the wind in storms is regulated. Professor Taylor, followed by Sir John Herschel, has shown that these characters of storms are the result of the "law of rotation" of the wind as devoloped by Dové, which takes effect when, owing to a local excess of heat or of aqueous vapour, the air over some extensive region rises in a vertical column. This rotatory feature of storms becomes intelligible when the winds are regarded as drawn in upon a centre of low atmospheric pressure along the globular surface of the earth rotating eastwards.*

565. 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

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* This view of the spirally in-moving course of the winds in storms, which is essentially Redfield's theory, has been adopted by the following meteorologists: Dr Buys Ballot, Utrecht, whose system of forecasting the weather, proposed by him in 1857, is based on it; Dr Joseph Henry, Secretary of the Smithsonian Institution, America; Maury; Dr H. Lloyd, Dublin; Sir John Herschel; William Stevenson; &c. &c.

centre in circles, subject only to a slight modification from the onward motion of the storm,—a state of the winds which in none of the storms examined has been found to exist, not even in those cases when the storm was increasing in area and deepening the depression at the centre. 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 hurricance 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 portion of the atmosphere, 300 miles in diameter, was 70 miles an hour.

566. An interesting question may be here suggested—viz., Does any portion of the atmosphere as it turns round and in upon the centre ever make one or more complete revolutions round the central area of least pressure, whilst it continues to blow as a wind in contact with the earth's surface, or before it rises into the upper regions of the atmosphere? It is probable that this seldom occurs, when it is considered that the qualities of the air, both as regards temperature and moisture, are generally essentially different in the front, as compared with the rear of a storm. Mr Meldrum, however, gives an example which occurred in May 1863, when a vessel belonging to Dundee, called the Earl of Dalhousie (Captain Campbell), scudded, at the rate of 10 to 13 miles an hour, three times round the centre of a revolving storm, which happened to be nearly stationary, till at length it reached the central calm.

567. *But the spiral rotation, instead of the purely circular rotation, of the winds in storms, completely alters 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.

568. 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 barometric pressure, suggest that the general movements of the atmosphere over the globe and in storms, are due to the same physical causes acting in the same way. Indeed, what has been expressed in par. 481 equally expresses what takes place in storms. But a theory of storms which would account for all the phenomena is a very different, and a very difficult, subject. To be satisfactory, it must account for all forms of storm areas, from the circular to the form of the ellipse so elongated as to appear trough-like ; for the direction in which they move, and the changes in that direction ; for the track they usually take in different parts of the world ; and, above all, *for the saturation of the atmosphere with vapour* often over a most extensive region, which must be considered as the necessary precursor of storms. Till synchronous charts be constructed, embracing, at least, the greater part of North America, the West Indies, the North Atlantic, Europe, and eastern and northern Asia, plausible or ingenious theories may be propounded, but since the chief

facts are wanting, nothing can be said which can be regarded as satisfactory or convincing.

569. The part of the track of the West Indian hurricanes after turning to the N.E., is in accordance with this theory; but how account for the first part of their course, which is at right angles to the prevailing trade-winds of that region? The usual place where the vapour brought by the trade-winds is condensed, is the region of calms, where heavy rains and thunderstorms daily occur. But since this condensation takes place simultaneously over a somewhat broad belt of the earth's surface, which for the time is stationary, it follows that the storm is neither rotatory nor progressive, the only effect of the condensation being the flow of the regular trade-winds towards the belt where it takes place. When the condensation is more copious than usual, the effect will be the acceleration of the speed of the trade-winds. This is the most probable explanation of the *harmattan* which occurs in December, January, and February, on the coast of Africa; it always blows in one direction from the land, and does not increase quite to the violence of a gale, and then dies away. Copious rainfall in the belt of calms opposite that part of Africa, and at some distance, is the probable cause of these winds. Similar in some respects to these are the *tornados* of Western Africa, which blow invariably off the land, first with little force, but ultimately they rise to the strength of a heavy gale, and then after an hour, or sometimes two hours, die away. The direction of the wind remains all the time unchanged; and the barometer varies little, if any, during their continuance. They are generally accompanied with rain and thunder, though sometimes they are quite dry winds. They are probably caused either by very heavy rains in the region of calms, falling over a limited region and lasting only for a short time, or by a sudden increase of pressure in the interior through the upper currents. On the other hand, it has been seen that when the region of calms lies in a slanting position, as in the Indian Ocean from November to May, storms are originated there. Is this slanting position of the region of calms

the chief cause of the stormy character of the weather of the Indian Ocean during these months? If so, then it is due to the diminution of pressure arising from the heating of South Africa at this season, and the increase of pressure to the north, arising from the cooling of the land north of the equator, which there slants from W.S.W to E.N.E.

570. Let us suppose that the atmosphere of the West Indian Islands has from some cause become exceptionally warm and moist, and that, at the same time, a high barometer is interposed between that region and the belt of calms. In such circumstances, as the trade-winds cannot flow towards the belt of calms, the usual provision for draining them of their moisture is taken away, and a rapid accumulation of aqueous vapour takes place to the north of the high barometer, ready to burst in any instant in rain and tempest. This would appear to have been the case before and during the Bahama hurricance of October 1866, Plate VIII. The following table shows the atmospheric pressure and winds at St Croix, and on board H.M.S. Buzzard, which sailed from Barbadoes, on the 26th September, for England. St Croix is in lat. 17° 44′ 29″ N. and long. 64° 41′ W., and the mean height of the barometer at sea-level is 30.080 inches.

BAROMETRIC PRESSURE AND WINDS OBSERVED AT ST CROIX, WEST INDIES, AND ON BOARD H.M.S. BUZZARD, FROM 26TH SEPTEMBER TILL 4TH OCTOBER 1866.

ST CROIX.				H.M.S. BUZZARD.					
Day of Month.	Hour.	Barometer.	Wind.	Day of Month.	Hour.	Lat. N.	Long. W.	Barometer.	Winds.
Sept. 26	6 a.m.	29.960	E. by S.	Sept. 26	a.m.	13.20	59.00	30.18	N.N.E.
,,	4 p.m.	29.950	S.E.	,,	a.m.	..	..	30.19	..
27	6 a.m.	29.930	E.	27	p.m.	14.10	57.20	30.10	S.W.
,,	4 p.m.	29.910	E.N.E.	,,	p.m.	..	..	30.08	S.W.
28	6 a.m.	29.860	N.E.	28	a.m.	15.30	56.15	30.10	S.E.
,,	4 p.m.	29.930	N.	,,	p.m.	..	..	30.08	E.S.E.
29	6 a.m.	29.734	W.	29	a.m.	17.24	55.42	30.06	E.N.E.
,,	2 p.m.	29.620	S.W.	,,	p.m.	..	..	30.18	E.N.E.
30	6 a.m.	29.920	S.	30	a.m.	19.21	56.60	30.27	E.N.E.
,,	4 p.m.	29.970	S.	,,	p.m.	..	..	30.26	E.N.E.
Oct. 1	6 a.m.	29.990	S.E.	Oct. 1	a.m.	21.50	56.50	30.24	E.N.E.
2	6 a.m.	29.960	E.	2	a.m.	22.55	57.35	30.17	E.N.E.
3	6 a.m.	29.930	E.S.E.	3	a.m.	24.35	58.15	30.11	E.
4	6 a.m.	29.910	E.S.E.	4	a.m.	25.42	58.70	30.20	S.

From this table it is seen that during the hurricane, which in all probability began a little to the north of Barbadoes on the evening of the 26th or morning of the 27th September, atmospheric pressure was above the average to the S.E. and E. of the region traversed by the storm. This being the case, the air would naturally flow from the high towards the low barometer—that is, a general movement of the atmosphere would set in to the N.W., which was the course pursued by the storm for the first four days, a course at right angles to the usual trade-winds. During this part of its course, the rate at which it travelled was slow, not exceeding fifteen miles an hour. A progressive motion, as slow, nay often much slower, is common to these storms until they enter the region of the return trades, when the course is changed to N.E., the onward movement becomes greatly accelerated, and the storm itself spreads over a wider area.

571. Newspaper accounts of the weather before the hurricane describe it as close and sultry, the whole atmosphere being abnormally heated and excessively loaded with moisture. At Bermuda, at 9 A.M. of the 4th October, the temperature of the air was 79°.4, and the dew-point 73°.6, giving a humidity of 83 : and this kind of weather had been prevailing for fully a week before. On the following day, the 5th, at 9 A.M., when the storm had just passed, the temperature was only 71°, the dew-point 56°, and the humidity 59°. Next night the temperature fell to 56°, whereas, before the storm, it did not fall on any night lower than 72°. It would be interesting to know if West Indian hurricanes occur simultaneously with a high pressure to the south, being thus interposed between that region and the usual position of the belt of calms at that season. If so, a considerable step will be gained toward understanding the causes of their origin, and how it is that they are, happily, phenomena of very rare occurrence.

572. Perhaps no writer on meteorology denies the influence of low pressures in drawing the wind towards them ; but the effect of this influence in accounting for the rotation of storms

round their centres is often tacitly subordinated to a theory by which the storm is conceived to rotate from some force, not explained, but quite distinct from that arising from differences of pressure; and in virtue of which the air is driven to the outside of the whirl, thus diminishing the pressure at the centre, —much in the same way as, in whirling round a pail of water, part of the water leaves the centre and rises up against the sides of the vessel. In applying this theory to cyclones, the wind at every point within the storm is stated to be under the influence of two forces, the one arising from the rotatory motion of the cyclone, and the other from its progressive motion. To illustrate this by an example: Suppose a storm advancing over England to the eastward at the rate of twenty-five miles an hour, and taking the simplest case of the wind whirling round within the storm at the rate also of twenty-five miles an hour, then both the rotatory motion of the winds and the progressive motion of the storm are from the west, at the extreme south point of the storm; hence there the wind ought to be due west. At the extreme east point of the storm, since the direction of the wind due to the rotatory motion would be south, and by the progressive motion west, the wind ought to be seen blowing there from the south-west. At the extreme north, since the rotatory motion would be east, and the progressive west, and both being equal, there should be no wind at all. Lastly, at the extreme west point of the storm, the rotatory motion being north, and the progressive west, the wind should be north-west. Further, since in the south half of the storm the direction of the two motions is generally the same, and in the north half generally opposite, the gale ought to be most severely felt in the southern half of the cyclone, attaining its height at places immediately south, and least at those immediately north of the centre. When the rotatory motion much exceeds the progressive, the deviations from the true circular course of the winds when laid down on a synchronous chart would be less than those stated above; but in all cases, unless when the cyclone was stationary, the winds in the front parts of the storm ought to be observed blowing *out of the circular area of the storm.* I am altogether at a loss to discover a storm to which this theory applies. If we look at the West Indian cyclone of October 1866, Plate VIII., we do not see any of the winds observed at 8 P.M. show even a tendency to blow in a direction in accordance with this theory, but, on the contrary, they all blow round and in upon the centre. To the European storm of the 2d November 1863, Plate VII., the same remark applies, as well as to every storm in tropical and temperate regions which I have examined by synchronous charts. The light winds which often prevail in the north-eastern part of European storms are sometimes referred to in illustration of this theory. In such cases it will be found, on examination, that there the isobarometric lines are considerably apart; but when it happens that the isobarometric lines are much crowded together on this side of the storm, the winds are strong and violent. The part of a storm where probably the winds are not so exactly proportioned to the difference of pressure, is that part of the front of the storm where the ascending current is strongest, thus diminishing the force of the surface-current; and that part in the rear where the air at the surface of the earth is coldest and driest, and where consequently the speed of the surface-current is increased.

573. It should be kept in mind that this theory was not arrived at through the slow and tedious process of a rigid induction—viz., by collecting the observations of the barometer and winds on synchronous charts, from which, their mutual relations having been observed, a theory was then constructed in strict accordance with the facts; but from observations, necessarily at the time few and scattered, it was inferred that the rotation of storms is circular. This inference necessitated another—viz., that the rotation is caused by some force or forces acting on the storm from without. Hence the theory proposed by the illustrious Dové, that storms are produced by the mutual lateral interference of two currents of air flowing in opposite directions. It is very difficult to imagine

how the polar and equatorial currents could be brought so to affect each other as they flow in opposite directions, that between them an atmospheric eddy or whirl 1200 miles in diameter could be formed rotating round its axis at the rate of 50 or 70 miles an hour. That storms often occur between these two great currents is undoubted; for in such cases the dry, heavy, polar current, by flowing under the moist, warm equatorial current, and thus thrusting it into the higher regions of the air, produces that disturbance in the atmospheric equilibrium which constitutes a storm. But what is maintained by the theory is this: By the lateral interference of these two currents, combined with the change in their direction produced by the rotation of the earth, a storm is formed.

574. In support of this theory, the great storm which occurred in the beginning of January 1855 is adduced. I have examined Dové's account of that storm,* and, from the Russian observations, Dr Buys Ballot's 'Jaarboek,' and other sources, have prepared eight synchronous charts of the weather of Europe from the 27th December 1854 to the 3d January 1855. From these charts the following facts regarding this singular storm appear: 1. It was for some time preceded by southerly winds, high temperatures, and low pressures over the north and north-west of Europe. 2. It originated in some locality within the arctic regions unknown. 3. It thence advanced over the Lofoden Islands, Stockholm, and Königsberg, to the Sea of Azov, its direction being thus from N.W. to S.E. 4. A high barometer prevailed to the west and south-west of its course, and another region of high barometer in eastern Russia and Siberia; these approached each other till the 29th December, after which they both fell back or gave way to the storm as it passed between them to the S.E. 5. The storm reached its greatest development on New Year's Day at noon, after which, as it proceeded on its course, its area became more contracted, and the depression at the centre became less. 6. In North Germany and Denmark, to the right hand of the storm's track, the

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* See 'Law of Storms,' p. 258 *et seq.* London, 1862.

wind veered from S.W., by W. and N.W., to N.; and at Riga, St Petersburg, and other places to the east or left-hand side, it veered from S.E., by E. and N.E., to N.—these directions being in accordance with the law of the veering of the wind in the storms of the northern hemisphere. 7. In every one of the charts the wind is represented as blowing from the high to the low barometer, and modified by the change produced by the rotation of the earth; no other movement of the wind is observable than the spirally in-moving currents of air towards the area of least pressure. 8. On the 1st January, the pressure at Christiania being 28.410 inches, and at Greenwich, only 700 miles distant, 30.002 inches, a furious nor'-wester of unexampled violence descended over the North Sea on the north coasts of Germany and the Netherlands, and washed away part of Wangeroog, an island near the mouth of the Weser.

575. From a high barometer, on the 1st, in the west of Europe and in the east of the United States, and a low barometer and storm in California, Dové infers a barometric maximum extending over the whole Atlantic, and supposes that the storm in Europe on the one hand, and the storm in the west of America on the other, were produced by the lateral interference of equatorial currents with the polar current which was between them; and attention is drawn to the circumstance that the Californian storm came from the S.W. and the European from the N.W. It will be observed that the only observations from which a high barometer is assumed for the whole of the Atlantic are the barometers on its eastern and western shores. From Professor Alexis Caswell's observations at Providence, Rhode Island, America, it is seen that a heavy storm passed over that place to the east on the 29th December, when the barometer fell to 29.41, after which the wind veered from W. to N.W., the barometer rose, and the temperature fell. A storm from the west passed over Scotland on the 4th of January, and reached St Petersburg on the 6th. We need not here stop to inquire if these were one and the same storm, but only to remark that their occur-

rence throws doubt on the supposition that the whole of the Atlantic was at this time under a high barometric pressure. The facts of the storms of the 1st and 2d January 1855 do not, so far as I can see, offer any support to the theory of the simple mutual interference of currents generating storms.

576. 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. We have seen waves of temperature creeping over that continent, apparently so vast that only a mere fragment of one of them could 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. When the pressure in the north of Europe is generally low, then the winds over the whole continent become southerly, accompanied with a general rise in the temperature; when the pressure in the north is high, and in the south low, northerly currents and low temperatures prevail; when the pressure in the west is generally low, but high in the east, then easterly winds prevail, and the temperature rises or falls according to the season;* when the pressure in the east is diminished, then westerly winds prevail; and finally, when the pressure is low over some contracted space such as the British Islands, then winds flow in upon it from all sides, giving rise to an extensive whirl in the atmosphere over that region, as the winds turn round and in upon the centre of least pressure.†

577. But of the causes of these vast atmospheric changes we are very ignorant. The general prevalence of the polar and equatorial currents may be, perhaps, satisfactorily rea-

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* See fig. 20, page 134, representing the pressure during the great frost of Christmas 1860.

† See Plate VII.

soned about; but why on any particular day the polar current descends from the frozen regions, and spreads itself over Europe, and why at another time the equatorial current flows wholly or partially over that continent, the area of our observations 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.

578. 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 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 to acquire this all-important knowledge that we urge the extension of the field of observation, so that synchronous 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 XIII.

MISCELLANEOUS.

ATMOSPHERIC ELECTRICITY.

579. 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 Peters-

burg 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.

580. *Electrometers* 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. 4~~7~~ 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.

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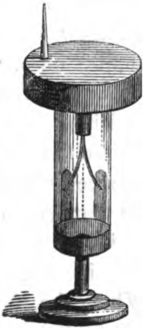
Fig. 49.

50/

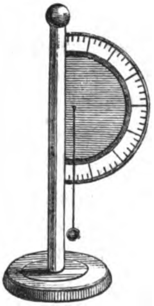
Fig. 50.

581. *Electroscopes* 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.

582. 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 occurred 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.

583. 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 was 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.

584. 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.

585. *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. Evaporation from water containing an alkali or a salt gives off negative electricity to the air, and leaves positive electricity behind; but when the water contains acid, positive electricity is given off, and negative is left behind. Hence it is supposed that seas, lakes, and rivers are abundant sources of 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 gas during the day, and carbonic gas during the night. In these cases positive electricity arises from the plants, and negative is left behind. 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.

586. *Effect of the Condensation of Vapour.*—The following are Sir John Herschel's views on the relations subsisting between the condensation of vapour and atmospheric electricity. 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 the annual fluctuation; 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 fluctuation 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, toward sunrise, when little dew is deposited, and evaporation is also small, the second and chief minimum period occurs. But great differences of opinion exist in regard to the electricity of the atmosphere, and many of the phenomena, especially those observed during storms, have not yet been explained. A sufficient number of trustworthy observations are the great desideratum; and not till some instrument has been devised of such a description that the observations made with it in different places may be comparable with each other, and the price be at the same time no barrier to its general use as a meteorological instrument, can we hope to be in a position adequately to investigate the subject.

THUNDERSTORMS.

587. The thunderstorm is probably originated in the same manner as cloud and rain—viz., by the condensation of vapour; but it differs in the condensation being more copious and more rapid, so as to bring about an accumulation of a sufficient quantity of electricity. If the condensation be not copious, the electricity will be too weak; and if not sudden, it escapes before collecting in sufficient quantity for a discharge. Hence each flash of lightning is almost always immediately followed by a heavy fall of rain or hail, which seems to begin to fall simultaneously with the electric discharge. On the other hand, when the centre of a great thunderstorm which occurred at Edinburgh a little before one A.M. of the 4th September 1867, was passing over the Calton Hill, Alexander Wallace, Royal Observatory, informs me that simultaneously with a vivid discharge of lightning and a loud peal of thunder, the rain, which had been previously falling in torrents, suddenly ceased.

588. Thunderstorms occur most frequently within the tropics, and diminish in frequency towards the poles. They are also more frequent in summer than in winter; during day than during night; after mid-day 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 arid deserts and during the dry season. Before the storm bursts, the air is felt to be exceptionally 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. The negative state is probably induced by the friction of the rain-drops on the air as they fall through it, Faraday having shown that the friction of drops of pure water develops negative electricity in the sub-

stance rubbed; and the positive state is a return to the normal condition after the action of the rain-drops has ceased.

589. *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. *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 almost always the reflection of the lightning of distant storms from the vapour of the upper regions of the atmosphere, the storms themselves being so far off that their thunder cannot be heard. In Scotland, silent-lightning is a prognostic of unsettled weather, it being considered as heralding a storm which is coming up. *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. When Nelson's Monument, on the Calton Hill, Edinburgh, was struck with lightning on the 4th of February 1863, the lightning was observed by Mr Wallace to approach the Monument in a manner as if wafted rapidly forward by air-currents. Professor Wheatstone has shown that the duration of a flash of lightning is less than the thousandth part of a second. A wheel was made to rotate so rapidly that the spokes were invisible; on being lighted up with the electric flash, the duration of the flash was so brief that the wheel appeared quite stationary, even though rotating with the utmost speed possible,—there

being no appreciable displacement of the spokes of the wheel during the time the flash lasted.

590. *Thunder* is probably the noise produced by the instantaneous rushing of the air in filling up the vacuum left 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 1118 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 is 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.

591. 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.

592. 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 known to all. 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 ribands, 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 siliceous tubes of various sizes vitrified internally.

593. *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.

594. *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 very destructive.

595. *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.

596. 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 most frequent within the tropics, less so in temperate climates, unless in the vicinity of mountains, and still less in the arctic regions. 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*). The observations are transmitted to the Imperial Observatory at Paris, and the results published in a magnificent atlas of storm-charts. The following storm is one of the most remarkable.

597. On the 7th May 1865 the north-east of France was visited by a hailstorm of unwonted violence, which has since been called the *Storm of Câtelet*, the place where it was most severe. It was preceded by six weeks of unusually dry and warm weather; after which, and for a few days before the storm, the temperature became quite scorching, and several times storms appeared to be forming, but they all passed off without hail or rain. At seven in the morning of the 7th the air freshened and the barometer rose. A wind from N.E. chased light clouds before it with astonishing speed; but higher up a S.W. wind prevailed, bearing slowly before it woolly-looking clouds, which grew denser towards noon. Still the air was calm at the surface of the earth, and continued so till three P.M., when dense heavy clouds, piled on each other, rose out of the south-west, and thunder began to be heard. Below, the mass of cloud was of a pale livid colour, out of which lightning darted continually; above, were many layers or banks of sombre-tinted clouds, forming

a broad base to the lower electrically-charged cloud, which resembled an inverted pyramid. The storm ascended the valley of the Somme, but little damage was done till it had crossed the heights and descended into the valley of the Escaut, where it fell with terrible violence on Vend'huile, le Câtelet, and Beaurevoir. At Câtelet the hailstones were as large as pigeon's eggs, and some even appeared as large as hen's eggs; but these latter, on examination, were found to be composed of several hailstones rolled together. Next morning, at one place the hail had piled together a mass of ice which was upwards of a quarter of a mile in length, 22 yards in breadth, and at certain points fully 16 feet in height; and at another place there was a similar mass of hailstones one mile and a quarter in length, and a furlong in breadth, which was not fully melted till after the 13th of the month. The damage done by this storm was immense—the tiles on the roofs of houses, the glass, and even the sashes of windows, were smashed to pieces; a mill was levelled with the ground; large trees were torn up by the roots; and crops of rye, barley, and wheat were beaten to the ground and destroyed. In the memory of the inhabitants of that part of France no storm had occurred fraught with such disastrous results.

598. 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 table-lands and mountain-ranges much in the same way apparently as rivers are when high banks oppose their course. 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.

599. 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.

600. In rainy weather, such as frequently occurs in March and September, when, between the intervals of sunshine, a cloud appears in the west, overspreads the sky, and as it passes pours down a considerable quantity of rain, if the barometer be watched from the time of the cloud's appearance in the west to its disappearance in the east, it will be observed to fall a little and then rise, the fall being of a strictly local character. This may be considered typical of the class of storms under discussion. Though no barometric observations are recorded during the thunderstorms of France in 1865, it is highly probable that a local barometric depression accompanied each storm in its course. In all cases before the storm the air is close and sultry and highly charged with moisture. These storms may thus be regarded as secondary storms or sub-storms within the area of the more general storm or atmospheric disturbance passing over Europe at the time, with the wind in all probability circling round them as they are carried forward in the larger storm. Barometric and wind observations made almost every minute during thunderstorms would go far to explain their true character. For registering these small barometric fluctuations so as to arrive at some explanation of gusts of wind, heavy showers, and

some other weather-changes, King's self-recording barometer, in use at the Liverpool Observatory, is the best.

WHIRLWINDS OR WATERSPOUTS AND TROMBES.

601. 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 north

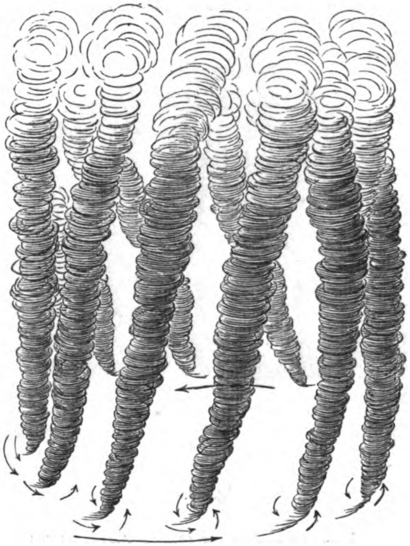

Fig. 51.

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.

602. 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. 51 52 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. 5~~0~~ 2 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 direc-

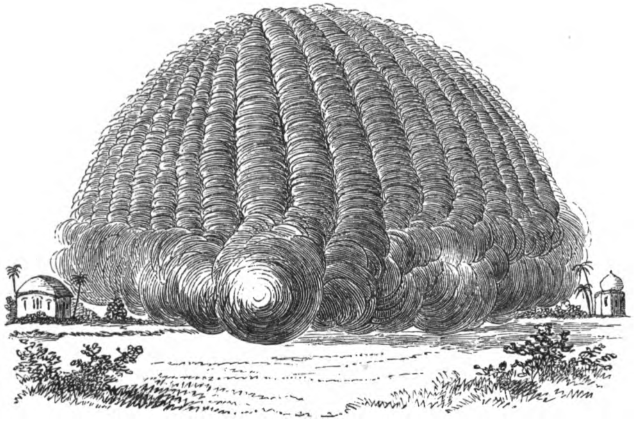

Fig. 52.

tion, 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 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."

603. Extensive fires, such as the burning of the prairies in America, and volcanic eruptions, also cause whirlwinds by the upward current produced by the heated air; and these, as well as the other whirlwinds already mentioned, are occasionally accompanied with rain and electrical displays.

604. *Waterspouts.*—Waterspouts are whirlwinds 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 exhibiting the same whirling motion round their axes, and the same progressive movement of the mass, as the "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 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.

605. The *aurora borealis* is the luminous appearance in the northern sky, which forms, in most vivid displays, spectacles of surpassing beauty. The aurora is observed also in the neighbourhood of the south pole, and is there called *aurora australis*. 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.

606. Auroras are very unequally distributed over the

earth's surface. In the Smithsonian Report for 1865, Professor Loomis gives the results of a comprehensive examination of auroral observations, to which we refer for fuller information respecting this interesting meteor. In reference to the geographical distribution, he 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 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."

607. 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."

608. 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.

609. 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.

610. 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.

611. R. 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 the 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.

612. The cirrus cloud, which is composed of very minute crystals, sometimes appears of a texture so delicate as to elude the eyes of all but the most practised observers; and no doubt it occasionally spreads a screen of microscopic crystals in the

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* 'Da la Prévision du Temps,' p. 493. Paris, 1866.

upper regions of the atmosphere so thin, that the eye cannot detect it till it is revealed by electric discharges passing through it. This cloud probably originates in the equatorial current beginning to prevail in the higher regions of the atmosphere, and depositing the watery vapour necessary for the electric discharges, the faint light of which, reflected by the minute crystals of the cirrus cloud, forms the aurora. For the elucidation of the important questions here raised more magnetic observatories are required, so that synchronous magnetic charts might be made for comparison with similar meteorological charts. If this were done, and the relations among these atmospheric elements discovered, the magnetic and electric states of the atmosphere and the aurora might take their place among the most valuable prognostics of the weather,—most valuable inasmuch as they would give early indication of approaching storms and changes of weather.

OZONE.

613. In the year 1848 Schönbein discovered a new chemical principle, to which he gave the name of *ozone* 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, oxydises 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 oxydising and chloridising 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.

614. Dr Moffat, Hawarden, has made some interesting observations on the connection between ozone periods and the changes of the weather and the prevalence of certain diseases. From these he concludes that when ozone is largely present in the air it is accompanied with diminished atmospheric pressure, increasing temperature and humidity, and the prevalence of the south-west or equatorial winds; and when it is in small quantities the pressure is increasing, the temperature and humidity decreasing, and the north-east or polar winds prevailing. There is a remarkable coincidence between the ozone periods and storm-telegrams. Also when any marked increase takes place in the ozone of the atmosphere it is accompanied with diseases of the nervous, muscular, and vascular systems.

615. *Ozonometer.*—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. The best 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. Care should be taken 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 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 is due to ozone, to nitric or other acid present in the atmosphere.

OPTICAL PHENOMENA.

616. 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.

617. *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.*

618. 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. Circular rainbows were seen by Colonel Sykes on the 29th April, 9th, 11th, and 12th May 1829, on the hill-fort of Hurreechundurghur, and are thus described by him in the 'Transactions of the Royal Society' of London, 1835:—"The stratum of fog from the Konkun on some occasions rose somewhat above the level of the top of a precipice, forming the north-west scarp of the hill-fort of Hurreechundurghur, from 2000 to 3000 feet in perpendicular height, without coming over the table-land. I was placed at the edge of the precipice, just without the limits of the fog, and with a cloudless sun at my back, at a very low elevation. Under such a combination of favourable circumstances, the circular rainbow appeared quite perfect, of the most vivid colours, one half above the level on which I stood, the other half below it. Shadows in distinct outline of myself, my horse, and my people, appeared in the centre of the circle as in a picture, to which the bow formed a resplendent frame. My

attendants were incredulous that the figures they saw under such extraordinary circumstances could be their own shadows, and they tossed their arms and legs about, and put their bodies into various postures, to be assured of the fact by the corresponding movements of the objects within the circle; and it was some little time ere the superstitious feeling with which the spectacle was viewed wore off. From our proximity to the fog, I believe the diameter of the circle at no time exceeded 50 or 60 feet. The brilliant circle was accompanied with the usual outer bow in fainter colours.

619. 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.

620. *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.

621. 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."

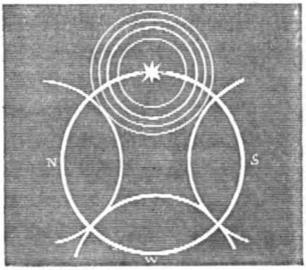
622. *Coronas.*—The corona is an appearance of faintly-coloured rings encircling the moon when seen behind the light fleecy cloud of the cirro-cumulus, or the otherwise invisible minute crystals referred to in par. 612. When the corona is perfect, the rings form several concentric circles, the blue prismatic 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.

623. Coronas can only be 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.

624. 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.

625. *Glories of light*, sometimes called *anthelia*, 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.



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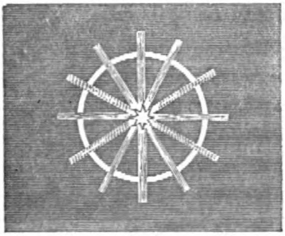

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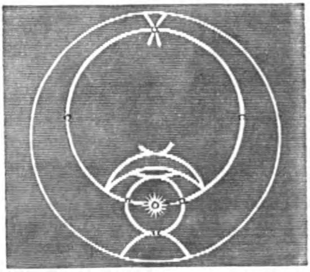

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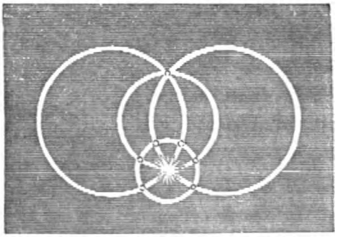

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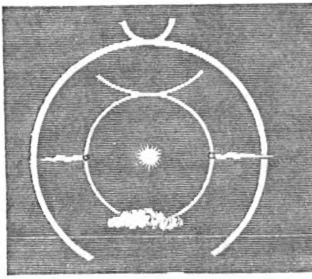

Fig. 57.

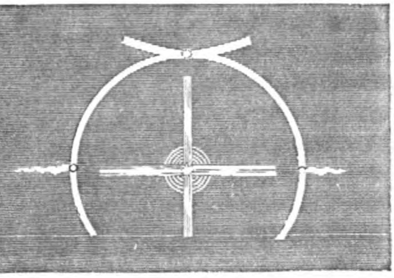

Fig. 58.

626. *Halos.*—Halos are circles of prismatic colours around

the sun (figs. 53, 54, 55, and 56) or moon (figs. 57 and 58), but they are perfectly distinct from coronas, with which they should 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.

627. *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* or *mock-suns*, and those of the moon *paraselenæ* or *mock-moons*, which also exhibit the prismatic colours of the halo.

628. COLOURS OF CLOUDS. — The gorgeous aërial landscapes of red and golden-coloured clouds which fire the western sky at sunset, "the day's dying glory" of the poet, all admire. They are observed to be the accompaniment of cumulus clouds (the cloud of the day during fine weather), while in the act of dissolving as they sink slowly down 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.

629. Frequently small thin clouds appear high up in the eastern sky some time before sunrise, or when

> "The dappled dawn doth rise;"

and 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, or the cirro-cumulus. 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.

630. 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. An attentive consideration of the changing tints of the evening sky after stormy weather, supplies valuable help in forecasting the weather; for if the yellow tint becomes of a sickly green, more rain and stormy weather may be expected; but if it deepen into orange and red, the atmosphere is getting drier, and fine weather may be looked forward to.

631. Some years ago, Principal Forbes showed from experiments that high-pressure steam, while transparent, and *in the act of expansion*, readily absorbs the violet, blue, and part of the green rays, thus letting the yellow, orange, and red pass; and he suggested that coloration may be produced in a mixture of air and vapour, when the vapour is in the intermediate state referred to above. Dr E. Lommel has shown that successive layers of air with visible vapour diffused through them act, so to speak, like sieves, which continually separate the transmitted light more and more perfectly 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 small 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 to the horizon the thickness of the vapour 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 appearing 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. These successive stages of a perfect dawn are felicitously described in the 'Purgatorio:'—

"The dawn was vanquishing the matin hour,
Which fled before it, so that from afar
I recognised the trembling of the sea. . . .
Already had the sun the horizon reached, . . .
So that the white and the vermilion cheeks
Of beautiful Aurora, where I was,
By too great age were changing into orange."
—Longfellow's translation.

Milton has accurately described the last stage of dawn in 'L'Allegro:'—

"The great sun begins his state,
Robed in flames, and amber light
The clouds in thousand liveries dight."

632. 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* 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."

633. POLARISATION OF THE ATMOSPHERE.—The ordinary rays of light can, in certain circumstances, acquire new and peculiar properties, so that they cannot be reflected or refracted in the same way as before; they are then said to be polarised. When the light of any self-luminous body, such as the sun, is transmitted through certain crystallised substances, or reflected from, or refracted by, bodies not metallic, it is divided into two portions of polarised light, one of which is polarised in a plane at right angles to that in which the other is polarised. In doubly refracting crystals the two portions are polarised in opposite planes, and when common light is reflected from any body not metallic, whether solid, liquid, or gaseous, a portion of the incident light enters the body; and of the portions thus reflected and refracted, precisely the same quantity is polarised—the light polarised by refraction being polarised in a plane at right angles to that which is polarised by reflection. The polarising angle of a substance is the angle which the incident ray must make with the normal to a plane polished surface of this substance, so that the polarisation may be complete. The polarising angle for diamond is 68°; for glass, 57° 35′; for quartz, 57° 32′; for obsidian, 56° 30′; and for water, 52° 45′. The atmosphere acts upon light like other bodies, and consequently produces that physical change which constitutes polarisation. The polarising angle for air is 45° 0′ 32″.

634. The distance of the place of maximum polarisation from the sun undergoes great variations, chiefly from 88° to 92°. The general mean of an extensive series of observa-

tions made by Dr Rubenson, Upsal, is 90° 2′, the half of which is so near the polarising angle of air as to leave no doubt that the light of the sky, as first stated by Brewster, is polarised by reflection from the particles of the air, and not from vesicles of water with parallel sides, as supposed by Clausius; nor, as conjectured by others, from minute drops of water, nor from molecules of aqueous vapour in an intermediate state between that of gas and that of vesicles.

635. Arago made the first great discovery respecting the polarisation of the atmosphere—viz., that there exists in the atmosphere a point or spot in which there is no polarisation. This neutral point is some distance above the point in the sky opposite to the sun, and which is called the *antisolar point.* The name of *Arago's neutral point* has been given to this spot of no polarisation, which is seen to best advantage after sunset. When the sun is in the horizon, Arago's point is about 18° 30′ above the antisolar point in the opposite part of the horizon; but when the sun is 11° or 12° above the horizon, and the antisolar consequently as much below it, the neutral point is in the horizon, or it is 11° or 12° above the antisolar point. In abnormal circumstances it is sometimes only 7°, 8°, 9°, or 10°. As the sun descends to the horizon and the antisolar point rises, the distance of the neutral point from the latter gradually increases, and when the sun reaches the horizon the neutral point is, as stated above, 18° 30′ above it. After the sun has set, the neutral point rises faster than the sun descends, and its maximum distance, when the twilight is very faint, is about 25°.

636. The second important discovery was made by M. Babinet in 1740. He discovered that there is a neutral point as far above the sun as Arago's neutral point is above the antisolar point. This spot is called *Babinet's neutral point.* It is best seen immediately after sunset, but is much fainter than Arago's point, being to some extent obscured by the yellow light of the setting sun.

637. Immediately after these discoveries, Sir David Brew-

ster was led by theoretical considerations to the conviction that a neutral point would be found between the sun and the horizon. Observations made with the polariscope at places around its probable locality appeared to confirm this belief; but it was not till the 28th February 1842, when the sun was in the meridian with an altitude of 22°, that he had the high gratification of actually observing it. The spot beneath the sun was fortunately visible from the end of a long dark passage running north and south; and having concealed the sun himself, and every part of the sky around him except the probable position of the spot, he obtained a distinct view of the new neutral point, which was about 15° or 16° below the sun. Babinet, after several unsuccessful efforts, obtained a distinct view of this point on the 23d July 1846. This spot has been called *Brewster's neutral point*, and it has hitherto been seen only by these two observers.

638. With regard to the causes which disturb the polarisation of the atmosphere, Sir David Brewster and Dr Rubenson have found that clouds, fogs, and smoke were the causes of the greatest perturbations, and that the intensity of the polarisation was reduced by those crystals of ice floating in the atmosphere which form the halo of 23°. Dr Rubenson has been led by his observations to the conclusion that the polarisation of the atmosphere is subject to a diminution during the morning, and to an increase during the evening, the precise hour of least polarisation being uncertain. These changes are frequently influenced by brief perturbations which occur at all hours of the day; they arise from smoke, clouds, and *probably often from cirrus too faint to be seen.* As regards the daily period of atmospheric polarisation, it will be observed that the time of diminution occurs in the earlier part of the day, when vapour is carried by the ascending currents into the higher regions of the atmosphere by which the cumulus cloud is formed, and, no doubt, higher up invisible crystals are deposited similar to those of the cirrus; and that the period of increase occurs towards evening, when the temperature of the lower stratum of the air is

falling, and the ascending currents having ceased, the cumulus clouds are dissolving, and the quantity of invisible crystals likewise diminishing. Thus the maximum polarisation occurs at that time of the day when the air is least encumbered with the invisible crystals of ice, and the minimum when these crystals are present in greatest abundance.

639. M. Liais, in 1859, made observations on the polarisation of the atmosphere, for the purpose of determining its height, during a voyage from France to Brazil, and in the Bay of Rio Janeiro. From the observations, he obtained 212 miles as the height of the atmosphere. From the above results—especially those showing the influence of the different states of the aqueous vapour of the air on its polarisation—we see the importance of this property of the atmosphere as a branch of meteorology. When the subject has been more widely observed, and the law of its modification by the presence of aqueous vapour is more accurately known, it is probable that the knowledge may be turned to excellent practical account in giving the earliest indication of the commencement of the saturation of the air in the upper regions; and, inferentially, of the approach of storms and of the rainy season within the tropics.

640. *Theories of Atmospheric Polarisation.*—In addition to the vertical polarisation (that is, polarisation in the vertical plane passing through the sun and the observer) produced by the illumination of the particles of the air, there must be an opposite polarisation by which the neutral points are produced. Arago, Babinet, and other writers, have supposed that the opposite polarisation results from a secondary illumination which the aërial particles receive from the rest of the atmosphere which sends light to them polarised horizontally, or oppositely to the light polarised vertically. Sir David Brewster did not consider this explanation to be satisfactory, on the ground that it omitted all consideration of the light polarised by refraction, and that there is no evidence of such a secondary reflection even in a perfectly cloudless sky; and still less evidence that, if it did exist, it could neutralise the

light polarised by reflection at considerable distances from the antisolar point. The theory of atmospheric polarisation proposed by this distinguished philosopher is, that the three neutral points in the atmosphere, and the partial polarisation of the light which it reflects, are produced by the opposite action of lights polarised by reflection and refraction which have nearly the same relative intensity.*

METEORS.

641. *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 has been forcibly drawn to their consideration by the magnificent star-shower of the night of the 13th and 14th November 1866, which had been predicted beforehand. During a shower of meteors, if the lines of the tracks of the different meteors be projected on the sky, it is found that they meet nearly all 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 the 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 regu-

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* For an exposition of this branch of meteorology, see Sir David Brewster's papers in Dr Keith Johnston's 'Physical Atlas,' in the 'Transactions of the Royal Society of Edinburgh,' and in the 'Philosophical Magazine,' from which the above notice of the subject has been prepared.

lar 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 11th of August; and, though not so general, at other times of the year. 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 cosmical bodies, which, as they enter the atmosphere with a speed of about 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. Alexander Herschel has particularly studied this class of bodies, and, from twenty well-observed cases, has determined the weight of the meteors as varying from 30 grains to upwards of 7 lb.

642. Since they become luminous on entering the atmosphere, it is evident that 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 concluded 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 supposes 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.

643. Speculation has gravely attempted to bring this interesting class of bodies within the legitimate domain of meteorology, by supposing that a shadow from the annular ring of meteors rotating round the sun falls on the earth at certain seasons—viz., in February, May, August, and November—in consequence of which part of the sun's heat is cut off, and the temperature of the earth therefore falls. It is conclusive proof against this theory, that when these interruptions of temperature are particularly investigated, it is found that the date of their occurrence varies backward and forward to some extent from year to year; that the duration of their occurrence varies from three to six days, or sometimes longer; that they are accompanied with a prevalence of the polar current, as indicated by northerly winds and increasing pressure in advancing northward; and that instead of appearing simultaneously at different places, they are propagated from place to place like other changes of temperature, thus pointing to a terrestrial instead of an astronomical origin.

CHAPTER XIV.

WEATHER, AND STORM-WARNINGS.

644. **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 atmospheric elements. From the direct bearing which weather-changes have on human interests and pursuits, they have been closely observed from the earliest times, in order 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. Any reference to Moore and other almanac-makers is unnecessary, except as testimonies to a widespread ignorance of even the most palpable elements of physical law, which is a disgrace to the educational system of the country. When prognosticators of higher pretensions appear before the public with revelations, weeks or months beforehand, of fine or stormy weather fraught with great advantage or incalculable disaster to agricultural and other interests, it is curious to note how their predictions are laid hold of by the newspapers and scattered broadcast over the country.

645. 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.

646. Of this class may be mentioned the *interruptions* which occur in the regular march of temperature in the course of the year, of which some account has been already given at page 140. Thus, since in Scotland at least, cold weather prevails some time in the second week of February, April, May, August, and November, and in the end of June; and warm weather in the second week of July and August, and in the beginning of December, it follows that, when at these times the weather begins to grow cold or warm, a continuance of such weather may be expected for a few days. Since these interruptions of temperature arise from a different distribution of atmospheric pressure from what usually prevails, they are generally either preceded or followed by stormy weather.

647. If, after an unusual prevalence of south-west wind, or the equatorial current, the polar current or north-east wind should set in, it is probable that easterly winds will prevail for some time. If the season be winter, frost, and perhaps snow, may be looked for; and if summer, the weather will 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. This latter prognostic is confidently believed in by several meteorologists; but a comparison of the weather of spring with that of the succeeding summer during the last eleven years in Scotland shows, that while it holds good in the majority of cases, the number of times it fails are too many to entitle it to the claim of a trustworthy prognostic.

648. 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 considerable 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.

649. Sir John Herschel states, in his 'Familiar Lectures,' that the moon has a tendency "to clear the sky of cloud, and to produce, not only a serene but a calm night, when so near the full as to appear round to the eye." Arago says, "La lune mange les nuages." If these opinions are founded on fact, *then the moon must have a very great and decided influence in clearing the sky of clouds.* William Ellis has examined the Greenwich meteorological records from 1841 to 1847, and shown from these seven years' observations that such a peculiar and striking effect does not exist.* The popular opinion probably arises from the circumstance that the

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* 'Philosophical Magazine' for July 1868.

clearing of the sky near the time of full moon arrests the attention, whereas the clearing of the sky when the moon is not present is less likely to be noticed.

650. From a most laborious investigation, which meteorologists alone can adequately appreciate, Park Harrison has shown that shortly after full moon there is a tendency to dispersion of cloud, which, though not very marked, is yet appreciable; and he has further shown, from the observations of temperature at Greenwich for 1841-47 and 1856-64, at Oxford for 1856-64, and at Berlin for 1820-35, that a maximum mean temperature occurs on the average at each of these places on the 6th and 7th day of the lunation, when the moon's crust turned towards the earth is coldest; and a minimum mean temperature shortly after full moon, when the moon's crust having been exposed for some days to the sun's heat is warmest. The conclusion has been drawn that the lowering of the temperature immediately after full moon is caused by the partial clearing of the sky of cloud by the higher temperature caused by the full moon, by means of which terrestrial radiation is less impeded, and the temperature consequently falls. Now, it is necessary to distinguish here between the facts of observation and the conclusions drawn from them. The lower averages of cloud and of temperature after full moon, and the higher averages in the moon's first quarter, are interesting facts in the meteorology of the places for which the averages were taken; and they are also valuable as suggesting further inquiry; but they do not warrant the broad conclusion which has been deduced from them.

651. Schübler has examined sixteen years' observations of the wind, and has found that the S. and W. winds increase in frequency from new moon to the second octant, whilst in the last quarter the same winds are at a minimum, and N. and E. winds reach their maximum. Glaisher has generally confirmed these results, from a discussion of the Greenwich observations of the wind from 1841 to 1847.* Let it be supposed that this relation of the winds to the phases of the

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* 'Proceedings of Meteorological Society of England,' March 1867.

moon were established, it would then be unnecessary to resort to dispersion of cloud and increased terrestrial radiation in order to account for the lower average temperature, seeing that the greater prevalence of northerly and easterly winds would be amply sufficient to bring about these results.

652. If it be the case that there is an immediate connection between the phases of the moon and these changes of temperature, then it necessarily follows that the same relation may be observed anywhere over the world. It is self-evident, especially to those who have charted the weather for considerable portions of the earth's surface, that if Schübler's and Glaisher's conclusions regarding the wind hold good for France and the south of England, the same winds will not prevail at the same time over even so small a portion of the earth's surface as Europe. These winds, it will be observed, possess different qualities, the one being moist and warm, and the other dry and cold; hence they point to a different distribution of the barometric pressure. The proving of the monthly recurrence of such distributions of pressure affecting the winds, and, through them, the temperature at Greenwich; the tracing of these perpetually recurring changes to lunar influence; and the extension of the inquiry into other parts of the world which would be necessary before any general result could be arrived at, present a problem so vast and so laborious that few would care to encounter it. Joseph Baxendell* has examined the St Petersburg observations for the years 1856-64, the years for which Mr Harrison examined the Greenwich and the Oxford temperature. There were 111 lunations during these nine years, and the mean temperatures were found to be as follows:—

Day after New Moon.	Mean Temp.	Day after Full Moon.	Mean Temp.
5th day,	38.32	3d day,	38.88
6th ,,	38.30	4th ,,	38.79
7th ,,	38.57	5th ,,	39.29
8th ,,	38.16	6th ,,	39.62
9th ,,	37.65	7th ,,	39.96
Mean,	38.20	Mean,	39.31

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* 'Proceedings of Lit. and Phil. Society of Manchester,' 1867-68.

Hence, instead of the highest temperatures occurring after new moon, and the lowest after full moon, as at Greenwich and Oxford, all the highest occurred at St Petersburg after full moon, and all the lowest after new moon. This result confirms what has been stated, and proves that the moon has no immediate sensible effect on the temperature of the air near the surface of the earth. Whether it has any disturbing influence on the barometric pressure, and thence on the winds and the temperature, has not yet been even attempted to be proved.

653. 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. Perhaps the very earliest indication of a change from dry to wet weather might be obtained from observations of the polarisation of the atmosphere, from the circumstance that the intensity of the polarisation is reduced by the crystals of ice floating in the atmosphere, being deposited there by the moist current which has already begun to prevail at these heights. This prognostic can be less frequently applied in such damp climates as that of Great Britain than in Africa, Hindostan, and other regions characterised by dry and rainy seasons. It is probable that when more is known of this peculiarity of the atmosphere, especially as modified by the presence of minute, invisible ice-crystals at great heights, the approach of the rains, on which so much depends, may be predicted some days earlier than can be done at present.

654. 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." It is also current as a weather-saw in the following distich:—

"North and south, the sign o' drouth;
East and wast, the sign o' a blast."

It has been shown in par. 479, from William Stevenson's observations of the motion of the cirrus cloud, and from the isobarometric lines (Plates I., II., and III.), that the upper atmospheric current in great Britain is generally from N.W. to S.E. when the barometric pressure in Europe is about the average. Hence, 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, "drouth," drought, or 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 great atmospheric disturbance indicated, pointing to a system of low pressures (the characteristics 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.

655. In addition to the prognostics from clouds already stated in the chapter on CLOUDS, another may be referred to here—viz., "the pocky cloud," which was first described by the Rev. Dr Charles Clouston, Sandwick, Orkney, and stated to be followed invariably by a storm in about twenty-four hours. This accurate observer com-

pares it to "a series of dark cumulus-looking clouds, like festoons of dark drapery, over a considerable portion of the sky, with the lower edge well defined, as if each festoon or pock was filled with something heavy; and generally one series of festoons lies over another, so that the light spaces between resemble an Alpine chain of white-peaked mountains. It is essential that the lower edge be well defined, for a somewhat similar cloud, with the lower edge of the festoons fringed or shaded away, is sometimes seen ; it is followed by rain only."* This cloud is probably caused by large volumes of saturated air forcing their way through drier and colder air, the form of this cloud suggesting moist air diffusing itself horizontally, or from above, just as the formation of the cumulus cloud, or the steam from a steam-engine, indicates diffusion upwards. If this supposition be correct, it shows the moist, warm current to be in greater strength than usual, and a sudden commingling of air-currents, differing widely in temperature and degree of saturation,—the very conditions of a storm. This cloud is well known, and is much dreaded by Orkney sailors. Since Dr Clouston has drawn attention to this cloud it has been several times observed farther south. In the autumn of 1866 the Hon. Ralph Abercrombie observed it twice in the west of Scotland, when it was on each occasion followed by a storm. It was also observed by R. Ballingall, at Eallabus, Islay, on the day before the great hurricane which swept over Scotland on the 24th January 1868.

656. The *south-east* wind, when rightly understood, 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 baro-

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* 'Explanation of Weather-Prognostics of Scotland,' by the Rev. Charles Clouston: 1867.

meter 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, and it does not veer to the south and west. Since this, our only really settled fine weather, is almost always a consequence of the polar current coming from the north of Russia and spreading itself over Europe, it will scarcely be necessary to point out the great value of daily telegrams of the barometer and winds from Archangel and Riga in giving the first intimation of its probable approach to spread sheets of ice over our ponds and lakes in winter, to dry the land in spring for the reception of seed, and to bring sunshine in summer and autumn for the ripening and ingathering of the fruits of the earth.

657. 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—there being nothing as yet to indicate any change.

658. It is thus by a careful observing and recording of the lesser changes of the weather from day to day that the approach of the greater changes included under storms of wind, rain, or snow, may to some extent be known beforehand. It is not by a single observation made at one time that an isolated observer can best draw conclusions regarding the weather likely to happen, but from the character of the changes which have been silently going forward for some time. Hence it is desirable to set down, in a pictorial form, the different observations as they are made, so that the eye may take in at once the whole of the changes which are going forward; and thus the observer may with less trouble and with greater certainty draw his conclusions. The Rev. R. Tyas's handy little annual, 'How to use the Barometer,' is calculated to be popularly useful for recording, pictorially and in tables, the successive changes of the weather from day to day.

STORM-WARNINGS.

659. 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 these 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, the direction and strength of the wind, and the direction and amount of cloud, supposes the existence of a storm as the disturbing agent at no great distance. This important practical problem has been worked out with great success by Mr Meldrum at Mauritius. A few words will explain the method of proceeding.

660. 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.

661. The direction in which the disturbance is from Mauritius is readily known from the wind. Thus, during the gale which occurred from the 11th to the 17th January 1860, the wind veered from S.E. to S., S.W., and W. This was a great revolving storm, the centre of which passed on the east side of the island, its nearest distance at any time being 129 miles. Here it will be observed that the storm with its low pressure being in the east, and travelling to the south-westward, the wind at Mauritius veered from E.S.E., its usual direction, into the west; or, to express the relation from the opposite point of view, the veering of the wind pointed to the east and south as the seat of the atmospheric disturbance. In all cases the wind is found to veer round so as to blow approximately at right angles (60° to 80°) to the bearing of the storm. 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.

662. 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, inferences (or predictions, as they may be called when the storm afterwards reached Mauritius), 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.

663. This gratifying result is of great value in various ways. It shows what may be done at an isolated station in the ocean; in other words, what may be done in ships at sea. Since these deductions regarding storms are made at Mauritius, from the observed deviations from the average height of the barometer and the direction and force of the wind, the reduction of the ocean statistics of meteorology, and the charting of the results for the use of sailors, becomes a question of pressing importance. Maury's Sailing Charts have already been referred to for the signal service they have rendered to navigation. The Isobarometric Charts given at the end of this book will, it is hoped, prove a valuable auxiliary to navigation; and when the whole thirteen have been prepared, their value will be much increased.

664. In discussing Meteorological Ocean Statistics referring chiefly to tropical and sub-tropical regions, the most important points to be determined are the following: 1. The daily range of the barometer for the different months, as applicable to different parts of the ocean; or, better still, the law of its variation according to season, latitude, and proximity to large masses of land. 2. The mean monthly barometric pressure of the different seas chiefly traversed by ships, given for every 0.050 inch, or, if possible, every 0.025 inch of mean pressure. 3. The deviation from the mean pressure of the month which may be regarded as an amount of disturbance sufficient to be considered as indicative of a storm at no great

distance. 4. The mean direction and force of the wind for the different months. This is no doubt a vast problem which it will take many years to work out. Mr Meldrum's paper on the Meteorology of Port Louis in the Island of Mauritius, printed *in extenso*, with its elaborately prepared 42 Tables, in the Report of the British Association for 1867, is one of the most valuable contributions towards its solution yet made. Much may in the mean time be done by ship-captains to enable them to steer clear of storms, if they would carefully note the occurrence of deviations from the average daily barometric range, and barometric fluctuations generally, taken in connection with the direction, force, and veering of the wind.

665. 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. The possibility of this is evident from what has been already stated in the chapter on STORMS, and its practicability is seen from what was done by Admiral Fitzroy, and his assistant, Mr Babington, previous to December 1866.

666. In his letter of 15th June 1865 to the Board of Trade, General Sabine states that he had examined the warnings given on our coasts during the two years ending 31st March 1865, and found that in the first year 50 per cent, and in the second year 73 per cent, were right; and he adds, "That it seems not unreasonable to attribute to increased experience the marked improvement of these results upon those of the preceding year, and to anticipate still further improvement." The above percentages of warnings which turned out correct, were formed from the warnings sent to all the seaports. But, since a number of these places

were not very favourably situated for receiving timely warning, being too near the west coast, if the warnings sent to places more favourably situated were examined, fewer failures would appear. The Channel may be considered as thus favourably situated. Warnings of storms were sent by Admiral Fitzroy to the north and west coasts of France. Captain de Rostaing, while at the head of the French Marine Meteorological Department, compared the warnings sent from the Meteorological Office in London with the gales (*vents forts*, or winds represented by 8 on Beaufort's scale) which occurred in France during the two winters 1864-65 and 1865-66. The results were published in the *Revue Marine et Coloniale.* From this investigation it appears that, out of 100 warnings sent to the north coast of France during the first of these winters, 71 were realised, and during the second winter 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.

667. A word or two may be here said regarding the causes of a considerable number of the failures. The first and chief source of failure was the want of a day-and-night watch maintained on the west coast of Ireland. This, which an examination of British storms shows at once to be the first requisite of any system of storm-warnings, was pointed out by R. Russell some years since, but with no practical result. Suppose only two observations a-day made in the west of Ireland, one at 9 A.M. and the other at 2 P.M., and that shortly after the latter hour the barometer began rapidly to fall and a storm to arise—then, since the average rate of the progressive motion of our British storms is nearly 20 miles an hour, rising at times to 30, and on rare occasions to 45 miles an hour, it would happen that by the time the telegrams were received next morning, and the warnings issued, the storm had already passed many of the seaports, especially in the west; was passing some places; whilst to only a very few places in the

east was it yet advancing. Thus the storm outstripped the warning at all except a very few places, to which only, therefore, it was of use as a warning.

668. The occasionally late arrival or non-arrival of the telegrams was also a source of failure. For thus the cautionary signals were sometimes ordered to be hoisted at places to which no warnings might have been sent, if the telegrams had arrived up to time. The direction and force of the wind were determined by estimation only, by the telegraph clerks intrusted with sending the telegrams; and these are known to have been in some cases defective. The same liability to error will to some extent continue until each station be provided with a vane to show the direction of the wind, and a simple pressure anemometer to indicate the force on the scale 0 to 12, together with the maximum force. There were too few stations on the Continent to the east and south-east of Great Britain, so that an important element in estimating the probable force of easterly and southerly gales, especially on the east coast, was wanting. But the barometric observations, which are the basis of every system of storm-warnings, were remarkably accurate.

669. If, then, allowance be made for the failures which arose from these causes, it can scarcely be doubted that we have the explanation of nearly every one of the 10 storms which were not signalled out of the 93 which occurred on the north coast of France during the winter of 1864-65, and of the 6 not signalled out of the 99 which occurred during the following winter. This leads to an important result. Since experience has shown it to be practicable for the north of France—and what is practicable for the north of France applies equally to the greater part of Great Britain—it follows that, practically, the approach of every storm which visits Great Britain may be signalled some time before it reaches the different ports.

670. There is thus no difficulty in carrying out a system of storm-warnings in this direction. The practical difficulty lies not in securing that a warning of each storm will be re-

ceived before it breaks out, but in securing that no warning be sent except to those places at which the wind will rise to the force of a gale. If this happened uniformly over the whole region included at any time within the low barometric pressure marking out the atmospheric disturbance, of which the wind-storm is one of the accompaniments; or if a certain wind-force invariably attended on a certain pressure in each storm—then the problem of storm-warnings might be regarded as completely solved. But it has been shown that in an atmospheric disturbance the force of the wind at a particular place is proportioned neither to the amount of fall of the barometer, nor absolutely to its rate of fall at any time, but to the relative differences of pressure as observed simultaneously at two other places between which it lies. To determine these relations for any place for the next 30 hours, so that from the result warnings might be framed for that place, is, it needs scarcely be said, a problem which admits only of an approximate solution; any exact solution and exact rules framed from such solution to guide in issuing storm-warnings being impossible. But in this as in many other cases where science is applied to the practical affairs of life, no such exactness is required. It is only necessary that the number of successful warnings be sufficient to warrant the practice of issuing them.

671. It is evident that the first requisites in a system of storm-warnings are these:—1. A day-and-night watch at Valentia in the 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. Till this be done, a considerable percentage of failures must occur, whatever be the system of warnings practised. The only difficulty in carrying it out is the expense. Any sum hitherto granted by the British Government for this purpose is altogether

inadequate for efficiently carrying it out. The sooner it is understood the better, that if early and more certain warning or notification of the approach of storms be wanted, it must be paid for; and that if not paid for, it must follow that storms will occasionally burst upon us unprepared.

672. The importance of stations in Scotland at Oban and Golspie, or the extreme north-western and northern points to which the telegraph wires extend, is very great, since these places are best situated for giving the earliest possible intelligence of the approach of heavy gales from N.W., N., and N.E. The storm of the 1st and 2d December, when the Ivanhoe of Leith and other 60 vessels were lost, and 201 vessels damaged, was of this description. It came on suddenly. The rate and manner in which it advanced over Great Britain is seen from the following figures, showing the hour at which the wind had risen to at least a gale at the different places :—

HOUR.	GALE HAD BEGUN AT
5 A.M.	North Unst (4.15 A.M.); the Hebrides and nearly all Shetland.
7 ,,	Skye, Wester Ross, Sutherland, and Orkney.
9 ,,	Ardnamurchan and Tarbet Ness.
11 ,,	Kinnaird Head and Islay.
1 P.M.	Isle of May; Pladda, south of Arran and Cork.
3 ,,	Hawick; Douglas, Isle of Man; and Dublin.
5 ,,	Liverpool.
7 ,,	Yarmouth and Oxford.
11 ,,	Christiania in Norway.

Hence, then, this storm might have been telegraphed from the north-west of Scotland in time for ample warning of its approach to be sent to every principal seaport in Great Britain.

673. If there had been telegraphic communication with Stornoway, where the storm began as early as 5 A.M., its approach could have been notified four or five hours earlier than from any place at present in connection with the telegraph. Hence the great importance of Stornoway in relation to storm-warnings. The advantages which would result to the shipping interests from weather-telegrams from this place would soon pay the laying of a cable to the Lewis. The

great shipping interests of the Clyde and the Mersey are chiefly interested in the carrying out of this suggestion, because of their greater proximity to the west, and the small extent of the arms of the sea, which peculiarly expose vessels to be wrecked. Dr Buys Ballot has for some years strongly advocated the Azores as an outpost which could not fail to prove of the utmost importance in warning of the approach of storms. The observations which the Scottish Meteorological Society has received from their observers in Farö and Iceland conclusively show the great importance of these islands in connection with storm-warnings. Indeed, with daily telegrams from the Azores and Iceland, two and often three days' intimation of almost every storm which visits Great Britain could be had. It is to be hoped that in laying down any new Atlantic cables, the advantages to navigation and commerce of either of these islands being in the route of the telegraph will not be lost sight of.

674. As the laws which regulate the general movements of the atmosphere become better known, the knowledge thus acquired will no doubt be turned to excellent account in its application to storm-warnings. Of these laws the most important are those which are concerned in the production of storms, and in their translation from place to place over the earth's surface till they die out. It is almost universally held as a truism among meteorologists that storms are produced by the mutual action of the polar and the equatorial currents, the chief difference of opinion being as to how the one acts on the other. Have we evidence, in the storms which pass over Western Europe, of the coexistence side by side of these great currents? Or is it the fact that in these storms the moist equatorial current is invariably succeeded and swept eastward by a polar current? On this point I would offer a few suggestions.

675. It will be necessary first to state what is here meant by polar and equatorial currents. A polar current is a movement of the atmosphere, which the distribution of the barometric pressure and the winds at the time connect with the

polar regions as the source out of which it is flowing. An equatorial current, on the other hand, is shown by the pressure and the winds to have its origin in southern latitudes—to be, in short, a vast atmospheric stream issuing from tropical or sub-tropical regions, and thence spreading itself continuously towards the north. In the case of a polar current, the barometer is highest in the north, from which it falls on proceeding southward as far as the current extends; but with an equatorial current pressures are highest in the south, from which they diminish on advancing northward, till the northern limit of the current is reached. These two currents, as regards moisture and temperature, are directly opposed to each other; but they are not opposed to each other as regards the absolute pressure which accompanies them at any place—the opposition being only in the manner of the distribution of the pressure. Thus it not unfrequently happens in Great Britain that the barometer is low during the prevalence of a polar current, in which case Great Britain is near the southern limits of the current; and high during the prevalence of the equatorial current; indeed, some of the highest pressures which occur advance on Great Britain *viâ* Spain and France.

676. From the 30th November to the 5th December 1863 several storms swept over Great Britain and Western Europe, during which the following pressures at 32° and sea-level were observed on the mornings of these days:—

	Greenland, Iviglut.	Iceland, Stykkisholm.	North of Norway, Vardö.	Russia, Archangel.	Spain, Lisbon.	France, Paris.	Russia. Warsaw.
1863.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Nov. 30	29.100	29.332	29.384	30.206	29.930	30.170	30.690
Dec. 1	28.920	28.795	29.384	30.041	30.110	30.030	30.600
,, 2	29.020	28.660	29.330	29.951	30.260	29.320	30.280
,, 3	29.010	28.681	29.740	30.301	30.390	29.500	29.960
,, 4	29.110	27.843	29.570	30.450	30.470	30.410	29.850
,, 5	...	28.385	29.467	30.410	30.450	30.480	30.450

Here, then, to the north-west, in Greenland and Iceland, whence the polar current, had it existed, would have descended to occupy the rear of the storms, the pressure continued constantly low; whereas from the south and south-west, in Spain and France, high pressures advanced northward, following in the rear of the storm. The great height of the barometer in the rear of this storm, as compared with the low barometer near the centre, occasioned one of the most furious storms which had occurred at Liverpool, the wind there rising to a force which equalled a pressure of 45 lb. to the square foot. In Iceland, heavy showers fell without intermission on the 2d, 3d, and 4th, and a very large quantity of snow fell. At Portree, in Skye, 12.5 inches of rain fell on the 5th, and from 3 to 5 inches at many places in the Scottish Highlands. The following were the mean temperatures of nine places in different parts of Scotland on the mornings of these six days:—40°.0, 42°.3, 38°.6, 34°.7, 42°.9, 47°.0. On the morning of 1st December a storm was advancing on Scotland, and the temperature rose from 40°.0 to 42°.3; on the following morning the centre of this storm had passed, and the temperature fell to 38°.6; another storm followed close on this one, and on the morning of the 3d its centre had passed Scotland, and the temperature fell further to 34°.7. Under the influence of the equatorial current indicated by the high pressures from the south, which closed the rear of the storms, the temperature rose on the two following days respectively to 42°.9 and 47°.0. This is the characteristic of most British storms which are commonly followed by high pressures on their south-west or west sides, and not by high pressures which are continued northward into the polar regions. Hence the mildness of our stormy winters, which is occasioned by the low mean winter pressure of Iceland, Plate II.

677. But it sometimes happens that storms are terminated by a polar current, and such storms are essentially different in many points from those just described. The storm in the beginning of December 1867 was of this sort.* The follow-

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* Professor Mohn, Christiania, has published a complete and interesting series of charts of this storm.

ing were the pressures at 32° and sea-level, as observed in the morning:—

	Iceland, Stykkisholm.	Farö, Thorshavn	Scotland, Aberdeen.	England, Liverpool.	France, Paris.	Norway, Christiania
1867.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Nov. 29	29.298	29.990	30.000	30.304	30.462	29.973
,, 30	29.730	29.410	29.780	29.940	30.280	29.865
Dec. 1	30.144	29.646	28.900	29.160	29.700	28.993
,, 2	30.063	29.996	29.530	29.670	29.570	28.666
,, 3	29.202	29.910	30.150	30.250	29.890	29.780

Here it is seen that the high pressures which closed the rear of this storm advanced on Great Britain from Iceland. The winds accompanying them were N.E., N., and N.W., and the temperature fell everywhere from 20° to 30°; and, what is still more remarkable, the greatest cold occurred at Edinburgh about 2 P.M. of the 2d, when the wind was blowing strongly.

678. It rarely, if ever, happens in British storms that the pressure rises equally all round from the region of lowest pressure as a centre, but the pressure is generally observed to be much higher on one side than on any of the other sides of the storm. This is a point of great importance, since it directs attention to that side of the storm where the greatest force of the wind will be felt, and shows at the same time the probable degree to which the temperature will fall in the rear of the storm. It also sometimes happens that high, and even rapidly rising, barometers are observed immediately to the E. and S.E. of the storm, as it passes over Great Britain; and in such cases the storm is most violent when the wind is from S.S.E. to S.S.W. The great hurricane which swept over Scotland on the 24th January 1868 was of this description.

679. If what has been suggested in par. 481 as the law regulating the movements of the lower and upper currents of the atmosphere be correct, the following will be the explanation of these facts regarding storms: The increase of

pressure over any region is brought about by means of the upper currents. When a storm is passing over Great Britain at the time atmospheric pressure remains persistently low in Iceland, as happened in the beginning of December 1863, it follows that the ascending current which rises from the storm cannot, when it reaches a great height, flow towards Iceland, but will flow over the region where the pressure at that height is least, or generally where the mean temperature and humidity of the whole atmospheric strata is least. Now, observation shows that this usually takes place in the rear of the storm; in other words, the upper current generally flows from the central region of the storm backward towards the S.W. and W., thus increasing the pressure there. But when, as in the beginning of December 1867, high pressures from Iceland follow the central depression, the temperature and humidity there are much lower than elsewhere, and consequently the upper current will flow over towards the N.W. Lastly, on the 24th January 1868 the temperature was lower in Scotland than in Farö, while the storm was yet advancing on Scotland; and thus part, at least, of the upper current flowed over to the eastward as the storm advanced; in consequence of which the heaviest part of the storm occurred when the wind was from S.S.E. to S.S.W., or in the direction from which the wind in storms is usually light. The temperature in Scotland was from 10° to 17° lower on the 23d, when the storm was advancing, than it was on the morning of the 25th, when its centre had passed, and barometers were everywhere rising, and the wind had veered to the N.W.

680. Whatever may be thought of this explanation of the facts of storms, there can be no difference of opinion regarding the facts themselves. The practical conclusion to be drawn from them is this: It is most desirable that the region from which daily telegrams of the weather are received be extended farther into the continent of Europe, especially toward the S.E., E., and N.E., in order that the system of storm-warnings may be made more definite and precise.

681. The following are the regions of the globe which are

chiefly characterised as stormy:—The region of the typhoons in China, which lies between the high pressure of the North Pacific and the low pressure of Asia: their general course is from E.N.E. to W.S.W. The typhoons of Hindostan occur between the high pressure in the Indian Ocean and the low pressure of Asia: their general course is from S.S.E. to N.N.W. The storms in the north-west part of the Indian Ocean have their origin in the low pressure towards which the trades blow, which lies between regions of high pressure to the north and south; their general course is towards W.S.W., after which they frequently turn round to S.E. The storms in the south of the Indian Ocean occur between the high pressures there and the lower pressures farther south; their course is, roughly speaking, eastward, the exact track of the greatest barometric disturbance being yet unknown. The West India hurricanes occur between the high pressure in the Atlantic north of the equator, and the lower pressure in the Gulf of Mexico, the United States, and farther north in the Atlantic; their course is nearly along the isobarometric line, 30.1 inches (Plate I.), which it will be seen approximates to a parabola. In North-Western America storms advance from the south-west, following a course between the high and low pressures there. In the United States in winter, they principally occur about the isobarometric line 30.15 inches (Plate II.), having a high pressure over the Gulf of Mexico to the south. In Europe they generally pass between the isobarometric lines 29.9 and 29.7 inches (Plate II.), being thus between the high pressure to the south in the Atlantic and the low pressure to the north. In all these cases the storm-tracks are contiguous to a high and comparatively steady barometer over a large evaporating surface on the one hand, and a much lower pressure on the other hand. When the whole thirteen Isobarometric Charts have been prepared, the interesting connection here suggested may be better discussed.

682. It is seen from Plates I. and II. that the highest at-

mospheric 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 in par. 96.

683. Isobarometric 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. But we are very far from this result, owing to the scantiness of observations, and reduced means, of the elastic force of atmospheric vapour. Considering the great importance of the inquiry, it is hoped that meteorologists in different parts of the world will lend their assistance, by reducing and publishing their observations of the vapour of the atmosphere.

684. Whilst the rule is, that the minimum pressure of dry air occurs in the hottest months, there are important exceptions. The following table gives the mean pressures of the dry air at five places in the British Islands from Sandwick in Orkney to Greenwich, calculated for the ten years from 1857 to 1866; they are not reduced to sea-level:—

	Sandwick.	Culloden.	Aberdeen.	Glasgow.	Greenwich.
	Inches.	Inches.	Inches.	Inches.	Inches.
January,.......	29.327	29.339	29.402	29.337	29.584
July,............	29.403	29.364	29.400	29.293	29.415

Hence 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. It does not admit of a doubt, that in Iceland the pressure of dry air in summer exceeds that in winter in a still greater degree than in Orkney. Deducting the mean elastic force of vapour, as observed in Iceland during the three winter and summer months of 1866 and 1867, from the whole barometric pressure of thirteen years, it is seen that the probable pressure of the dry air in winter is 29.215 inches, whereas in summer it is 29.402 inches. At Sitka, in the north-west of North America, the pressure of the dry air on a mean of ten years is 29.393 inches in January, and 29.515 inches in July; whereas to the south, at New Westminster, in British Columbia, the pressure of the dry air for two years was 29.885 inches in January and 29.596 inches in July—thus showing the same peculiarity to prevail in the North Pacific that prevails in the North Atlantic.

685. 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. This is doubtless the explanation of the higher pressure of the dry air in these regions in summer—viz., a falling-off of the outflow owing to a diminished pressure all around, and not, as has been supposed, to an overflow into these regions by the upper currents from regions contiguous.

686. It is evident that very great differences between the winter and summer pressures of dry air will take place in dry climates, where the annual diminution of pressure which

occurs arises solely from the high summer temperature. It is to the centre of Asia we must look for an example of this; and accordingly the pressure of the dry air at Barnaul, in Siberia, on a mean of ten years, is 29.760 inches in January, and 28.666 inches in July,—thus showing the enormous difference of nearly eleven tenths of an inch.

687. 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 barometric pressure, which has its centre in Iceland. As the summer temperature falls in September and October the pressure is increased over the continents of Asia, Europe, and North America, and consequently air-currents are poured into 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	.558	.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	915	.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 the paragraphs of the text, and not to the pages of the Volume.*

THE END.

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